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SYSTEMATIC REVIEW

Diagnosis and Treatment of Tethered Spinal Cord

In Partnership with

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Number 274

Diagnosis and Treatment of Tethered Spinal Cord

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None of the investigators have any affiliations or financial involvement that conflicts with the material presented in this report. Dr. Hsieh disclosed royalties for Medtronics Spine [unrelated to the diagnosis tethered spinal cord; some instrumentations are used during rare cases of spine surgery but they are not specific to tethered spinal cord] and Nuvasive, Zimmer Biomet [unrelated to diagnosis and treatment of tethered spinal cord].

The information in this report is intended to help healthcare decision makers—patients and clinicians, health system leaders, and policymakers, among others—make well-informed decisions and thereby improve the quality of healthcare services. This report is not intended to be a substitute for the application of clinical judgment. Anyone who makes decisions concerning the provision of clinical care should consider this report in the same way as any medical reference and in conjunction with all other pertinent information, i.e., in the context of available resources and circumstances presented by individual patients.

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Preface

The Agency for Healthcare Research and Quality (AHRQ), through its Evidence-based Practice Centers (EPCs), sponsors the development of evidence reports and technology assessments to assist public- and private-sector organizations in their efforts to improve the quality of healthcare in the United States. The Patient-Centered Outcomes Research Institute (PCORI®) requested this report from the EPC Program at AHRQ. AHRQ assigned this report to the Southern California EPC (Contract Number: 75Q80120D00009).

AHRQ EPC reviews provide comprehensive, science-based information on common, costly medical conditions, and new healthcare technologies and strategies.

The Patient-Centered Outcomes Research Institute was established to fund research that helps patients and caregivers make better informed healthcare choices. To fulfill its authorizing mandate, PCORI partners with AHRQ to generate evidence synthesis products and make comparative effectiveness research more available to patients and providers.

Systematic reviews are the building blocks underlying evidence-based practice; they focus attention on the strength and limits of evidence from research studies about the effectiveness and safety of a clinical intervention. In the context of developing recommendations for practice, systematic reviews can help clarify whether assertions about the value of the intervention are based on strong evidence from clinical studies. For more information about AHRQ EPC systematic reviews, go to https://effectivehealthcare.ahrq.gov/about/epc/evidence-synthesis.

AHRQ expects that the EPC evidence reports and technology assessments, when appropriate, will inform individual health plans, providers, and purchasers as well as the healthcare system as a whole by providing important information to help improve healthcare quality. Transparency and stakeholder input are essential to the Effective Health Care Program. Please visit the website (www.effectivehealthcare.ahrq.gov) to see draft research questions and reports or to join an email list to learn about new program products and opportunities for input.

If you have comments on this systematic review, they may be sent by mail to the Task Order Officer named below at: Agency for Healthcare Research and Quality, 5600 Fishers Lane, Rockville, MD 20857, or by email to epc@ahrq.hhs.gov.

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Key Informants

In designing the study questions, the EPC consulted several Key Informants who represent the end-users of research. The EPC sought the Key Informant input on the priority areas for research and synthesis. Key Informants are not involved in the analysis of the evidence or the writing of the report. Therefore, in the end, study questions, design, methodological approaches, and/or conclusions do not necessarily represent the views of individual Key Informants.

Key Informants must disclose any financial conflicts of interest greater than $5,000 and any other relevant business or professional conflicts of interest. Because of their role as end-users, individuals with potential conflicts may be retained. The TOO and the EPC work to balance, manage, or mitigate any conflicts of interest.

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Technical Expert Panel (TEP)

In designing the study questions and methodology at the outset of this report, the EPC consulted several technical and content experts. Broad expertise and perspectives were sought. Divergent and conflicting opinions are common and perceived as healthy scientific discourse that results in a thoughtful, relevant systematic review. Therefore, in the end, study questions, design, methodologic approaches, and/or conclusions do not necessarily represent the views of individual technical and content experts.

Technical Experts must disclose any financial conflicts of interest greater than $5,000 and any other relevant business or professional conflicts of interest. Because of their unique clinical or content expertise, individuals with potential conflicts may be retained. The TOO and the EPC work to balance, manage, or mitigate any potential conflicts of interest identified.

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Peer Reviewers

Prior to publication of the final evidence report, EPCs sought input from independent Peer Reviewers without financial conflicts of interest. However, the conclusions and synthesis of the scientific literature presented in this report do not necessarily represent the views of individual reviewers. AHRQ may also seek comments from other Federal agencies when appropriate.

Peer Reviewers must disclose any financial conflicts of interest greater than $5,000 and any other relevant business or professional conflicts of interest. Because of their unique clinical or content expertise, individuals with potential nonfinancial conflicts may be retained. The TOO and the EPC work to balance, manage, or mitigate any potential nonfinancial conflicts of interest identified.

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Diagnosis and Treatment of Tethered Spinal Cord

Abstract

Objectives. To summarize the evidence regarding diagnosis, prophylactic treatment, symptomatic treatment, and repeat surgery of tethered spinal cord

Data sources. We searched PubMed®, Embase®, CINAHL, Web of Science, SCOPUS, clinicaltrials.gov, ICTRP, Cochrane Database of Systematic Reviews, PROSPERO, ECRI repository, G-I-N, MagicApp, and ClinicalKey from inception to March 2024; reference-mined reviews; and contacted research authors.

Review methods. The review followed a detailed protocol and was supported by a Technical Expert Panel. Systematic review software (DistillerSR) was utilized for all screening and data extraction tasks. Citation screening was facilitated by machine learning; two independent reviewers each screened full text citations for eligibility; one literature reviewer extracted data and a methodologist checked for accuracy. Risk of bias assessments focused on key sources of bias for diagnostic and intervention studies. We conducted strength of evidence (SoE) and applicability assessments for key outcomes. The protocol for the review has been registered in PROSPERO (CRD42023461296).

Results. Searches identified 6,285 citations; 2,005 were obtained as full text. In total, 103 studies met inclusion criteria, with an additional 355 case series providing additional information. We found the strongest evidence for accuracy of MRI in diagnosing tethered spinal cord. Specifically, studies indicated this modality has medium to high diagnostic sensitivity and specificity (moderate SoE). A small number of existing studies suggested benefits of prophylactic surgery, but it was also associated with complications such as surgical site infection (low SoE). A larger body of evidence evaluated various treatments for symptomatic patients, with the majority focused on surgical detethering. Studies reported improvement of neurological status after surgical detethering (low SoE), but it was also associated with post-operative complications such as cerebrospinal fluid leakage (moderate SoE). A very small body of evidence exists for revision detethering and spinal column shortening for repeat surgery (low or insufficient SoE for all outcomes). Across diagnosis, prophylactic treatment, symptomatic treatment, and repeat surgery there was insufficient evidence for multiple key outcomes (e.g., over- or undertreatment, clinical impact of diagnostic modalities, ambulation or quality of life outcomes) and thus no evidence statements could be derived.

Conclusions. The evidence base for the diagnosis and treatment of tethered spinal cord is limited, with few exceptions (use of MRI or ultrasound for diagnosis, surgical detethering improving neurological status in symptomatic patients, complications associated with open detethering surgery) and would benefit from stronger study designs that include tool evaluations reporting diagnostic performance and treatment studies with concurrent comparator.

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Executive Summary

Main Points

- The strongest evidence exists for MRI accurately diagnosing tethered spinal cord and studies showed moderate to high sensitivity and specificity (moderate strength of evidence).
- A small number of existing studies indicated benefits of prophylactic surgery for motor function and stability of neurological status over time, but it is also associated with complications such as surgical site infection (low strength of evidence).
- A larger body of evidence evaluated various treatments, primarily surgical detethering, for symptomatic patients. Studies reported improvement of neurological status with surgical detethering (low strength of evidence) but it was also associated with post operative complications such as cerebrospinal fluid leakage (moderate strength of evidence).
- A very small body of evidence exists for revision detethering and spinal column shortening for repeat surgery (low or insufficient strength of evidence for all outcomes).

Background and Purpose

Tethered spinal cord is a condition in which the lower end of the spinal cord is abnormally attached to the surrounding tissues, which prevents the spinal cord from moving to keep up with the lengthening of the spine as individuals grow. As a result, there is abnormal tension on the lower spinal cord and associated nerves that leads to neurological injuries and pain in patients. It is most commonly caused by spinal dysraphism, including myelomeningocele, lipomyelomeningocele, diastematomyelia, dermal sinus tract, and thickened/fatty filum terminale. Tethered cord syndrome is a clinical disorder associated with excessive spinal cord tension that leads to motor and sensory deficits involving the cauda equina and spinal cord. Many patients initially present in childhood, adolescence, or early adulthood due to the congenital nature of spinal dysraphism disorders. Nevertheless, patients with tethered cord syndrome can present in adulthood and later in life when there is an occult tethered cord with delayed presentation or when patients develop recurrent tethered cord syndrome after prior surgical treatments.

The review will summarize the evidence regarding diagnosis, prophylactic treatment, symptomatic treatment, and repeat surgery of tethered spinal cord. With funding from the Patient Centered Outcomes Research Institute (PCORI), the Agency for Healthcare Research and Quality (AHRQ), commissioned this work to synthesize the findings on the diagnosis and treatment of tethered spinal cord. The systematic review will support the Congress of Neurological Surgeons (CNS) clinical practice guidelines.

Methods

We followed methods outlined in the AHRQ Evidence-based Practice Center Program Methods Guidance.[1] Key informants and a technical expert panel provided input. We searched five databases, two research registries, and four guideline repositories from inception to March 2024. We reference-mined reviews and contacted primary research authors for additional data. Eligibility screening was supported by machine learning. One researcher abstracted the data, and

a second reviewer checked for accuracy and completeness. We assessed the risk of bias, strength of evidence (SoE), and applicability.

Results

Searches identified 6,285 citations of which 2,005 were obtained as full text. In total, 103 studies met inclusion criteria, and an additional 355 case series (in 469 publications) provided additional information.

Although multiple diagnostic modalities have been suggested for the diagnosis of tethered spinal cord, we only identified studies reporting on diagnostic accuracy of MRI, ultrasound, myelogram, and evoked potential. None reported on comparative impact of using the test. The strongest evidence existed for MRI and ultrasound. While MRI produced consistently moderate to high sensitivity and specificity (moderate strength of evidence), ultrasound produced more variable results (low SoE).

A small body of evidence evaluated prophylactic surgery and indicated benefits for motor function and neurological function (low strength of evidence). However, prophylactic surgery appeared to be associated with post operative complications such as surgical site infection (low SoE).

A larger body of evidence documented treatment of symptomatic patients, with the most evidence being available for surgical detethering. Surgical detethering may improve neurological status, urinary function, and pain outcomes (low SoE). Earlier detethering surgery may have neurological benefits (low SoE). Surgical detethering was associated with postoperative complications such as cerebrospinal fluid leakage (moderate SoE).

Combined scoliosis and TSC surgery may improve sensory deficits and lead to a more complete recovery (low SoE). Intraoperative monitoring may improve neurological status and may be associated with fewer post operative complications (low SoE). Combined surgery versus staged surgery for different spine conditions may be associated with fewer post operative complications (low SoE). Maintaining patients flat after detethering surgery may not prevent cerebrospinal fluid leakage (low SoE).

A very small body of evidence exists for revision detethering and spinal column shortening for repeat surgery but SoE was low or insufficient for all outcomes, including adverse events.

Limitations

The systematic review identified a large number of studies, but the body of evidence is limited due to the lack of controlled studies and limited reporting of outcomes for diagnostic modalities other than MRI and initial treatments other than surgical detethering. Multiple key outcomes could not be addressed due to insufficient evidence. Despite the large volume of existing research on tethered spinal cord diagnosis and treatment evaluated in this review, better reporting and controlled studies are urgently needed to advance the evidence base for this important clinical condition.

Implications and Conclusions

The evidence base for the diagnosis and treatment of tethered spinal cord is limited with few exceptions (use of MRI or ultrasound for diagnosis, surgical detethering improving neurological status in symptomatic patients, complications associated with open detethering surgery) and

would benefit from stronger study designs (tool evaluations reporting diagnostic performance and treatment studies with concurrent comparator).

References

1. Agency for Healthcare Research and Quality (AHRQ). Methods Guide for Effectiveness and Comparative Effectiveness Reviews. Content last reviewed March 2021. Effective Health Care Program. Rockville, MD: 2021. https://effectivehealthcare.ahrq.gov/products/cer-methods-guide

1. Introduction

1.1 Background

Tethered spinal cord is most commonly caused by spinal dysraphism, including myelomeningocele, lipomyelomeningocele, diastematomyelia, dermal sinus tract, and thickened/fatty filum terminale. Tethered cord syndrome is a clinical disorder associated with excessive spinal cord tension that leads to motor and sensory deficits involving the cauda equina and spinal cord. Many patients initially present in childhood, adolescence, or early adulthood due to the congenital nature of spinal dysraphism disorders. Nevertheless, patients with tethered cord syndrome can present in adulthood and later in life when there is an occult tethered cord with delayed presentation or when patients develop recurrent tethered cord syndrome after prior surgical treatments.[1]

The condition is believed to be caused by diverse etiologies resulting in the distal spinal cord and nerve tension. The main proposed pathophysiology is the ischemic hypothesis, in which the chronic tension on the spinal cord and nerves leads to impaired local blood flow, local spinal cord ischemic injury, and neuronal damage.[2-7] Much of the ischemia hypothesis is supported by animal models, often insufficient to mimic human conditions.[7, 8] In vivo, the degree of tension of the conus medullaris and filum in tethered spinal cord patients has never been measured. In addition, no alteration of blood flow has ever been measured or observed in patients with tethered spinal cord as compared to normal spinal cord blood flow. Finally, there is no human histological evidence of chronic ischemia resulting from tethered spinal cord. Thus, some experts believe that the ischemic hypothesis is theoretical and unproven as the pathophysiology of tethered spinal cord.

1.1.1 Diagnosis of Tethered Spinal Cord

Clinical assessments and imaging are the primary modalities for diagnosing tethered cord syndrome. Patients often present with pain, motor or sensory dysfunction, or bladder and bowel functional disturbances with symptomatic tethered spinal cord. Classically, those symptoms worsen with flexion of the spine in patients with symptomatic tethered spinal cord. Additionally, patients with spina bifida occulta related spinal dysraphisms may have cutaneous stigmata that includes tufts of hair, nevi, lipoma, dermal sinuses, or hemangiomas. On imaging, patients with classical tethered spinal cord have a low-lying conus medullaris that is generally associated with thickened filum terminale, spinal lipoma with extension through the dura and into the subcutaneous fat, or adhesion of the neural placode to the dura or surrounding soft tissues.[9] Unfortunately, imaging alone is insufficient to make the diagnosis of symptomatic tethered cord, and clinical features are a critical element of diagnosis.

1.1.2 Treatment of Tethered Spinal Cord

Clinicians generally believe that tethered spinal cord results in a progressive and stepwise neurological decline in patients. This belief is widely accepted and most research has supported the natural history of neurological decline. However, the evidence supporting this belief is primarily based on retrospective case series and case controlled studies rather than randomized controlled studies or large prospective cohort studies.[10] In contrast, there are a few studies in which patients treated conservatively were followed for their natural history and, in those limited studies, most patients did not develop clinical or neurological decline that impaired function.[11, 12]

Thus, the notion that patients with tethered spinal cord will surely progress and deteriorate with motor or sensory loss is not supported by high-quality prospective randomized controlled studies and may not be true for all patients with tethered spinal cord.

While patients with symptomatic tethered spinal cord may benefit from surgical treatments, the neurological risks, and peri-operative morbidity associated with surgery for tethered spinal cord are not insignificant. Surgical treatment may prevent additional motor or sensory loss associated with tethered cord syndrome. Still, direct detethering of the spinal nerves and cord also carries considerable risks to patients.[13] Despite the common belief that patients will have progressive and irreversible motor or sensory loss with symptomatic tethered spinal cord without intervention, the time course and severity of progression for such neurological injuries for any particular patient is unknown. Some patients progress rapidly with significant neurological injuries, while others may have a more insidious course and gradual stepwise neurological decline.[10] On the other hand, it is well known that neurological injury and other complications associated with surgical treatment can be quite high.[14] Therefore, the potential benefits of any surgical treatment for tethered spinal cord, particularly prophylactic surgery for asymptomatic or marginally symptomatic patients, should be carefully weighed against the possible complications and adverse effects of surgery.

1.2 Purpose and Scope

The review summarizes the evidence regarding diagnosis, prophylactic treatment, symptomatic treatment, and repeat surgery of tethered spinal cord. With funding from the Patient Centered Outcomes Research Institute (PCORI), the Agency for Healthcare Research and Quality (AHRQ) commissioned this work to synthesize the findings on the diagnosis and treatment of tethered spinal cord. The systematic review aims to support the Congress of Neurological Surgeons (CNS) clinical practice guidelines.

2. Methods

2.1 Review Approach

The methods for this evidence review followed the Agency for Healthcare Research and Quality (AHRQ) Methods Guide for the Evidence-based Practice Center (EPC) Program (available at https://effectivehealthcare.ahrq.gov/products/collections/cer-methods-guide). The topic of this report was nominated by the Congress of Neurological Surgeons (CNS) and refined by the Patient-Centered Outcomes Research Institute (PCORI) in collaboration with AHRQ. Key Questions were posted on AHRQ's Effective Health Care (EHC) website for public comment in April 2023 to ensure that the review is addressing the right questions and all aspects have been considered. The Key Questions were developed following input from Key Informants. Key Informants included a patient with tethered spinal cord, a patient advocate from the Spina Bifida Association, and a content expert developing the planned CNS guideline.

A panel of technical experts provided high-level content and methodological expertise throughout development of the review protocol. Discussions with the Technical Expert Panel (TEP) resulted in further refinement of the questions. The protocol was developed following this input through public posting of the Key Questions, input from Key Informants, and the TEP. The final protocol is posted on the EHC website at https://effectivehealthcare.ahrq.gov/products/tethered-spinal-cord/protocol. The protocol for the review has been registered in PROSPERO (Record number: CRD42023461296).

2.2 Key Questions

The Key Questions for the systematic review addressed the diagnosis (Key Question 1), prophylactic treatment (Key Question 2), symptomatic treatment (Key Question 3), and repeat surgery (Key Question 4) of tethered spinal cord:

Key Question 1. What is the accuracy of radiographic and other diagnostic criteria in diagnosing tethered spinal cord?

Key Question 2. What are the benefits and harms of prophylactic surgery for asymptomatic tethered spinal cord patients?

Key Question 3. What are the effectiveness, comparative effectiveness, and harms of surgical and non-surgical treatments for symptomatic tethered spinal cord?

a. Stratified by symptom type, intensity, and patient age?

b. Are effects modified by use of special surgical equipment or techniques?

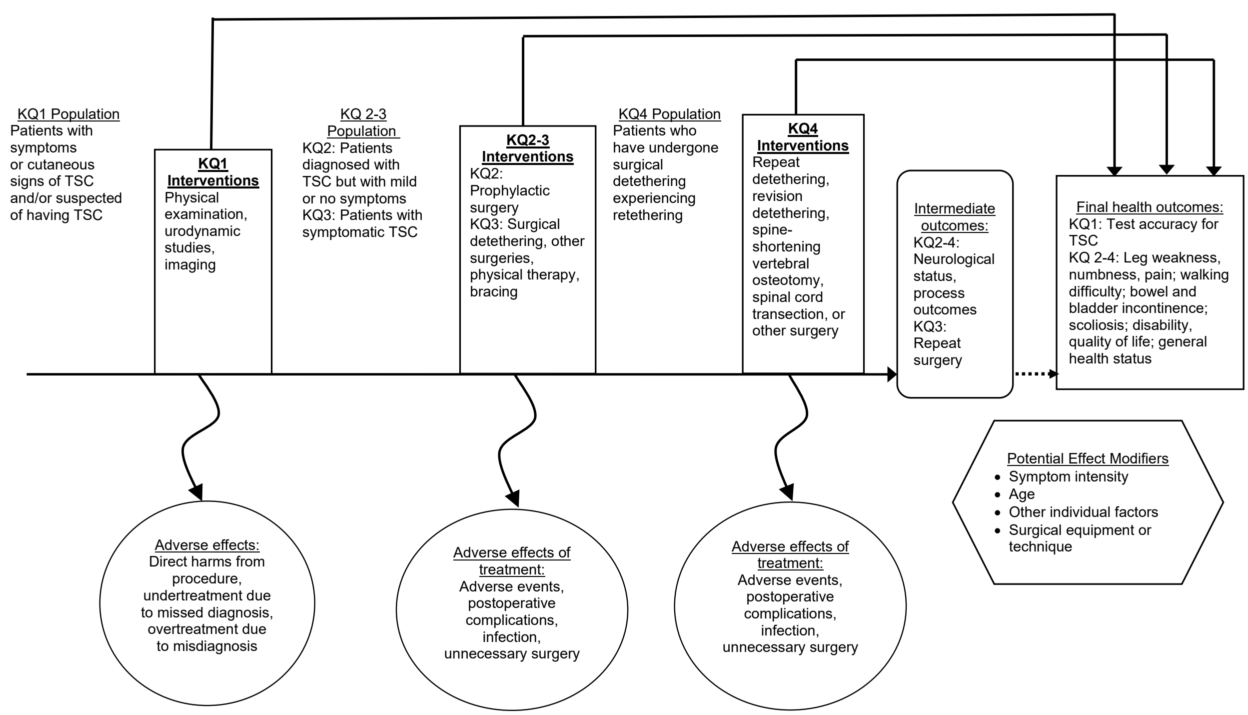
Key Question 4. Among individuals who experience retethering after spinal detethering surgery, what are the benefits, harms, and long-term outcomes of another surgery compared with no treatment?

a. Are individual factors with which a patient presents (e.g., primary symptoms, symptom intensity, age) associated with better or worse outcomes after repeat surgery?

2.3 Logic Model

The analytic framework (Figure 1) depicts the patient population, the interventions, and the outcomes addressed in the evidence synthesis.

Figure 1. Analytic framework



KQ: Key Question; TSC: Tethered Spinal Cord

The framework guides the report and the response to the Key Questions.

2.4 Study Selection

2.4.1 Search Strategy

For primary research studies we searched the databases PubMed® (biomedical literature), Embase® (pharmacology emphasis), CINAHL® (allied nursing), Web of Science (technical innovation), and SCOPUS (general research) from inception to March 2024. We also searched U.S. and international research registries (clinicaltrials.gov, ICTRP) to capture all relevant data regardless of the publication status; increasingly, these registries include data and often provide a complete record of adverse events, making them an important evidence review tool. We also used existing reviews for reference-mining where available. We searched the same databases used for primary research plus the Cochrane Database of Systematic Reviews and PROSPERO

to systematically identify existing research syntheses. We also systematically searched for existing clinical practice guidelines using the ECRI repository, G-I-N, MagicApp, and ClinicalKey. We reference-mined relevant reviews. The peer-reviewed search strategy is shown in Appendix A.

We used detailed pre-established criteria to determine eligibility for inclusion and exclusion of publications in accordance with the AHRQ EPC Methods Guide[15] for Effectiveness and Comparative Effectiveness Reviews. To reduce reviewer errors and bias, all citations were reviewed by a human reviewer and a machine learning algorithm. Citations deemed potentially relevant were obtained as full text. Each full-text article was independently reviewed for eligibility by two literature reviewers. Any disagreements were resolved by consensus. We maintained a record of studies excluded at the full-text level with reasons for exclusion. Any publications suggested by peer reviewers or that arose from the public posting process, submissions through the Supplementary Evidence And Data for Systematic reviews (SEADS) portal, or responses to a Federal Register notice were assessed using the same criteria and process.

While the draft report was being posted for public comment, the search was updated and eligible studies identified either during that search or through peer or public review were incorporated in the final report. Furthermore, we contacted all authors of included studies and asked whether the authors could provide additional information on the key outcomes. We contacted all authors three times if we initially received no response. We first contacted the corresponding author of the study. If we were unable to identify a valid email address for the corresponding author, we contacted the first and/or senior author of the study. All authors that provided a response are documented in the acknowledgement section.

2.5 Inclusion/Exclusion Criteria

The eligibility criteria are shown in Table 1.

Table 1. Eligibility criteria

Element	Inclusion Criteria	Exclusion Criteria
Population	KQ1: Pediatric or adult patients assessed for tethered spinal cord KQ2: Pediatric or adult patients with tethered spinal cord and no symptoms or marginally symptomatic without functional deficits KQ3: Pediatric or adult patients with symptomatic tethered spinal cord KQ4: Pediatric or adult patients who experience retethering after spinal detethering surgery	Tethering of the spine as an adverse event associated with an intervention (not patients being treated for tethered spinal cord)
Interventions	KQ1: Screening and diagnostic approaches, tools, and criteria such as physical examination, urodynamic studies, MRI, myelogram, CT scan, or ultrasound KQ2: Prophylactic or early surgery KQ3: Surgical or non-surgical treatment or management interventions such as surgical detethering, or other surgery (e.g., spine-shortening vertebral osteotomy, spinal cord transection), physical therapy, bladder therapy for bladder function, or bracing KQ4: Surgical interventions such as repeat detethering, revision detethering, spine-shortening vertebral osteotomy, vertebral column shortening, spinal cord transection, or other surgery	Interventions and approaches not addressing tethered spinal cord

Element	Inclusion Criteria	Exclusion Criteria
Comparators	KQ1: Confirmation of diagnosis by a neurosurgeon or neurologist KQ2-4: No surgery, sham surgery, no treatment, or alternative treatments for effectiveness outcomes	KQ 1-4: no reference standard or comparator but case series were retained to abstract clinical experiences with the intervention
Outcomes	KQ1: Diagnostic performance (e.g., diagnostic accuracy measured as concordance with neurosurgeon or neurologist diagnosis); adverse events of the diagnostic procedure; and clinical impact of a correct or incorrect diagnosis such as (e.g., overtreatment due to misdiagnosis, delayed treatment, or undertreatment due to missed diagnosis) KQ2-4: Patient health and other patient effects such as leg weakness, leg numbness, leg pain, other pain, gait, walking difficulty, bowel incontinence, bladder incontinence, scoliosis, disability, adverse events, postoperative complications, infection, 30-day complication rate, morbidity, quality of life, or general health status, as well as process measures such as repeat surgery	Provider satisfaction and frequency of procedures
Timing	No restrictions regarding the timing or duration of the intervention or the follow up	N/A
Setting	Settings compatible with US healthcare settings, no restrictions regarding the clinical setting	Very low resource countries or conflict zones
Study Design	KQ1: Diagnostic accuracy and diagnostic impact analyses KQ2-4: RCTs, clinical trials without randomization, cohort studies comparing two cohorts, controlled post-only studies, and case-control studies. Experimental single arm trials and observational case series, with or without structured pre- and post-intervention data, need to report on neurological status or bladder or bowel function to be eligible.	Secondary data, but systematic reviews will be retained for reference-mining
Other limiters	Data published in journal manuscript and trial records	Data reported in abbreviated format (e.g., conference abstracts)

Abbreviations: CT: Computed tomography; KQ: Key Question; MRI: Magnetic Resonance Imaging; N/A: Not Applicable; RCT: Randomized controlled trial

The review was not restricted to specific tests or interventions and instead included all studies addressing the diagnosis or the treatment of patients with tethered spinal cord.

2.5.1 Screening Process

All citations retrieved by the literature searches were screened by at least one human literature reviewer and a DistillerSR software machine learning algorithm trained by the human reviewers to ensure that no relevant citation was missed. Any citations identified as potentially relevant by the algorithm that were not selected for full text publication review were rescreened for relevance by an independent literature reviewer. Publications reporting on the same participants were consolidated into one study record. Uncontrolled studies exclusively published in non-English language publications were excluded. The list of excluded studies and background studies are in Appendix B.

2.6 Data Extraction

Data abstraction forms for the Key Questions were created in DistillerSR, an online program for systematic reviews. Forms included detailed guidance to support reviewers to aid both reproducibility and standardization of data collection. Literature reviewers were assigned to

abstract data from each of the eligible articles based on their clinical and methodological expertise. One literature reviewer abstracted the data, and a methodologist checked for accuracy and completeness. Disagreements were resolved by consensus.

We documented the diagnostic approaches and their diagnostic performance in detail for all suggested indicators to address Key Question 1 (diagnosis). We abstracted all reported diagnostic performance data, including false negatives and false positives, sensitivity, specificity, accuracy, area under the curve, negative and positive predictive value. In addition, we accepted other measures of concordance, including rater agreement. We also abstracted adverse events associated with the diagnostic procedure. Where reported, we abstracted information on the consequences of misdiagnosis or false positives to provide an accurate picture of the diagnostic approaches to tethered spinal cord.

We designed the data abstraction forms for this project to collect the data required to evaluate the study, as well as demographic and other data needed for determining outcomes. Abstraction categories were informed by the National Institute of Neurological Disorders and Stroke spinal cord injury common data elements. [16] Given the controversy regarding the best approach in the presence of no symptoms or very mild symptoms, we abstracted cases of prophylactic treatment (Key Question 2) in detail, reporting patient characteristics and context that may provide further detail on why the approach was chosen and observed results.

For Key Question 3 (effects, comparative effectiveness and comparative safety) we documented the included patients and treatment approach in addition to the study design, analysis, and conceptual framework for measuring effects. We documented the details of the treatment (e.g., approach, surgical equipment, technique), patient characteristics (e.g., symptom intensity, age), and study design (e.g., statistical power, comparator) that may be related to outcomes. We differentiated short-term and long-term outcomes for all studies. Studies that reported on outcomes after skeletal maturity in children and five years of follow up in adults were considered long-term. In addition, we documented comparators in detail, as treatment standards may have changed during the period covered by the review.

For Key Question 4 (repeat surgery), we documented the sequence of events in terms of timing of the surgeries and duration of follow up to clearly document the existing research evidence. Throughout Key Questions 2 to 4, we captured the treatment approach in detail so that the reader can evaluate the study results in context. This included detailed information on the patients (e.g., clinical presentation) as well as the interventions (e.g., surgical approach and experience of surgeon), because of the complexity of condition as well as the treatment.

Data necessary for assessing quality and applicability as described in the AHRQ EPC Methods Guide[15] were also abstracted. Forms were pilot-tested with a sample of included articles to ensure that all relevant data elements were captured and that ambiguity is avoided. Final abstracted data will be uploaded to the Systematic Review Data Repository (SRDR+). The evidence tables for the included studies are in Appendix C.

2.7 Risk of Bias Assessment

Many different study designs were eligible for the review, hence the critical appraisal for individual studies needed to be conducted thoughtfully. We thought it to be important that studies can still be compared across study designs, and we applied a set of evaluation criteria that focused on the underlying risk of biases, rather than applying dozens of different study design-specific tools.

2. Methods

For the diagnostic studies, we applied criteria consistent with Quality Assessment of Diagnostic Accuracy Studies (QUADAS)-2. The instrument evaluates four domains: patient selection, index test characteristics, reference standard quality, as well as flow and timing:[17]

Patient selection: The domain patient selection addresses whether the selection of patients could have introduced bias, taking into account whether the study enrolled a consecutive or random sample, whether the data are not based on a retrospective case-control design, and whether the study avoided inappropriate or problematic exclusions from the patient pool.

Index test: The index test domain evaluates whether the conduct or interpretation of the test could have introduced bias, taking into account whether the results of the test were interpreted without knowledge of the results of the reference standard and whether any thresholds or cut-offs were pre-specified (e.g., instead of determined in the study to maximize diagnostic performance).

Reference standard: The domain reference standard evaluates whether the reference standard, its conduct, or its interpretation may have introduced bias, taking into account the quality of the reference standard in correctly classifying the condition (e.g., a gold standard may not exist) and whether the reference standard test results were interpreted without knowledge of the results or index test.

Flow and timing: The last domain evaluates whether the conduct of the study may have introduced bias. The assessment took into account whether the interval between the test and the reference standard was appropriate, whether all patients received the reference standard and whether they received the same reference standard, and whether all patients were included in the analysis.

For each domain, we assessed the potential risk of bias in the study in order to identify high risk of bias and low risk of bias studies. Consistent with QUADAS-2,[17] the critical appraisal evaluated whether there were concerns regarding the applicability of the study results to the review question. This encompassed whether the patients included in the studies did match the review question; whether the test, its conduct, or interpretation differed from the review question; or whether the target condition as defined by the reference standard did not fully match the review question.

Throughout, the critical appraisal was focused on how study design features may have affected the reported results. For all intervention studies we also used a bias-focused approach, i.e., determining whether reported effects are distorted from the true value. The critical appraisal for all treatment studies were based on the Risk of Bias (RoB) 2 guidance for common sources of bias in intervention studies adapted for the eligible study designs.[17, 18] Because of the large proportion of observational studies in this topic area, assessing confounding variables was of particular importance. The risk of bias assessment addressed selection, detection, performance, attrition, reporting, and study-specific sources of bias:

Selection bias: For selection bias, we assessed the randomization sequence and allocation concealment in randomized controlled trials (RCTs) as well as baseline differences and potential confounders in all studies.

Performance bias: Performance bias evaluated whether patient- or caregiver knowledge of the intervention allocation or circumstances such as the trial context may have affected the outcome, and whether any deviations from intended interventions were balanced between groups.

Attrition bias: Attrition bias considered the number of dropouts, any imbalances across study arms, and whether missing values may have affected the reported outcomes.

Detection bias: Detection bias assessed whether outcome assessors were aware of the intervention allocation, whether this knowledge could have influenced the outcome measurement, and whether the outcome ascertainment differed between arms.
Reporting bias: Reporting bias assessment included an evaluation of whether a pre-specified analysis plan exists (e.g., a published protocol), whether the numerical results likely have been selected on the basis of the results, and whether key outcomes were not reported (e.g., an obvious effectiveness indicator is missing) or inadequately reported (e.g., anecdotal adverse event reporting).
Other sources of bias: In addition to the types of bias listed above, we assessed other, study-specific potential sources of bias such as early termination of studies, inadequate reporting of intervention details, and lack of intention-to-treat analyses.

The overall goal of the appraisal was to identify high risk of bias studies for sensitivity analysis (e.g., determine whether effects are primarily based on low-quality studies) as well as low-risk studies that can strengthen evidence statements through confirmation of results in strong studies. We incorporated the risk of bias results into the strength of evidence assessment and downgrade our confidence in evidence summaries in the presence of study limitations. The critical appraisal and applicability tables are in Appendix D.

2.8 Data Synthesis and Analysis

We answered each Key Question with the available evidence, highlighting findings from controlled studies. We ordered our findings by diagnostic and treatment strategy and then by outcome. We determined the feasibility of a quantitative synthesis (i.e., meta-analysis) for each intervention and outcome. Feasibility depended on the volume of relevant literature, conceptual homogeneity of the studies, and completeness of the reporting of results. Discussions with the TEP informed pre-planned subgroup analyses.

When a meta-analysis was appropriate, we aimed to use random-effects models corrected for small numbers of studies to synthesize the available evidence quantitatively.[19] We aimed to present summary estimates and 95 percent confidence intervals. We aimed to test for heterogeneity using graphical displays and the I-squared statistic. We aimed to explore potential sources of heterogeneity while recognizing that the ability of statistical methods to detect heterogeneity may be limited.[20]

The included studies and reported effects were heterogeneous. The methodological rigor of individual studies, intervention characteristics, and patients' underlying clinical presentation were potentially associated with the intervention effects. We stratified Key Question 1 (diagnosis) by studies evaluating first-time diagnosis versus studies evaluating retethering. We stratified Key Question 3 (treatment) by symptom type, intensity, and patient age. Furthermore, we differentiated patients with suspected (occult tethered cord syndrome) versus confirmed tethered spinal cord syndrome. We performed meta-regression analyses for study type, intervention characteristics (diagnostic approach, surgical equipment/technique), and patient presentation characteristics, for each Key Question.

All studies were summarized in a narrative synthesis. The synthesis was guided by the Key Questions, evaluated diagnostic and therapeutic interventions, and key outcomes. For diagnostic studies, we differentiated physical examination, magnetic resonance imaging (MRI), ultrasound, computed tomography (CT), myelogram, evoked potentials, urodynamic studies, intraoperative neurophysiological monitoring, and other diagnostic approaches. For treatment studies, we differentiate surgical detethering, repeat detethering, revision detethering, vertebral osteotomy,

spinal cord transection, other surgery, bracing, physical therapy, bladder therapy for bladder function, intra-operative monitoring, and other interventions.

2.9 Grading the Strength of the Body of Evidence

The strength of evidence assessment documented uncertainty, outlined the reasons for insufficient evidence where appropriate, and communicated our confidence in the findings. The strength of evidence for each body of evidence (based on the Key Question, diagnostic and treatment approach, comparator, and outcome) was initially assessed by one researcher with experience in determining strength of evidence for each primary clinical outcome by following the principles for adapting GRADE (Grading of Recommendations Assessment, Development and Evaluation), outlined in the AHRQ EPC Methods Guide.[15] The initial assessment was discussed in the team.

We prioritized outcomes with the help of the TEP in combination with team expertise. We considered outcomes most clinically relevant and important to patients and clinicians to guide clinical practice. The outcomes that were considered for summary of findings statements were as follows:

Key Question 1 (diagnosis) outcomes: Any diagnostic accuracy measure most commonly reported, overtreatment or undertreatment due to misdiagnosis, clinical impact of correct or incorrect diagnosis, specificity, sensitivity, accuracy, concordance with neurosurgeon's or neurologist's diagnosis, and inter-rater reliability.

Key Question 2 (prophylactic surgery) outcomes: Bladder or bowel function, ambulation, quality of life, standardized symptom scores, pain, post-operative complications, number of patients with adverse events, need for repeat surgery.

Key Question 3 (interventions for symptomatic patients) outcomes: Neurological status, ambulation, standardized symptoms scores, pain, post-operative complications, 30-day complication rate, number of patients with adverse events, need for repeat surgery.

Key Question 4 (repeat surgery) outcomes: Neurological status, ambulation, bladder or bowel function, quality of life, pain, post-operative complications, 30-day complication rate, number of patients with adverse events, need for repeat surgery.

In determining the strength of a body of evidence, the following domains were evaluated:

Study limitations: The extent to which studies reporting on a particular outcome were likely to be protected from bias. The aggregate risk of bias across individual studies reporting an outcome was considered; graded as low, medium, or high level of study limitations.

Consistency: The extent to which studies reported the same direction or magnitude of effect for a particular outcome; graded as consistent, inconsistent, or unknown (in the case of a single study).

Directness: Describes whether the intervention (test, treatment, or strategy) and the comparator were directly compared (i.e., in head-to-head trials) or indirectly (e.g., through meta-regressions across studies). In addition, indirectness reflects whether the outcome is directly or indirectly related to health outcomes of interest. The domain is graded as direct or indirect.

Precision: Describes the level of certainty of the estimate of effect for a particular outcome, where a precise estimate is one that allows a clinically useful conclusion. Graded as precise or imprecise. When quantitative synthesis was not possible, sample size and assessment of variance within individual studies were considered.

Reporting bias: Occurs when publication or reporting of findings is based on their direction or magnitude of effect. Publication bias, selective outcome reporting, and selective analysis reporting are types of reporting bias. Reporting bias is difficult to assess as systematic

identification of unpublished evidence is challenging. When sufficient numbers of RCTs were available, we reviewed Begg and Egger tests and used trim and fill methods to assess the robustness of effect estimates.

Bodies of evidence consisting of RCTs are generally initially considered high strength, while bodies of comparative observational studies begin as low-strength evidence. The strength of the evidence was downgraded based on the limitations described above. There are also situations where observational evidence may be upgraded (e.g., large magnitude of effect, presence of dose-response relationship or existence of plausible unmeasured confounders) as described in the AHRQ EPC Methods Guide.[15] A final strength of evidence grade was assigned by evaluating and weighing the combined results of the above domains. The strength of evidence was assigned an overall grade of high, moderate, low, or insufficient according to a four-level scale outlined in Table 2.

Table 2. Definitions of the grades of overall strength of evidence[21]

Grade	Definition
High	We are very confident that the estimate of effect lies close to the true effect for this outcome. The body of evidence has few or no deficiencies. We believe that the findings are stable (i.e., another study would not change the conclusions).
Moderate	We are moderately confident that the estimate of effect lies close to the true effect for this outcome. The body of evidence has some deficiencies. We believe that the findings are likely to be stable, but some doubt remains.
Low	We have limited confidence that the estimate of effect lies close to the true effect for this outcome. The body of evidence has major or numerous deficiencies (or both). We believe that additional evidence is needed before concluding either that the findings are stable or that the estimate of effect is close to the true effect.
Insufficient	We have no evidence, we are unable to estimate an effect, or we have no confidence in the estimate of effect for this outcome. No evidence is available, or the body of evidence has unacceptable deficiencies, precluding reaching a conclusion.

Summary tables include reasons for downgrading or upgrading the strength of evidence.

2.10 Assessing Applicability

Applicability was assessed in accordance with the AHRQ EPC Methods Guide.[15] Factors that may affect applicability, which we have identified a priori, include patient, intervention, setting, and study design features.

We addressed whether outcomes are different across studies that recruit different populations or use different methods to implement the interventions of interest. We used these data to evaluate the applicability to clinical practice, paying special attention to the following: clinical and demographic features of the enrolled population in comparison to the target population; the setting in the international studies, characteristics of the intervention used in comparison with care models currently in use in the United States; the comparator to determine what the study compared against; and clinical relevance and timing of the outcome measures.

We used this information to assess the situations in which the evidence is most relevant and to evaluate applicability to real-world clinical practice in typical U.S. settings, summarizing applicability assessments qualitatively.

2.11 Peer Review and Public Commentary

The report underwent peer review, was made available for public comment for 45 days, and was updated after peer review and public commentary.

2.12 Use of Artificial Intelligence and/or Machine Learning

All citations retrieved by the literature searches were screened by at least one human literature reviewer and a DistillerSR software machine learning algorithm trained by the human reviewers to ensure that no relevant citation was missed. Any citations identified as potentially relevant by the algorithm that had not been selected for full text publication review was rescreened for relevance by an independent literature reviewer.

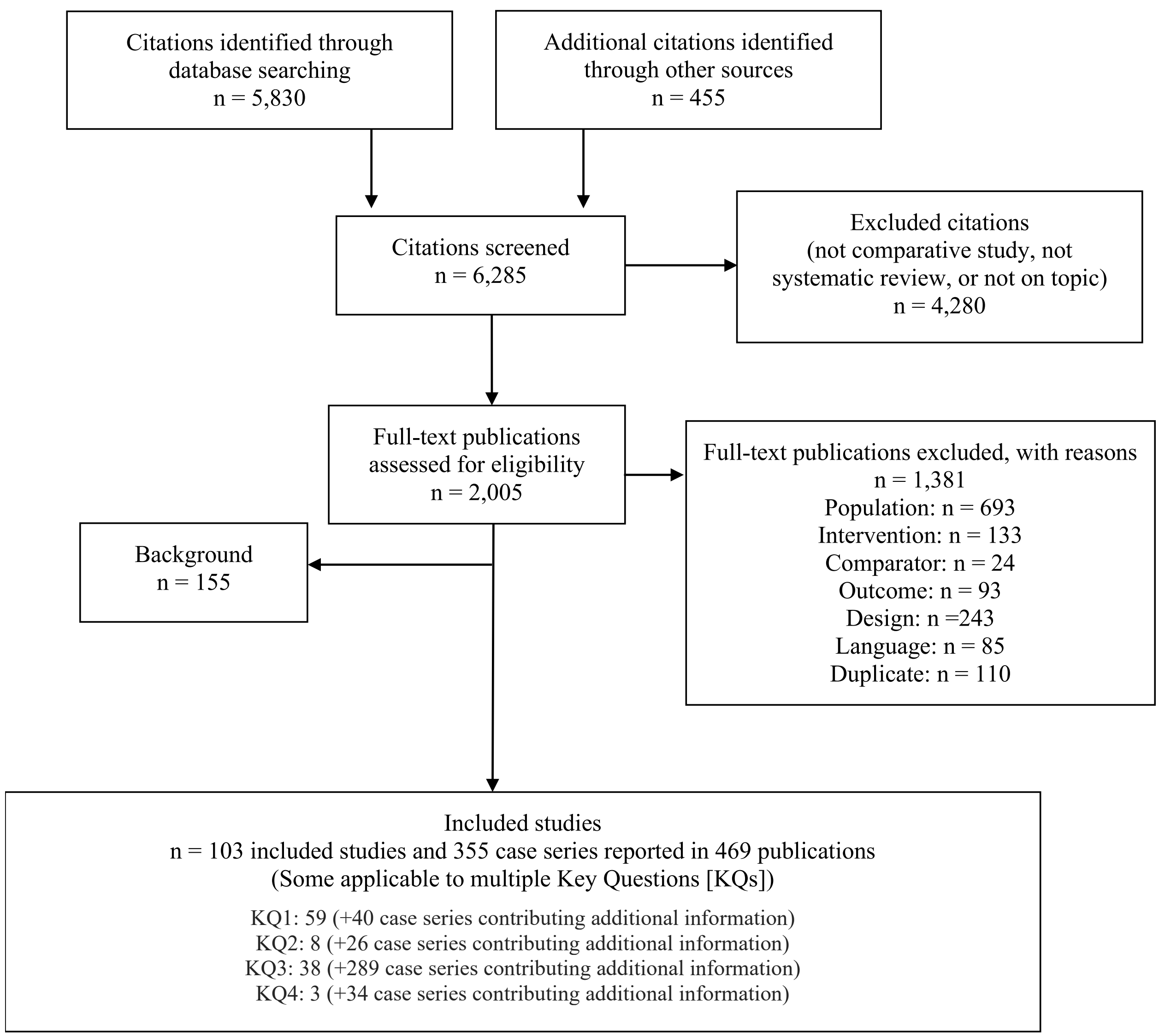
3. Results

The following outlines the identified studies for each Key Question (KQ). Within KQs, an overview paragraph is followed by a summary of findings table to address the KQ with the identified outcomes.

3.1 Results of Literature Search

The searches identified 6,285 citations. Of these, we obtained 2,005 as full text. The flow diagram (Figure 2) describes the study flow through the literature review.

Figure 2. Flow diagram



In total, 103 studies met inclusion criteria, with an additional 355 case series providing additional information in 469 publications.[1, 12, 13, 14, 22-373]

3. Results

Appendix E includes a list of included studies. The evidence tables for the case series are in Appendix F. Throughout the report, included studies are listed by the study ID which is composed of the first author's last name of a key publication reporting on the study and the publication year of the key publication. The evidence table in Appendix C shows the study ID and cites the main publication selected for the study and all multiple publications providing additional input on the study. Due to the limited information provided by case series, these studies did not contribute to the strength of evidence assessment. However, we reviewed the studies for any mention of complications or red flags that may be associated with the diagnostic modalities or treatments. In addition, we briefly summarized the content of the case series in a second evidence table as a resource for the interested reader (also Appendix C).

The flow diagram summarizes the main reason for exclusion from the review. In addition, it shows that we retained a large number of papers as Background. The excluded studies and background studies are listed in Appendix B. In most cases, these background publications were existing systematic reviews addressing an individual aspect of tethered spinal cord research that were then reference-mined to ensure that all eligible studies had been included in the report. Appendix G shows the PCORI methodology checklist.

3.2 Results: KQ 1, Diagnosis of Tethered Spinal Cord

Key Question 1. What is the accuracy of radiographic and other diagnostic criteria in diagnosing tethered spinal cord?

We identified 59 diagnostic studies addressing KQ1.[374-432]

3.2.1 KQ1, Tethered Spinal Cord Diagnosis Key Points

Key points pertaining to the diagnosis of tethered spinal cord are as follows:

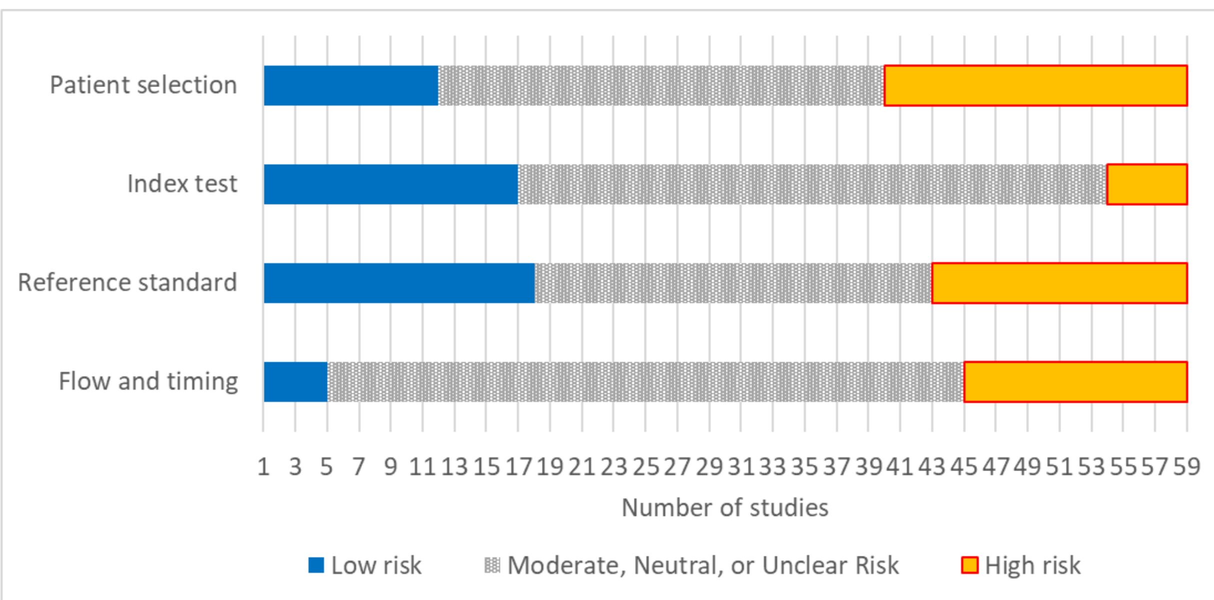
- Although multiple diagnostic modalities have been suggested for the diagnosis of tethered spinal cord, we only identified studies reporting on diagnostic accuracy of magnetic resonance imaging (MRI), ultrasound, myelogram, and evoked potential; none reported on comparative impact of using the test.
- The strongest evidence exists for MRI, which demonstrated consistently medium to high sensitivity and specificity in diagnostic accuracy (moderate strength of evidence). Ultrasound demonstrated more variable results (low strength of evidence).

3.2.2 KQ1, Tethered Spinal Cord Diagnosis Study Characteristics

The first study meeting eligibility criteria were published in 1979.[389] Studies were conducted in 14 countries, but most were U.S.-based. Study sample sizes were generally small and ranged from 13 to 340. Studies included participants of all ages, with the oldest participant being 77, but a third of studies was restricted to pediatric patients. Some of the studies included a portion of patients that were being assessed for the presence or absence of retethering, but the large majority of studies included only patients seeking a diagnosis of tethered spinal cord for the first time.

The potential for risk of bias in the studies is documented in Figure 3.

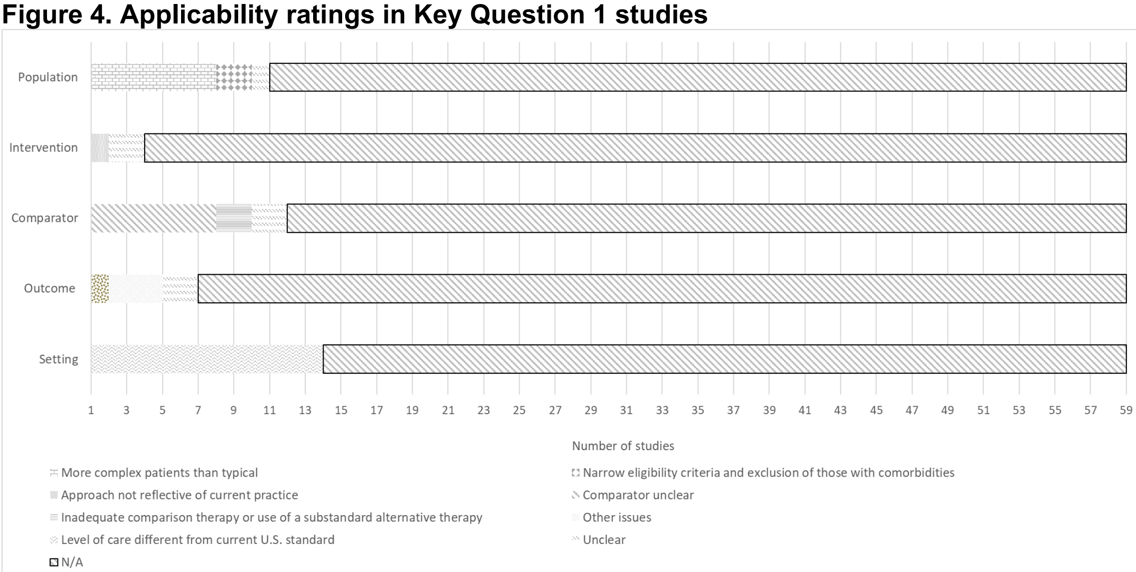
Figure 3. Risk of bias in Key Question 1 studies



Across studies, the main potential source of bias in the diagnostic studies concerned the selection of patients entering the studies. The critical appraisal for the individual studies is documented in Appendix D where individual tables show the risk of bias assessment for each study and criterion.

We also assessed the applicability of studies and flagged any instances where studies reported on participants, interventions, comparators, outcomes, or settings that differ from typical circumstances for which the findings of this report would be relevant. Figure 4 shows the results across studies.

Figure 4. Applicability ratings in Key Question 1 studies



N/A = no applicability issues detected

The majority of the studies did not raise specific flags that would seriously limit their applicability to U.S. clinical practice. Of the studies where applicability was flagged, there were concerns regarding the populations, either because included patients were more complex (e.g., all patients with tethered spinal cord had severe neurological symptoms) or the eligibility criteria were much narrower than seen in usual practice. In addition, the comparator in the study was inadequately described in some of the studies, which limits the conclusions that can be drawn. Several studies were flagged for the geographical settings where we suspected that the level of care in the low income country is different from current U.S. standards. The responses for each study and each criterion are shown in Appendix D.

3.2.3 KQ1, Tethered Spinal Cord Diagnosis Summary of Findings

The tests evaluated in the studies included the use of MRI, ultrasound, computed tomography (CT), myelogram, evoked potentials, urodynamic studies, and intraoperative neurophysiological monitoring. MRI studies evaluated different modalities and combinations such as volumetric interpolated breath-hold examination/liver acquisition with volume acceleration (VIBE/LAVA).[411]

Many of the identified studies did not report concrete diagnostic accuracy measures such as sensitivity, specificity, or area under the curve. Multiple (in particular older) studies reported on the advantages of using MRI for the diagnosis of tethered spinal cord based on the achieved visual quality. The results of all identified diagnostic accuracy studies are shown in the evidence

table in Appendix C. Case series reporting on the experiences with the different modalities are also documented in Appendix F.

Table 3 shows the findings for the outcomes of interest together with the number of studies contributing to the evidence statement and study identifiers for diagnostic approaches. Results of studies not reporting on the key outcomes are documented in the evidence table in the appendix.

Table 3. KQ1, summary of findings and strength of evidence for diagnostic studies

KQ Diagnostic Test	Outcome	Number of Studies and IDs	Findings	Reasons for Downgrading	SoE
KQ1 MRI	Sensitivity	5 studies[378, 411, 414, 419, 420]	Reported sensitivity ranged from 99% (no corresponding specificity)[414] to 62% (corresponding specificity 61%)[419]	I	Moderate for medium to high sensitivity
KQ1 Ultrasound	Sensitivity	3 studies[377, 390, 394]	Reported sensitivity ranged from 96% (corresponding specificity 96%)[377] to 36% (corresponding specificity 100%)[390]	I	Low for medium to high sensitivity
KQ1 Myelogram	Sensitivity	1 study[404]	Reported sensitivity was 82% (corresponding specificity 96%)[404]	C	Insufficient
KQ1 Evoked Potentials	Sensitivity	3 studies[391, 399, 424]	Reported sensitivity ranged from 100% (no corresponding specificity)[399] to 83%[391]	I	Low for medium sensitivity
KQ1 MRI	Specificity	4 studies[378, 411, 419, 420]	Reported specificity ranged from 100% (corresponding specificity 93%)[420] to 61% (corresponding specificity 62%)[419]	I	Moderate for medium to high specificity
KQ1 Ultrasound	Specificity	3 studies[377, 390, 394]	Reported specificity ranged from 96% (corresponding specificity 96%)[377] to 84% (corresponding specificity 36%)[390]	I	Moderate for medium to high specificity
KQ1 Myelogram	Specificity	1 study[404]	Reported specificity was 96% (corresponding sensitivity 82%)[404]	C	Insufficient
KQ1 Evoked Potentials	Specificity	2 studies[391, 424]	Reported specificity ranged from 97% (corresponding sensitivity 83%)[391] to 74% (corresponding sensitivity 88%)[424]	C	Low for medium specificity
KQ1 MRI	Accuracy	1 study[419]	Reported accuracy was 61%[419]	C	Insufficient
KQ1 Evoked Potentials	Accuracy	1 study[424]	Reported accuracy was 77%[424]	C	Insufficient
KQ1 MRI	Concordance	1 study[431]	80% of patients clinically suspected to have TSC by neurologists had a definitive diagnosis of tethered cord syndrome based on initial supine MRI findings showing no movement[431]	C	Insufficient
KQ1 Urodynamic studies	Concordance	1 study[405]	100% concordance, all surgically seen patients had TSC[405]	C	Insufficient
KQ1 MRI	Rater agreement	1 study[419]	Kappa between two evaluators was 0.94[419]	C	Insufficient
KQ1 Ultrasound	Rater agreement	2 studies[387, 397]	ICC ranged from 0.977 across two operators[387] and 0.949 across two radiologists[397]	C	Low for good agreement
KQ1 Tests	Over-or under treatment	0 studies	No data	C	Insufficient
KQ1 Tests	Clinical impact	0 studies	No data	C	Insufficient

Notes: AUC area under the curve, KQ Key Question; MRI magnetic resonance imaging; C inconsistency, I imprecision, S study limitation; SoE strength of evidence; TSC tethered spinal cord

We downgraded the strength of evidence due to imprecision given the wide range in reported results. We also downgraded for the domain inconsistency when it was not possible to determine the consistency of results with only one identified study or the absence of studies reporting on the outcome.

3.3 Results: KQ2, Tethered Spinal Cord Prophylactic Surgery

Key Question 2. What are the benefits and harms of prophylactic surgery for asymptomatic tethered spinal cord patients?

We identified eight treatment studies that provided some information on prophylactic treatment (KQ2).[239, 433-439]

3.3.1 KQ2, Tethered Spinal Cord Prophylactic Surgery Key Points

Key points pertaining to prophylactic surgery for tethered spinal cord are as follows:

- A small body of evidence exists that evaluated prophylactic surgery. Identified studies indicated benefits for motor function and stability of neurological status over time (low strength of evidence).
- However, prophylactic surgery appeared to be associated with post-operative complications such as surgical site infection (low strength of evidence).

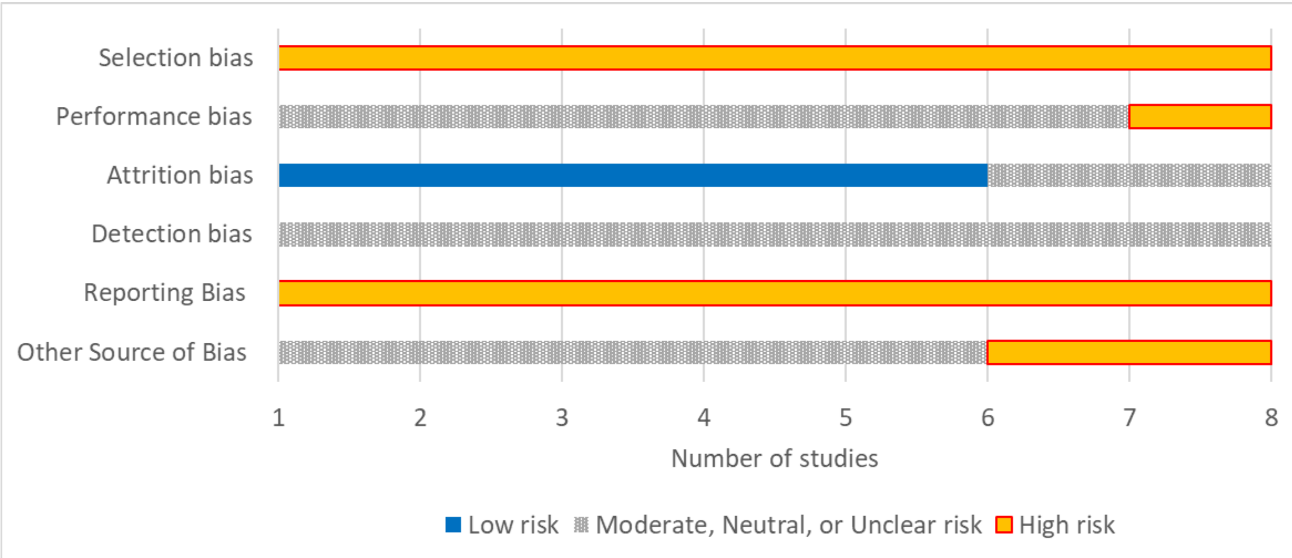
3.3.2 KQ2, Tethered Spinal Cord Prophylactic Surgery Study Characteristics

The first study reporting on prophylactic surgery that meet eligibility criteria was published in 1995.[433] Studies were conducted in seven countries, with two studies each from the U.S. and Japan. Most studies were small, but sample sizes ranged from 41 to 354 across all patients included in the study. Studies included patients of different ages, and the oldest participant was 21; however, most studies used exclusively pediatric samples. Although all studies included asymptomatic patients, most identified studies were based on mixed participants samples and very few were exclusively in asymptomatic patients. Where stated, studies addressed the initial diagnosis of tethered spinal cord, rather than diagnostic approaches to determine the presence or absence of retethering.

The risk of bias in the small set of prophylactic surgery studies is shown in Figure 5.

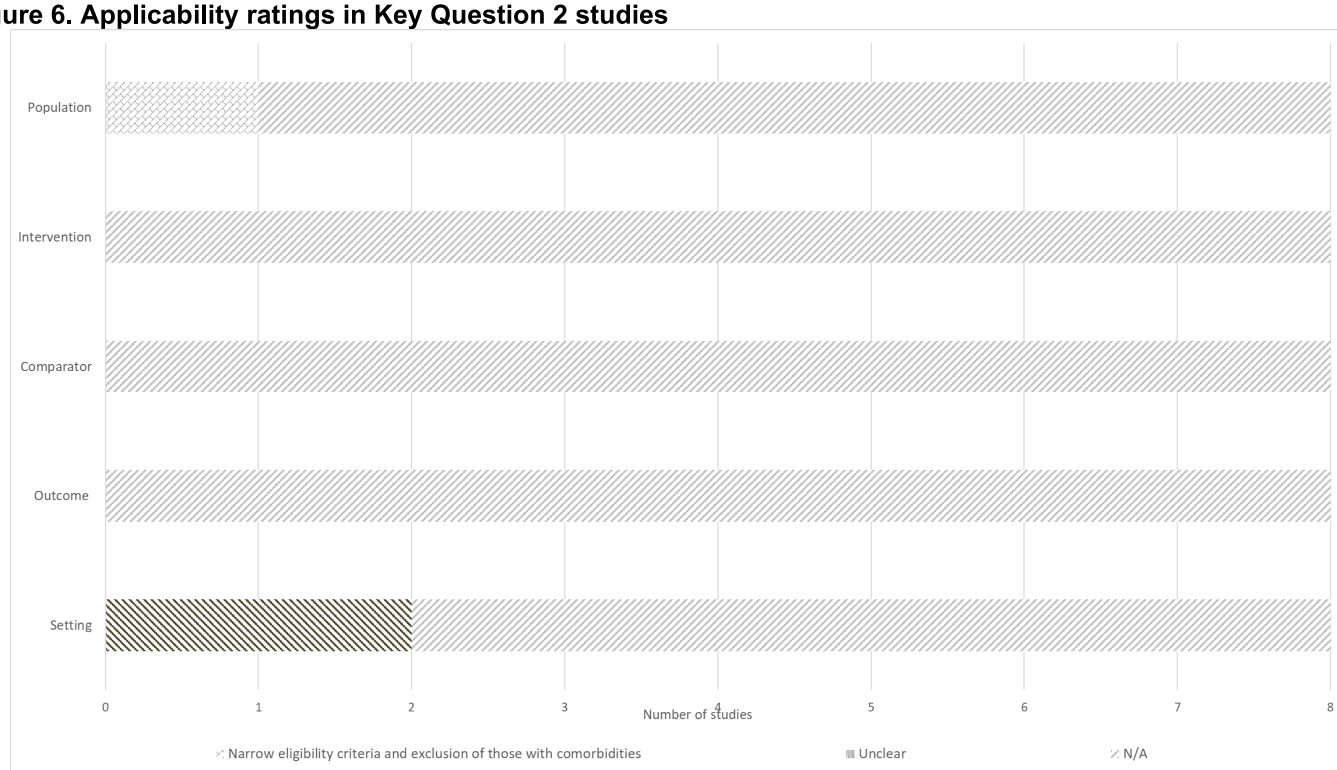
3. KQ2 Results

Figure 5. Risk of bias in Key Question 2 studies



In this small set of prophylactic surgery studies, selection bias was suspected in most studies. The applicability ratings for this subset of studies is shown in Figure 6.

Figure 6. Applicability ratings in Key Question 2 studies



N/A = no applicability issues detected

Most studies were unremarkable and no applicability issues were raised. The issues in this set of studies included narrow eligibility criteria for patients, short followup times, and a suspected different level of care from current U.S. standard.

3. KQ2 Results

Studies evaluated prophylactic surgical detethering approaches. Some studies evaluated specific methods, such as scoliosis correction, hemivertebra resection, postoperative duration of horizontal decubitus position, and microsurgery combining meningocele repair with tethered spinal cord release. Studies compared against no intervention, delayed surgical detethering, or a different intervention. The evidence table in Appendix C provides more information on the context and decision to perform prophylactic surgery.

Studies reported on neurological status, bladder or bowel function, ambulation, post-operative complications, and other adverse events. The results of all identified controlled studies are shown in the evidence table in Appendix C. Case series reporting on the clinical experiences with the different interventions are also documented in Appendix F. Given the absence of a control group or comparator, it was not possible to attribute the patient health characteristics to the interventions.

Table 4 shows the findings for the outcomes of interest together with the number of studies and study identifiers for prophylactic surgery studies. Other results are documented in the evidence table in the appendix.

Table 4. KQ2, summary of findings and strength of evidence for prophylactic surgery

KQ Intervention	Outcome	Number of Studies and IDs	Findings	Reasons for Downgrading	SoE
KQ2 Prophylactic Surgery	Neurological status	5 studies[239, 433-435, 438]	One study reported benefits in gross motor function associated with microsurgery compared to treatment as usual (follow up 72 months);[435] one study reported all patients remained stable during the follow up (mean 68 months) after prophylactic surgery but data were insufficient for the control group;[438] another study reported no asymptomatic infant deteriorated postoperatively and 93% of children remained symptom-free at follow-up (mean 44 months);[433] one study reported 0.7% displayed deterioration after surgery (mild sensory disturbance) and 4.3% of patients managed with observation presented with varus (mild), the other 95.7% had stable neurological states;[239]one study reported no change in motor/sensory function in any treatment group (follow up 3 months, RR 4.62; CI 0.30, 72.01)[434]	I, C, S	Low for benefit
KQ2 Prophylactic Treatment	Symptom score	0 studies	No data	C	Insufficient
KQ2 Prophylactic Surgery	Bladder or bowel function	3 studies[239, 433, 434, 439]	One study reported improved urologic function after concomitant prophylactic detethering compared to no detethering or detethering prior to scoliosis surgery (RR 13.85; CI 1.49, 129.17);[434] one study reported no asymptomatic infant deteriorated after detethering and 93% of children remained symptom free at follow up (mean 44 months) but the proportion of children with bladder or bowel function symptoms in the cosmetic procedure group was not reported;[433] one study noted that urinary retention was seen 0.7% of patients postoperatively but the deficit resolved after a few weeks and there were no data on the observation control group[239]	I, C, S	Low for benefit

3. KQ2 Results

KQ Intervention	Outcome	Number of Studies and IDs	Findings	Reasons for Downgrading	SoE
KQ2 Prophylactic Surgery	Ambulation	0 studies	No data	C	Insufficient
KQ2 Prophylactic Treatment	Quality of life	0 studies	No data	C	Insufficient
KQ2 Prophylactic Treatment	Pain	0 studies	No data	C	Insufficient
KQ2 Prophylactic Surgery	Post-operative complications	6 studies[433, 434, 436-439]	One study reported increased risk of surgical site infection with concomitant detethering compared to no detethering or detethering prior to scoliosis surgery (p 0.01); one study reported 33% of patients experienced a surgical complication compared to no complication without surgery;[434, 438] two studies reported 33% of patients undergoing untethering surgery experienced a complication;[437] one study reported no CSF leaks;[436] one study reported no cases of abscess formation or meningitis;[433] another study reported no operative mortality[439]	I, C, S	Low for complications
KQ2 Prophylactic Treatment	Number with adverse events	0 studies	No data	C	Insufficient
KQ2 Prophylactic Treatment	Need for repeat surgery	1 study[439]	One study reported one of five asymptomatic patients required a second operation after partial untethering[439]	C	Insufficient

Notes: KQ Key Question, CI confidence interval; CSF cerebrospinal fluid, C inconsistency (consistency could not be determined to lack of studies), I imprecision (estimate varied widely or could not be determined), S study limitation (study provided insufficient data, e.g., did not report counts for the control group); RR relative risk; SoE strength of evidence

Strength of evidence was low for all statements as no two studies reported on the same outcome measure, there were insufficient data to compute effect sizes, and data were based on observational studies prone to selection bias. Despite the importance of the outcomes, we identified no studies reporting on symptom scores, quality of life, pain, the number of participants with adverse events, or the need for repeat surgery. The evidence was insufficient for any evidence statements on these outcomes. The strength of evidence was low for all other statements as only single studies contributed to each evidence statement, there were insufficient data to compute effect sizes, and/or data were based on observational studies.

Information on other outcomes is documented in the evidence table in Appendix C.

3.4 Results: KQ3, Tethered Spinal Cord Treatment

Key Question 3. What are the effectiveness, comparative effectiveness, and harms of surgical and non-surgical treatments for symptomatic tethered spinal cord?

a. Stratified by symptom type, intensity, and patient age?
b. Are effects modified by use of special surgical equipment or techniques?

We identified 38 studies addressing KQ3, treatment of tethered spinal cord.[239, 433, 436, 438-472]

3.4.1 KQ3, Tethered Spinal Cord Treatment Key Points

Key points pertaining to treatment for symptomatic tethered spinal cord are as follows:

- A large body of evidence evaluated treatments of symptomatic patients, with the most evidence being available for surgical detethering. Across studies, surgical detethering may improve neurological status (low strength of evidence).
- Earlier surgery may have neurological benefits (low strength of evidence).
- Combined scoliosis and tethered spinal cord surgery may improve sensory deficits and lead to a more complete recovery (low strength of evidence).
- Intraoperative monitoring may improve neurological status, may be associated with fewer postoperative complications (low strength of evidence).
- Surgical detethering may improve urinary function (low strength of evidence) but is associated with postoperative complications such as cerebrospinal fluid leakage (moderate strength of evidence).
- Surgical detethering or spine shortening surgery may improve pain (low strength of evidence).
- Combined surgery versus staged surgery for different spine conditions may be associated with fewer post operative complications (low strength of evidence).
- Maintaining patients flat after detethering surgery may not prevent cerebrospinal fluid leakage (low strength of evidence).

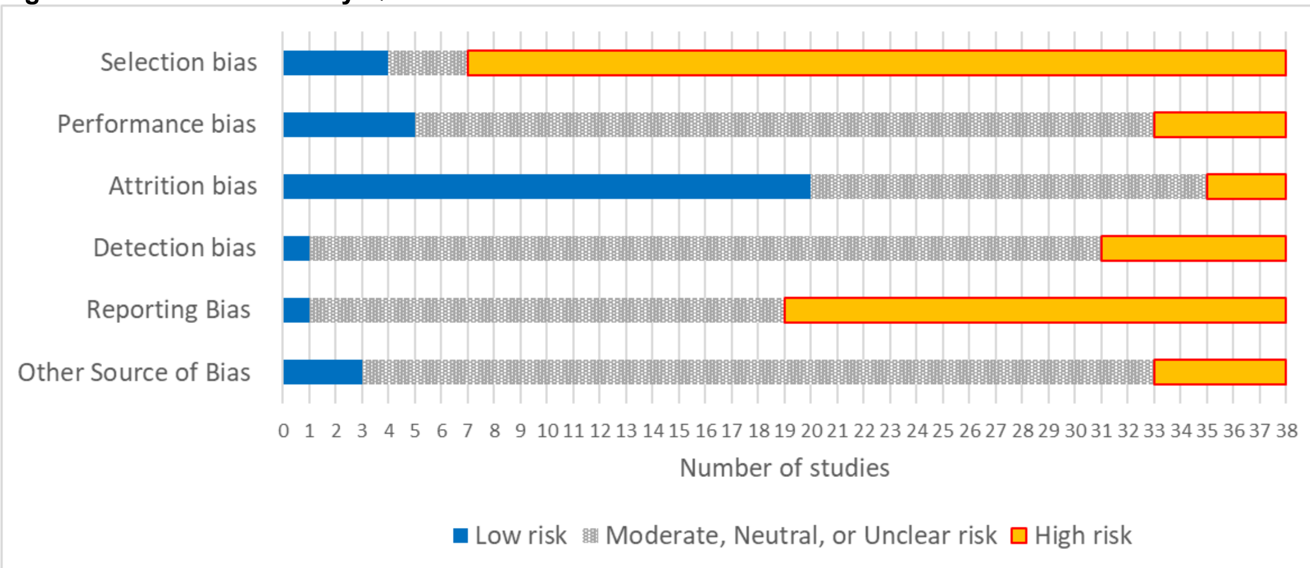
3.4.2 KQ3, Tethered Spinal Cord Treatment Study Characteristics

The first study meeting eligibility criteria was published in 1985.[472] Studies were conducted in 15 countries, with the largest group being U.S.-based studies. Most studies were small, but sample sizes ranged from 6 to large retrospective review of 6,457 patients. Studies included patients of different ages, and the oldest participant was 82 years old;[445] however, most studies used exclusively pediatric samples. Two studies addressed tethered cord syndrome in adulthood, specifically.[444, 461]

Risk of bias in the treatment studies is shown in Figure 7.

3. KQ3 Results

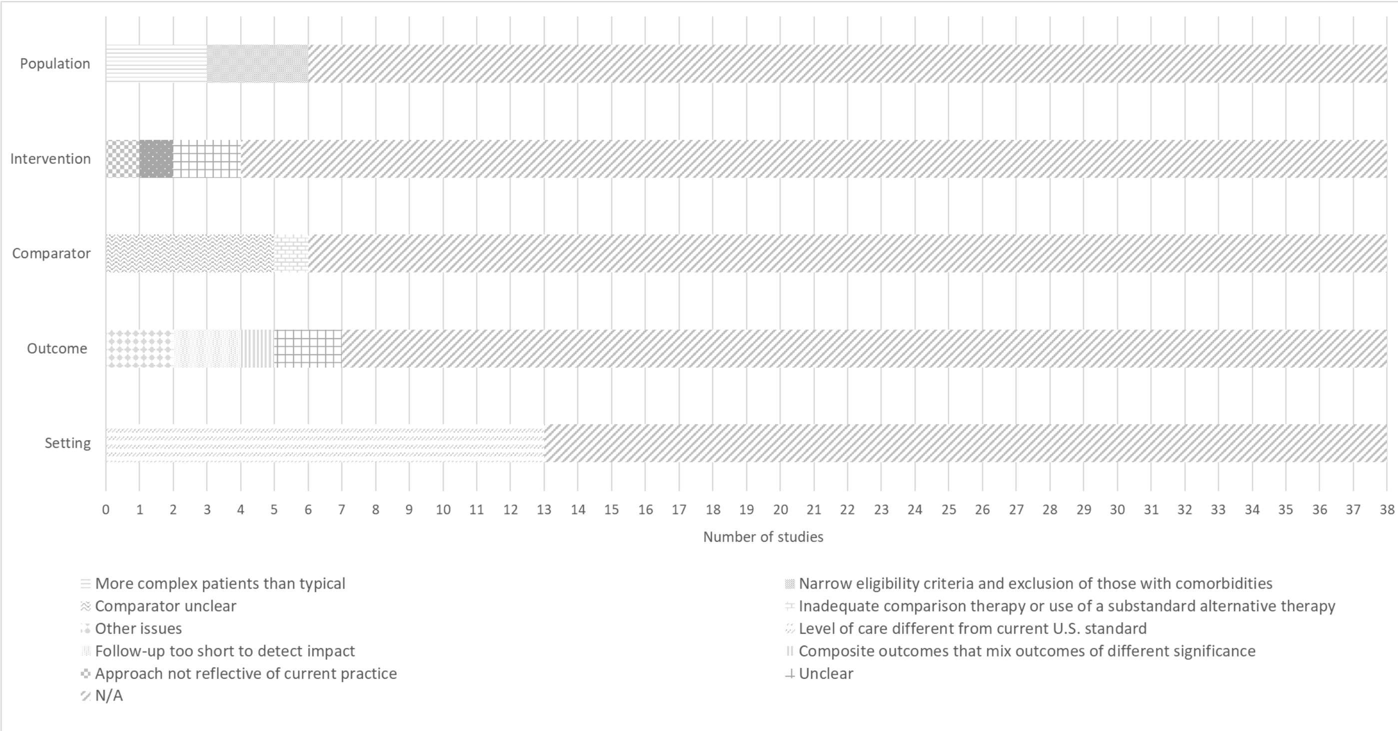
Figure 7. Risk of bias in Key Question 3 studies



Several studies evaluating treatments in symptomatic patients were also rated high risk of bias due to selection bias due to the lack of experimental studies. Participants were not randomly assigned to treatments, but were followed in observational studies. In some cases, the intervention was likely associated with patient characteristics such as experienced symptoms. The reporting was problematic in multiple studies where it was not possible to determine the number of patients in the intervention and the control or comparator group for a specific outcome. Results for all studies and each critical appraisal criterion are shown in Appendix D.

Figure 8 shows the applicability ratings across all identified treatment studies.

Figure 8. Applicability ratings in Key Question 3 studies



N/A = no applicability issues detected

There were multiple areas where we flagged studies for deviating from standard clinical practice in the U.S. Selected studies had issues such as addressing more complex patients than typical in clinical practice or the intervention was outdated or indistinguishable from the effect of the cointerventions. Some studies were flagged because the comparator was either not described in detail, the outcomes in the comparator group were not reported and it was subsequently unclear to fully evaluate the effect of the intervention, or the follow up was flagged as too short to detect an impact of the intervention. Most applicability flags concerned the setting, i.e., a low income country with less resources that likely did not meet the general U.S. standard for treatment of patients with tethered spinal cord. Appendix D shows the results for all individual studies and criteria.

3.4.3 KQ3, Tethered Spinal Cord Treatment Summary of Findings

Most identified studies evaluated surgical detethering approaches. Of these, some evaluated combining cord release with other surgical interventions versus a sequential approach,[445, 449, 452, 455, 459, 460, 462] comparing surgical techniques such as laminectomy versus laminoplasty;[469] laminectomy versus drainage approach;[446] duraplasty versus primary dural closure,[466] laminoplasty versus hemilaminectomy;[440] microsurgery versus open surgery;[448, 464, 465] untethering with or without laser;[433] or conservative observation.[239]

One study compared detethering surgery and spine-shortening osteotomy;[461] another compared detethering and spinal fusion in a large retrospective review[450] Other studies compared surgery with outcomes of patients who declined surgery or who were purposefully managed with standard medical treatment or observation.[439, 442, 444, 450, 456, 468, 472] Other studies compared

different timing of the intervention after diagnosis, for example early surgery versus surgery after conservative treatment first or surgery in the first year of life versus later.[438, 454, 458]

One study compared three approaches to correct congenital spinal deformity associated with a tethered cord without intradural detethering.[470] Some studies evaluated the incremental value of using intraoperative monitoring during surgery.[447, 451, 457]

A small set of studies addressed horizontal decubitus position after surgery, the ideal duration or management with acetazolamide, or wound treatment approaches after detethering surgery.[436, 441, 443, 453, 463, 467, 471]

Table 5 shows the findings for the outcomes of interest together with the number of studies and study identifiers for treatment studies. Other results are documented in the evidence table in the appendix.

Table 5. KQ3, summary of findings and strength of evidence for tethered spinal cord treatment

KQ3 Intervention	Outcome	Number of Studies and IDs	Findings	Reasons for Downgrading	SoE
KQ3 Open Surgical Detethering	Neurological status	7 studies[239, 442, 449, 452, 454, 461, 472]	One study compared detethered with cosmetic repair only and found a favorable effect (RR 9.78; CI 1.48, 64.41);[449] one study found more patients reported excellent results at follow up in the surgery group compared to no surgery (RR 7.62; CI 0.98, 59.37);[472] another study reported better outcomes for motor function associated with cord release (RR 2.02; 0.40, 10.10);[452] one study reported all 11 children improved after detethering and all 11 children improved after other spine corrections;[442] one study reported improvement in 44% of patients treated with surgery, 20% of patients improved immediately after surgery, and worsening symptoms were seen in 9% but decreased to 6% at the final follow-up, whereas the 2 symptomatic patients who were conservatively managed had stable neurologic status;[239] one study reported that 61% of operation (including repeat operations) resulted in clinical improvements and 33% left patients unchanged while 50% of patients who had refused surgery experienced neurological deterioration;[454] one study reported more improvement in spine shortening surgery than detethering (p 0.003);[461]	I, C, S	Low for benefit
KQ3 Combined Surgery	Neurological status	3 studies[433, 445, 446]	Combined approaches (detethering and surgical drainage of the syrinx) resulted in more resolution of sensory deficits,[446] and were correlated with positive clinical outcomes;[445] another study compared lipoma surgery with detethering to cosmetic lipoma treatment only and concluded that detethering should be performed when addressing lipomas (in symptomatic patients, 39% improved, 58% stabilized, and 3% worsened, none of the asymptomatic children lost function as a result of surgery)[433]	I, C, S	Low for benefit

3. KQ3 Results

KQ3 Intervention	Outcome	Number of Studies and IDs	Findings	Reasons for Downgrading	SoE
KQ3 Early Surgical Detethering	Neurological status	2 studies[438, 454]	Early surgery showed benefits in neurological symptoms compared to patients treated conservatively first before surgical management[438] and patients with surgery before one year of age reported more surgical benefit compared to children with surgery after one year of age[454]	I, C, S	Low for benefit
KQ3 Laminectomy vs Laminoplasty	Neurological status	2 studies[440, 469]	One study found no difference in clinical improvement comparing laminectomy versus laminoplasty (RR 0.25; CI 0.03, 1.99);[469] one study reported that laminectomy in a multivariate regression comparing with laminoplasty and hemilaminectomy was associated with poor or marginally improved surgical outcomes[440]	I, C, S	Insufficient
KQ3 Minimally Invasive Detethering	Neurological status	1 study[465]	One study reported 91% vs 100% improvement in the minimally invasive vs open tethered cord release (RR 0.92; CI 0.69, 1.21)[465]	I, C, S	Insufficient
KQ3 IOM during Surgical Detethering	Neurological status	3 study[447, 451, 457]	Neurological progression was lower in the intraoperative monitoring group[447] or achieved more complete recovery (RR 1.39; CI 1.01, 1.90);[451] while one study found no difference for stable neurological status (RR 1.00; CI 0.93, 1.07)[457]	I, C, S	Low for benefit
KQ3 TSC Treatment	Symptom scores	0 studies	No data	C	Insufficient
KQ3 TSC Open Detethering or Spine Shortening Surgery	Bladder or bowel function	9 studies[433, 439, 444, 452, 456, 459, 461, 468, 472]	Urologic dysfunction occurred in 11% in the detethering and 50% in the spine shorting group (RR 0.22; CI 0.02, 2.24);[461] average urodynamics change did not statistically significantly differ between the surgical and medical groups (p 0.80) in a further study;[468] one study reported 67% of patients experienced improvement in urgency but the corresponding data for the patient refusing surgery was not clear;[444] one study reported more satisfactory results for urinary tract dysfunction after laminectomy compared to no surgery (RR 1.94; CI 0.62, 6.10).[472] Pre-operative conservative medical treatment had to be continued in all operated children and 67% of children without untethering remained continent in another study;[456] one study reported 39% of children improved with untethering but 93% of untreated patients remained symptom free at follow up (mean 44 months);[433] one study reported surgery is effective in stopping further deterioration but few patients return to normal overall function;[439] a further study reported an effective rate for bladder dysfunction of 86% for complete release and 33% for no release (RR 1.97; CI 0.39, 9.95), as well	I, C, S	Low for benefit for detethering surgery

3. KQ3 Results

KQ3 Intervention	Outcome	Number of Studies and IDs	Findings	Reasons for Downgrading	SoE
			as 50% for partial release, and the rates for defecation dysfunction were 93% for complete release, 57% for partial release, and 33% for no release[452] one study reported the mean time to improvement was 3.5 months for urinary dysfunction across duraplasty and nonduraplasty procedures after detethering following myelomeningocele repair[459]		
KQ3 Combined Debulking spinal lipoma plus detethering	Bladder or bowel function	1 study[433]	One study reported that the combined surgery was effective while cosmetic non-detethering procedures led to delayed postoperative deterioration[433]	I, C, S	Insufficient
KQ3 Open Surgical Detethering or Spine Shortening Surgery	Ambulation	3 studies[439, 454, 461]	One study reported similar gait ataxia scores between detethered and control group;[454] another that 2% of patients were wheelchair bound after surgery but did not report frequencies in the control group;[439] one study compared detethering and spine shortening and reported gait disturbance improved in 50% in the detethering and 100% of the spine shortening group (N=3, p 0.39);[461]	C	Insufficient
KQ3 Minimally Invasive Detethering	Ambulation	1 study[448]	One study compared a minimally invasive surgical approach to standard one level laminectomy/laminotomy and reported that all patients can walk independently[448]	I C, S	Insufficient
KQ3 Surgical Detethering or Spine Shortening surgery	Pain	5 studies[444, 448, 456, 459, 461]	One study reported 2 patients operated on for back pain became symptom-free postoperatively for others preoperative medical treatment had to be continued, 1 boy without surgical untethering reported increasing back pain;[456] one study reported back pain improved in 20% in the detethering and 100% of the spine shortening group (N=6, p 0.12);[461] another study only reported on postsurgical back pain with bed rest;[448] one study assessed back pain and leg pain and reported a reduction in the surgery group but did not report on equivalent data for the patients who had declined surgery;[444] another study reported the mean time to pain relief was 3.21 months across duraplasty and nonduraplasty[459]	I, C, S	Low for benefit
KQ3 Open Surgical Detethering	Post-operative complication s	8 studies[438, 439, 444, 452, 461, 465, 466, 469]	Seven studies reported cerebrospinal fluid leakage in addition to other surgical complications in the open detethering group[438, 439, 444, 452, 461, 466, 469]; one of the studies found no difference between duraplasty and primary dural closure/non-duraplasty (RR 0.92; CI 0.25, 3.34);[466] one study reported no postoperative complications in the open or minimally invasive detethering group (RR 1.00; CI 0.07, 14.34)[465]	I, S	Moderate for association with post operative complications

3. KQ3 Results

KQ3 Intervention	Outcome	Number of Studies and IDs	Findings	Reasons for Downgrading	SoE
KQ3 Combined Surgery	Post-operative complications	5 studies[433, 449, 455, 460, 462]	Combined surgery was associated with fewer complications in two studies;[455, 460] one study did not report any adverse neurological events and provided no further data;[462] one study reported a complication rate of 16% across treatment groups[433] and another study reported 3% of patients across treatment groups developed temporary CSF leakage[449]	I, C, S	Low for fewer complications
KQ3 Minimally Invasive Detethering	Post-operative complications	2 studies[464, 465]	One study reported no postoperative complications in both groups (RR 1.00; CI 0.07, 14.34),[465] one study reported a pseudomenigocele developed in the minimally invasive detethering group with no surgical combinations in the other[464]	I, C, S	Insufficient
KQ3 Laminotomy vs Laminoplasty	Post-operative complications	2 studies[448, 469]	One study reported no difference in the number of early complications between laminotomy and laminoplasty[469] Another study reported 1/49 complications (CSF leak) with laminotomy or laminoplasty[448]	I, C, S	Insufficient
KQ3 IOM during Surgical Detethering	Post-operative complications	4 studies[447, 451, 457, 463]	Intraoperative monitoring arms reported statistically significantly fewer permanent surgery-related complications[447] or new complications in two studies;(RR 0.48; CI 0.24, 0.96)[451] while one study reported no difference in the total 60-day complications,[463] one study reported that intraoperative monitoring was not associated with any complications and found no difference for wound dehiscence (RR 1.15; CI 0.07, 17.84)[457]	I, C, S	Low for fewer complications
KQ3 Position after Detethering Surgery	Post-operative complications	3 studies[436, 443, 453]	Maintaining patients flat did not prevent CSF leakage in two studies and the effect estimate could be calculated for one (RR 0.59; CI 0.05, 6.41),[443, 453] while one study reported none of the patients developed a CSF leak regardless of the flat bed rest duration[436]	I, C, S	Low for no effect on cerebrospinal fluid leakage
KQ3 Treating CSF Leaks after Detethering Surgery	Post-operative complications	2 studies[441, 471]	Cystoperitoneal shunt successfully resolved CSF leaks compared to primary wound revision in one study (RR 0.11; CI 0.01, 0.78),[471] another study reported no difference between conservative and additional wound management such as ventriculoperitoneal shunt[441]	I, C, S	Insufficient
KQ3 Wound Treatment after Surgery	Post-operative complications	1 study[467]	One study reported that administration of acetazolamide either alone or in combination with prone positioning, could not systematically lower complication rates (RR 0.43; CI 0.09, 2.09)[467]	I, C, S	Insufficient
KQ3 TSC Treatment	30-day complication rate	0 studies	No data	C	Insufficient
KQ3 TSC Treatment	Number with adverse events	0 studies	No data	C	Insufficient

3. KQ3 Results

KQ3 Intervention	Outcome	Number of Studies and IDs	Findings	Reasons for Downgrading	SoE
KQ3 Duraplasty vs primary dural closure	Need for repeat surgery	2 studies [459, 466]	In two studies there was no statistically significant difference between retethering for duraplasty vs primary dural closure but no meaningful summary estimate could be derived (RR 4.43; CI 0.02, 77.24);[459, 466]	I, C, S	Insufficient
KQ3 Surgical Detethering	Need for repeat surgery	4 studies[447, 456, 460, 461]	One study reported the intraoperative monitoring group was associated with a significantly lower rate of reoperation;[447] two-stage patients reported a higher rate of repeat surgery vs the combined group in another study (RR 0.45; CI 0.05, 3.97);[460] one study reported 11% of patients in the detethering surgery group underwent spinal shortening due to worsening symptoms;[461] one study reported 15% patients had signs of retethering after surgical detethering[456]	I, C, S	Insufficient

Notes: CI confidence interval; IOM intra operative monitoring; KQ Key Question; CSF cerebrospinal fluid leakage; C inconsistency, I imprecision, S study limitation; RR relative risk; SoE strength of evidence; TSC tethered spinal cord

The strongest evidence base was identified for neurological status and postoperative complications. Despite the importance of the outcomes, we identified no studies reporting on symptom scores, 30-day complication rate, and the number of participants with adverse events. The evidence was insufficient for any evidence statements on these outcomes. The strength of evidence was low for all other statements as only single studies contributed to each evidence statement, there were insufficient data to compute effect sizes, and data were based on observational studies. The combined surgery approach was downgraded for study limitation despite the presence of a randomized controlled trial, given that both of the available studies are published by the same author group and have not been replicated by other author groups yet. The evidence was insufficient to determine whether minimally invasive surgery is associated with fewer or more adverse events than open surgery due to conflicting results across the small number of studies. Whether specific strategies for addressing cerebrospinal fluid leakage are beneficial could not be determined because studies reported on different strategies and comparators.

Information on other outcomes is documented in the evidence table in Appendix C.

Studies were insufficient to stratify results by presenting symptoms by type, intensity, or patient age. Similarly, we did not detect effect modifiers such as surgical equipment or technique across studies, given the paucity of studies reporting on the outcome of interest.

3.5 Results: KQ4, Tethered Spinal Cord Retethering Treatment

Key Question 4. Among individuals who experience retethering after spinal detethering surgery, what are the benefits, harms, and long-term outcomes of another surgery compared with no treatment?

a. Are individual factors with which a patient presents (e.g., primary symptoms, symptom intensity, age) associated with better or worse outcomes after repeat surgery?

We identified three studies addressing treatment of retethering (KQ4).[473-475]

3.5.1 KQ4, Tethered Spinal Cord Retethering Treatment Key Points

A key point pertaining to treatment for retethering in tethered spinal cord is as follows.

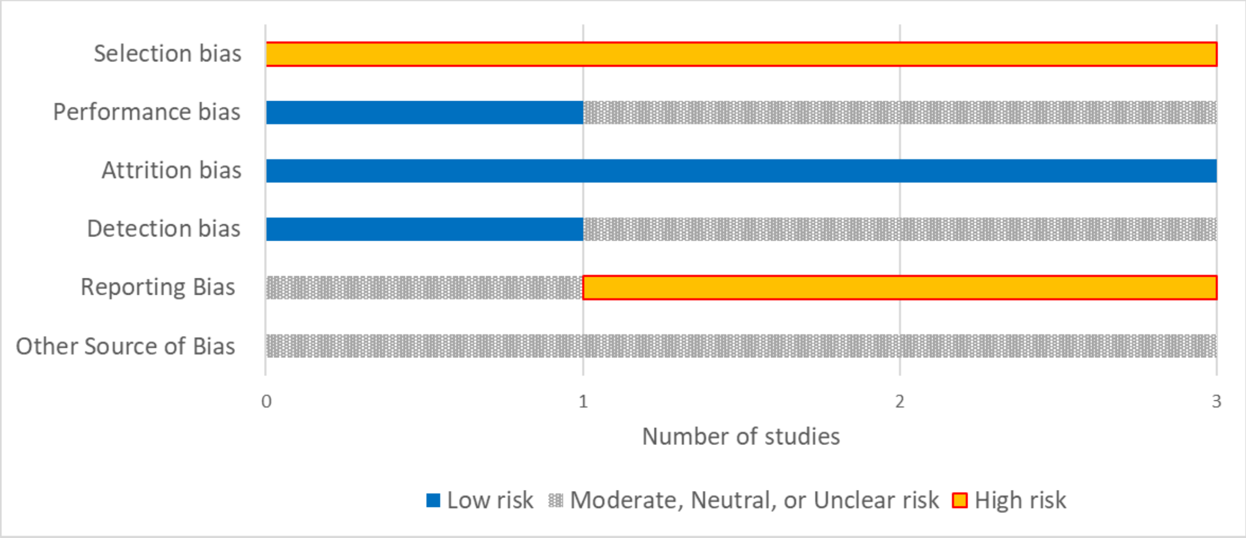
- A very small body of evidence exists for revision detethering and spinal column shortening for repeat surgery (low or insufficient strength of evidence for all outcomes, including adverse events).

3.5.2 KQ4, Tethered Spinal Cord Retethering Treatment Study Characteristics

The first study meeting eligibility criteria was published in 2004.[474] All studies were conducted in the United States except for one German study. Study sample sizes varied from 16 participants to 340 patients. The oldest participant included in the studies was 25 years old (where specified).[473] We identified one pediatric study, one study exclusively in adults, and one sample that included children and adults. All studies included participants with at least one completed primary repair; one study highlighted that some included patients underwent multiple repeat spinal cord untethering procedures.[473]

Risk of bias in the treatment studies is shown in Figure 9.

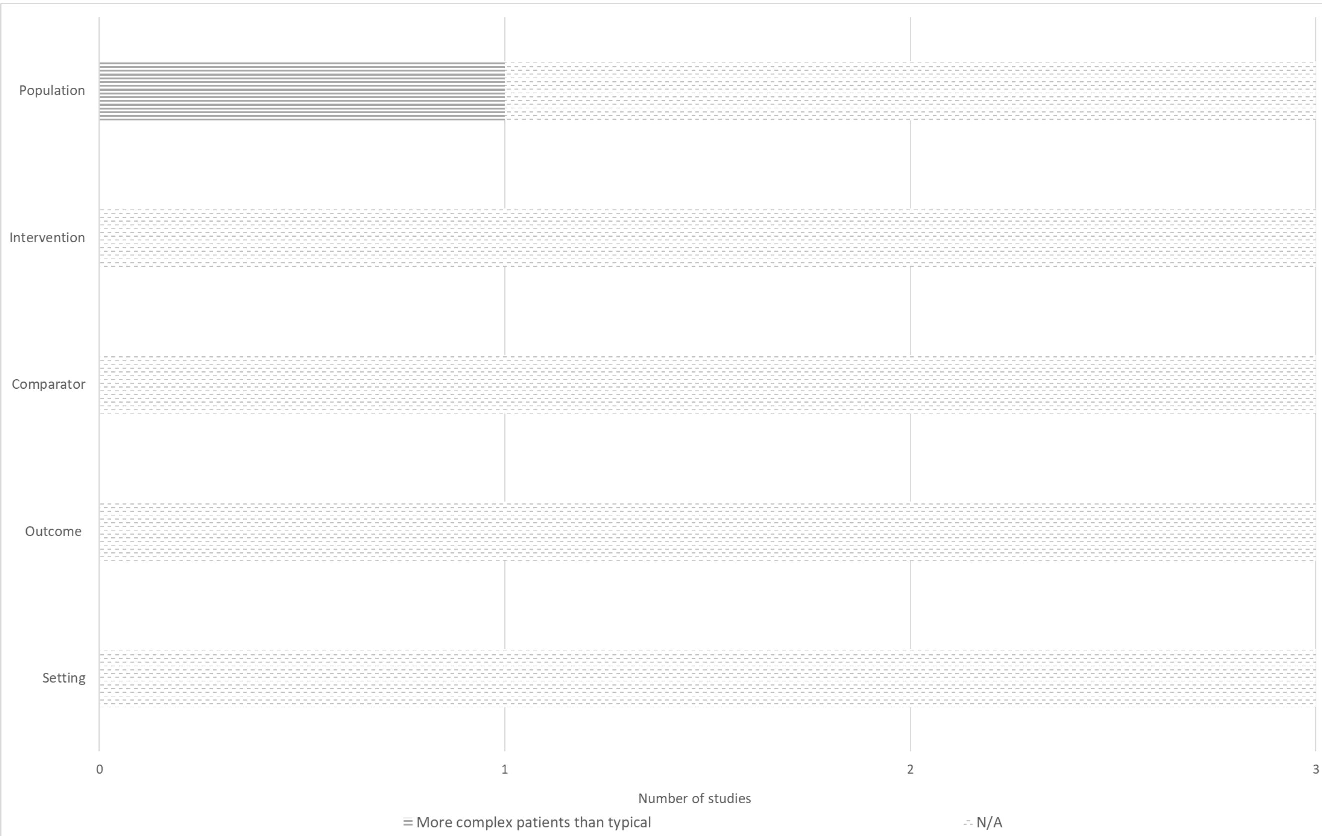
Figure 9. Risk of bias in Key Question 4 studies



Selection bias was identified as an issue in all retethering studies. The potential for reporting bias was problematic in this very small set of studies. Studies provided no numerical data for central outcomes or acknowledged that the follow up time was insufficient for the outcomes of interest. The results for the individual studies and criteria are documented in Appendix D.

Figure 10 shows the applicability ratings for studies addressing repeat surgery for tethered spinal cord.

Figure 10. Applicability ratings in Key Question 4 studies



N/A = no applicability issues detected

The figure shows the applicability issues that have been assessed for the small set of studies meeting eligibility criteria for KQ4. This dataset was problematic because there was only one study where the patient sample composition was not reflecting the full range of patients with tethered spinal cord. Appendix D shows the results for each study and criterion.

3.5.3 KQ4, Tethered Spinal Cord Retethering Treatment Summary of Findings

The studies compared vertebral column shortening versus revision detethering,[475] complete versus incomplete detethering during cord release,[473] bilateral dural incision undercutting arachnoid adhesion versus conventional dural midline approach,[474] respectively. The results of

all identified controlled studies are shown in the evidence table in Appendix C. Case series reporting on the experiences with the different interventions are also documented in Appendix F.

Two studies reported improvement in neurological status after surgical detethering (low strength of evidence), but reported no data on the control group or did not detect a statistically significant difference between groups.[473, 474] One study reported 50 percent of patients had improved urinary function after spinal column shortening while 75 percent of patients had worsening of bowel and bladder function after revision detethering;[475] one study reported 26 percent of patients showed improvement of bladder dysfunction after repeat detethering with no data reported for the comparator group.[474] One study reported 50 percent of patients had improved urinary function after spinal column shortening while 75 percent of patients had worsening of bowel and bladder function after revision detethering.[475] One of the studies found 75 percent of patients after spinal column shortening reported improved pain;[475] one study reported improved low back pain in 3 out of 13 patients after tethered cord release through bilateral dural incision, but no information was given on the outcomes of the comparator group operated on using a conventional dural midline approach.[474]

Table 6 shows the findings for all key outcomes together with the number of studies and study identifiers for repeat detethering surgery studies.

Table 6. KQ4, summary of findings and strength of evidence for spinal cord retethering, treatment

KQ Intervention	Outcome	Number of Studies and IDs	Findings	Reasons for Downgrading	SoE
KQ4 Surgery	Neurological status	2 studies[473, 474]	One study reported improvements of a variety of symptoms in 26% of patients undergoing lateral dura opening but the corresponding results of the control group are not known;[474] one study reported improved motor outcomes in patients with complete circumferential detethering but many patients who underwent incomplete untethering still had positive outcomes with no statistical difference between groups[473]	I, C, S	Low for benefit of surgical detetheri ng
KQ4 Spinal Column Shortening	Neurological status	1 study[475]	One study found no patients with worsening of lower extremity strengths after spinal column shortening vs 25% of patients reported worsening after revision detethering[475]	I, C, S	Insufficie nt
KQ4 Surgical Detethering or Spinal Column Shortening	Bladder or bowel function	2 studies[474, 475]	One study reported 50% of patients had improved urinary function after spinal column shortening while 75% of patients had worsening of bowel and bladder function after revision detethering;[475] one study reported 26% of patients showed improvement of bladder dysfunction after repeat detethering (no data on the comparator group)[474]	I, C, S	Low for benefit of surgery
KQ4 Surgical Detethering	Ambulation	0 studies	No data	C	Insufficie nt
KQ4 Treatment	Quality of life	0 studies	No data	C	Insufficie nt
KQ4 Surgery	Pain	2 studies[474, 475]	One study found 75% of patients after spinal column shortening reported improved pain;[475] one study reported a small number of patients with improved pain after tethered cord release but no information was given on the comparator[474]	I, C, S	Low for benefit of surgery

3. KQ4 Results

KQ Intervention	Outcome	Number of Studies and IDs	Findings	Reasons for Downgrading	SoE
KQ4 Surgery	Post-operative complications	1 study[475]	One study reported no complications in 8 spinal column shortening patients, but 3 wound-related complications in 8 patients with revision detethering (2 CSF leaks, 1 wound infection); one study	I, C, S	Insufficient
KQ4 Treatment	30-day complication rate	0 studies	No data	C	Insufficient
KQ4 Surgical Detethering	Number with adverse events	0 studies	No data	C	Insufficient
KQ4 Treatment	Need for repeat surgery	0 studies	No data	C	Insufficient

Notes: CSF cerebrospinal fluid; KQ Key Question; C inconsistency, I imprecision, S study limitation; SoE strength of evidence

Despite the importance of the outcomes, we identified no studies reporting on ambulation, quality of life, 30-day complication rate, number of patients with adverse events, or the need for additional surgeries. The evidence was insufficient for any evidence statements on these outcomes. The strength of evidence was either low or insufficient for all other statements as only single studies contributed to each evidence statement, there were insufficient data to compute effect sizes, and/or data were based on observational studies.

Information on other outcomes is documented in the evidence table in Appendix C.

The evidence base was insufficient to determine whether individual factors with which a patient presents, such as primary symptoms, symptom intensity, or age, are associated with better or worse outcomes after repeat surgery.

4. Discussion

4.1 Findings in Relation to Decisional Dilemmas

Tethered spinal cord syndrome is a congenital developmental disorder with a constellation of structural abnormalities with highly variable clinical presentations. Patients can present at different ages and with a wide range of symptoms, including neurological or pain symptoms or urological disturbances. Patients may present with symptomatic tethered spinal cord shortly after birth or remain asymptomatic for many years until they develop pain, weakness, sensory loss, or bladder and bowel dysfunctions. Treatment requires detethering surgery with direct dissection and release of the spinal cord and nerves from the adhesions related to the tethered cord, and surgery can be associated with peri-operative neurological injury and other peri-operative complications. On the other hand, without surgery, patients with tethered spinal cord can develop progressive neurological deficits associated with irreversible and permanent functional deficits due to neurological injuries from symptomatic tethered cord. Given the dual concerns of neurological compromise with or without surgery, timely and accurate diagnosis of symptomatic tethered spinal cord syndrome is critical as is weighing the potential benefits and risks of surgery. For patients with symptomatic tethered spinal cord syndrome, or in cases of recurrent tethering after prior surgical detethering of the tethered spinal cord, it is essential to determine if surgical risks associated with tethered spinal cord release are reasonable and acceptable relative to the projected natural history of tethered cord syndrome. And, in cases of asymptomatic tethered cord, it is also crucial to weigh the unique potential benefits and harms of prophylactic surgery in the context of the potential risks of symptomatic progression.

Accurate and timely diagnosis is critical to direct treatment decisions for tethered spinal cord. Clinicians aim to utilize tests associated with the highest sensitivity, specificity, and accuracy rates in clinical diagnostic tests. Thus, our first Key Question is, “What is the accuracy of radiographic and other diagnostic criteria in diagnosing tethered spinal cord?” Our systematic review assessed the sensitivity, specificity, and accuracy of diagnostic tests commonly used for patients with suspected tethered spinal cord. The studies evaluated magnetic resonance imaging (MRI), ultrasound, computed tomography (CT), myelogram, evoked potentials, urodynamic studies, and intraoperative neurophysiological monitoring in diagnosing tethered spinal cord.

Our review found that ultrasound and MRI had the most studies related to our first review question on tethered spinal cord diagnosis accuracy. MRI had the highest level of strength of evidence in our review, with moderate strength of evidence for medium to good sensitivity and medium to good specificity. Ultrasound had the second highest strength of evidence finding in our review for diagnosing tethered spinal cord, with low strength of evidence for medium to good sensitivity and moderate strength of evidence for medium to good specificity. On the other hand, both myelogram and evoked potential had low strength of evidence for medium sensitivity and medium specificity.

One of the most important considerations in tethered spinal cord is determining how to best manage asymptomatic patients, and a critical issue for clinicians and patients is how to best monitor asymptomatic patients to detect any neurological progression. Important considerations in monitoring asymptomatic patients include the interval of clinical assessments and timing and type of diagnostic tests to best triage those patients. Historical clinical experiences supports that many asymptomatic patients can develop significant and irreversible neurological injuries resulting in motor or sensory loss of limbs, bladder, and bowel, if left untreated. However, if prophylactic surgical treatment is pursued when patients are asymptomatic, and the patient

experiences surgically induced neurological injury, then the treatment could paradoxically create issues in their previous absence. Our second Key Question was, "What are the benefits and harms of prophylactic surgery for asymptomatic tethered spinal cord patients?" Most of the studies in our review have a mixture of symptomatic and asymptomatic patients in their analysis, and very few studies are devoted to exclusively studying the benefits and harms of prophylactic surgical treatment in asymptomatic patients. A small number of studies suggested benefits of prophylactic surgery, yet, complications such as surgical site infection were reported. Sample sizes of the studies were generally small, and the strength of evidence for the Key Question was mostly low to insufficient due to imprecision and inconsistency of results.

In evaluating the effectiveness, comparative effectiveness, and harms of surgical and non-surgical treatments for patients with symptomatic tethered spinal cord, our review found that most studies report favorable outcomes associated with surgical treatment of tethered spinal cord. Neurological statuses were mostly improved after surgery compared to those without surgery, and early surgery in patients who are mildly symptomatic and diagnosed early in their disease course is associated with more favorable neurological outcomes. Conversely, surgery was associated with surgical risks, including infection, cerebrospinal fluid leaks, and wound complications compared to non-surgical treatment.

Even with improvement from prophylactic surgery or early detethering surgery, patients can develop recurrent tethered cord syndrome that leads to progressive neurological and functional decline. In patients with recurrent tethering, it is critical to weigh the benefits, harms, and long-term outcomes of another surgery compared with no treatment. Our systematic review found benefits, including in the areas of neurological status, bladder or bowel functioning, and pain, associated with revision detethering surgery. Pain improvement appears superior in spinal column shortening compared to traditional detethering surgery. Unfortunately, there was a lack of studies reporting other outcomes, including 30-day complication rates, adverse events, or additional repeat surgeries.

4.2 Implications

MRI had the strongest body evidence, followed by ultrasound for diagnostic accuracy in diagnosing tethered spinal cord. Although many diagnostic modalities have been suggested, most identified studies did not report diagnosis accuracy measurements. Very few studies assessed asymptomatic patients for the benefits and harms of prophylactic surgical treatment, and it is difficult to draw conclusions from the research due to limitations in the strength of evidence. For treating symptomatic tethered spinal cord, most studies reported favorable outcomes associated with surgical treatment of tethered spinal cord, but surgery was associated with surgical risks. However, there was lack of comparative effectiveness and safety studies to provide further guidance on the best course of action. Although we found benefits associated with revision detethering and spinal column shortening, the body of evidence was small and there was insufficient evidence to provide definitive recommendations on the benefits of those procedures with recurrence of tethered cord syndrome.

We also searched for published clinical practice guidelines to support the review and found the Congress of Neurological Surgeons systematic review and evidence-based guidelines for pediatric myelomeningocele;[476] guidelines by the National Institute for Health and Care Excellence (NICE) on open prenatal repair for open neural tube defects in the fetus[477] and on fetoscopic prenatal repair for open neural tube defects in the fetus;[478] a guideline published by the Spina Bifida Association;[479] the European Association of Urology / European Society for

Paediatric Urology guidelines on the management of neurogenic bladder in children and adolescents;[480] guidelines by the International Children's Continence Society on tethered cord syndrome in occult spinal dysraphism;[481] and an expert consensus document on best practices to minimize wound complications after complex tethered spinal cord surgery.[482] However, all identified guidelines were considered only partially relevant, i.e., they are related to the diagnosis or high association with tethered cord but do not constitute clinical practice guidelines for the diagnosis or treatment of tethered spinal cord. The planned Congress of Neurological Surgeons (CNS) guideline will address an important gap for clinical practice. Additionally, the current review indicates that while there are data to support the current practice to diagnose, triage, and treat patients with tethered cord, there is significant gap and need for better clinical research with comparative studies between intervention and control population with more well-defined and measurable clinical outcomes.

4.3 Strengths and Limitations

Our systematic review has established a large and unique collection of relevant research studies on tethered spinal cord, aiming to advance the field. Over 400 studies contribute to this review and document clearly the relevant research undertaken to support patients with suspected or confirmed tethered spinal cord. The systematic review identified a large number of studies, but the body of evidence is limited due to the lack of controlled studies and limited reporting of outcomes for effect estimates for diagnostic modalities other than MRI and initial treatments other than surgical detethering. There are several limitations to our analysis. A significant limitation of many studies was the lack of reporting on comparative data for a control group, a comparative treatment group, an alternative diagnostic modality or reference standard. In addition, the sample sizes were small for many of the studies reviewed. most identified studies evaluating diagnostic tests did not report diagnosis accuracy measurements such as sensitivity, specificity, or area under the curve. In addition, the synthesis of treatment studies was often downgraded for strength of evidence due to imprecision and inconsistency. Many statements were downgraded due to imprecision, usually because no numerical effect estimate could be determined due to lack of reporting. And in situations when only a single study was available, it is impossible to determine the consistency of results. We found very few studies reporting on asymptomatic patients and patients experiencing retethering, limiting conclusions that can be drawn on these patient groups.

An important contribution of this study is identifying the limitation of current research and data on tethered spinal cord. The current state of knowledge and data on tethered cord has many uncertainties that leads to wide variation of practices in the community. Several sources of heterogeneity and variation in clinical practice and data reporting exist. The primary source of heterogeneity in clinical management and data reporting is the variation in patients' clinical presentation, neurological condition, treatment expectation, and risk tolerance. Patients can present with little to no neurological symptoms or severe neurological injuries with motor and sensory loss and bladder/bowel incontinence. While there is a continuum of clinical presentation, there is an insufficient number of patients and sample size for studies to compare patients based on similar degrees of neurological involvement in most studies. Thus, despite the documented research volume on tethered spinal cord diagnosis and treatment in this review, better reporting and concurrently controlled studies (randomized controlled trials [RCTs], controlled clinical trials) are urgently needed to advance the evidence base for this important clinical condition. And although we found numerous studies reporting on experience with a diagnostic modality,

the reporting of diagnostic accuracy outcomes was very sparse. Similarly, we identified hundreds of case series reporting on patients with tethered spinal cord; however, the reporting of the studies was sparse and the limitations of the study design provide the reader with little information that can be used for clinical practice recommendations.

4.4 Next Steps

Existing research needs to improve study designs by including a control group. Tethered spinal cord is a progressive disease and single arm studies cannot distinguish effects of the intervention from the natural course of the disease. Diagnostic accuracy studies should clearly report on the performance of a test compared to a reference standard. For treatment studies, assignment to interventions (such as in RCTs) not based on patient characteristics are needed to formulate stronger evidence statements. Ideally, studies that stratify tethered cord patients by degree of neurological impairment and tethered cord subtypes will be conducted in which patients are randomized to surgical and non-surgical management to answer the question of which treatments are better for whom. However, ethical concerns may limit the ability to conduct such randomized studies because the current general assumption is that even asymptomatic and only mildly symptomatic patients will permanently decline neurologically and functionally without treatment. Alternatively, large sample prospective cohort studies that closely follow asymptomatic tethered cord patients with quantitative outcome measures and neurological assessments would provide valuable information on the natural history and risk of progression on those patients.

Furthermore, there was limited relevant data on diagnostic modalities beyond MRI and ultrasound. The use of and the clinical experience with other diagnostic modalities is documented especially in case series; however, many open questions remain, particularly in terms of concrete diagnostic accuracy data. In addition, we still know very little about non-surgical interventions and future research should investigate more thoroughly what the options are for patients beyond surgery.

Future research should report outcomes, including adverse events, quantitatively and systematically, and provide information on a control or comparator group. For all Key Questions, experts advised on key outcomes, and despite the large number of identified studies, there was insufficient evidence for a number of these key outcomes. For diagnostic tests used to diagnose tethered spinal cord, we did not identify studies reporting on over-or under treatment, or any clinical impact of using the diagnostic modality; hence the strength of evidence remains insufficient. For prophylactic surgery, we have no data on the effects on symptom scores, ambulation, quality of life, pain, the number of patients reporting adverse events, and the need for repeat surgery. Despite the large number of treatment studies evaluating interventions in symptomatic patients, we did not identify studies that reported on a standardized scale to assess relevant tethered spinal cord symptoms. Similarly, although we identified studies reporting on post-operative complications, the small number of studies reported conflicting results and more research is needed for definitive evidence statements. Furthermore, experts suggested that the 30-day complication rate and the number of patients reporting adverse events would be key outcomes to judge the success of interventions, however, none of the studies reported on these specific outcomes. Multiple identified studies reported quantitative data for the main intervention group but not the control group; future studies should report on quantitative outcomes for all included patients. Finally, the evidence base for interventions to address spinal cord retethering was insufficient for the outcomes ambulation, quality of life, post-operative complications, 30-

day complication rate, the number of patients reporting adverse events, and the need for further surgeries. Despite the importance of the outcomes there were insufficient studies and this lack of information points to the need for more research. In general, we suggest that future studies collect and report more patient-centered outcomes such as ambulation or preserving renal function; these are key considerations for patients when determining whether to undergo surgical detethering.

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Abbreviations and Acronyms

Acronym	Definition
AHRQ	Agency for Healthcare Research and Quality
CNS	Congress of Neurological Surgeons
CSF	Cerebrospinal fluid
CT	Computed Tomography
EHC	Effective Health Care
EPC	Evidence-based Practice Center
GRADE	Grading of Recommendations Assessment, Development and Evaluation
KQ	Key Question
MRI	Magnetic Resonance Imaging
PCORI	Patient-Centered Outcomes Research Institute
RCT	Randomized controlled trial
SEADS	Supplementary Evidence And Data for Systematic Reviews
SoE	Strength of Evidence
SRDR	Systematic Review Data Repository
TEP	Technical Expert Panel
TSC	Tethered Spinal Cord
VIBE/LAVA	Volumetric interpolated breath-hold examination/liver acquisition with volume acceleration

Appendix A. Methods

Search Strategies

Search date: 2/27/2024

PubMed
No Limits
tethered cord syndrome[Title/Abstract] OR tethered spinal cord[Title/Abstract] OR tethered cord[Title/Abstract] OR spinal column shortening[Title/Abstract] OR (spinal column shortening[Title/Abstract] AND tethered[Title/Abstract]) OR low lying conus[Title/Abstract] OR fatty filum terminale [Title/Abstract] OR thickened filum terminale[Title/Abstract] OR tight filum terminale[Title/Abstract] OR low lying spinal cord[Title/Abstract] OR filum terminale syndrome[Title/Abstract] OR lipomyelomeningocele[Title/Abstract] OR tight filum syndrome[Title/Abstract]
Results: 2057

EMBASE
('tethered cord syndrome' OR 'tethered spinal cord' OR 'tethered cord' OR 'spinal column shortening' OR ('spinal column shortening' AND tethered)) NOT [medline]/lim OR ("low lying conus" OR "fatty filum terminale" OR "thickened filum terminale" OR "tight filum terminale" OR "low lying spinal cord" OR "filum terminale syndrome" OR "Lipomyelomeningocele" OR "tight filum syndrome") NOT [medline]/lim
Results: 1364

CINAHL
Limit: Academic Journals
TI ("tethered cord syndrome" OR "tethered spinal cord" OR "tethered cord" OR "spinal column shortening" OR ("spinal column shortening" AND tethered)) OR AB ("tethered cord syndrome" OR "tethered spinal cord" OR "tethered cord" OR "spinal column shortening" OR ("spinal column shortening" AND tethered)) OR SU ("tethered cord syndrome" OR "tethered spinal cord" OR "tethered cord" OR "spinal column shortening" OR ("spinal column shortening" AND tethered)) OR TI ("low lying conus" OR "fatty filum terminale" OR "thickened filum terminale" OR "tight filum terminale" OR "low lying spinal cord" OR "filum terminale syndrome OR "Lipomyelomeningocele" OR "tight filum syndrome") OR AB ("low lying conus" OR "fatty filum terminale" OR "thickened filum terminale" OR "tight filum terminale" OR "low lying spinal cord" OR "filum terminale syndrome OR "Lipomyelomeningocele" OR "tight filum syndrome") OR SU ("low lying conus" OR "fatty filum terminale" OR "thickened filum terminale" OR "tight filum terminale" OR "low lying spinal cord" OR "filum terminale syndrome" OR "Lipomyelomeningocele" OR "tight filum syndrome")
Results: 321

Web of Science
Limit: Science Citation Index Expanded, Conference Proceedings Citation Index, Emerging Sources Citation Index
"tethered cord syndrome" OR "tethered spinal cord" OR "tethered cord" OR "spinal column shortening" OR ("spinal column shortening" AND tethered) (Topic) OR "low lying conus" OR "fatty filum terminale" OR "thickened filum terminale" OR "tight filum terminale" OR "low lying spinal cord" OR "filum terminale syndrome" OR "Lipomyelomeningocele" OR "tight filum syndrome") (Topic)
Results: 2121

Scopus
TITLE-ABS-KEY ("tethered cord syndrome" OR "tethered spinal cord" OR "tethered cord" OR "spinal column shortening" OR ("spinal column shortening" AND tethered)) OR TITLE-ABS-KEY ("low lying conus" OR "fatty filum terminale" OR "thickened filum terminale" OR "tight filum terminale" OR "low lying spinal cord" OR "filum terminale syndrome" OR "Lipomyelomeningocele" OR "tight filum syndrome")
Results: 3362

Clinicaltrial.gov
(classical website)
No limits
"tethered cord syndrome" OR "tethered spinal cord" OR "tethered cord" OR "spinal column shortening" OR "low lying conus" OR "fatty filum terminale" OR "thickened filum terminale" OR "tight filum terminale" OR "low lying spinal cord" OR "filum terminale syndrome OR Lipomyelomeningocele" OR "tight filum syndrome"
Recruitment: Completed studies
Study Results: All studies
Phase: Phase 2, Phase 3, Phase 4
Results: 8

ICTRP
No limits
“tethered cord syndrome” OR “tethered spinal cord” OR “tethered cord” OR “spinal column shortening” OR “low lying conus” OR “fatty filum terminale” OR “thickened filum terminale” OR “tight filum terminale” OR “low lying spinal cord” OR “filum terminale syndrome OR Lipomyelomeningocele” OR “tight filum syndrome”
Phase: Phase 2, Phase 3, Phase 4
Results: 3

Cochrane Database of Systematic Reviews
tethered cord syndrome OR tethered spinal cord OR tethered cord OR spinal column shortening OR (spinal column shortening AND tethered) OR low lying conus OR fatty filum terminale OR thickened filum terminale OR tight filum terminale OR low lying spinal cord OR filum terminale syndrome OR lipomyelomeningocele OR tight filum syndrome
Results: 10

PROSPERO
tethered cord syndrome OR tethered spinal cord OR tethered cord OR spinal column shortening OR (spinal column shortening AND tethered) OR low lying conus OR fatty filum terminale OR thickened filum terminale OR tight filum terminale OR low lying spinal cord OR filum terminale syndrome OR lipomyelomeningocele OR tight filum syndrome
Completed Studies
Results: 1

ECRI Guidelines Trust
"tethered cord syndrome" OR "tethered spinal cord" OR "tethered cord"
Results: 1

G-I-N (https://guidelines.ebmportal.com/)
Searched: International Guidelines Library
tethered cord syndrome, tethered spinal cord, tethered cord
Results: 0

MagicApp (https://app.magicapp.org/#/guidelines)
Searched: Guidelines
tethered cord syndrome, tethered spinal cord, tethered cord
Results: 0

ClinicalKey
Searched: Guidelines
tethered cord syndrome, tethered spinal cord, tethered cord
Results: 5

Appendix B. List of Excluded Studies

This appendix shows the list of excluded studies with reasons for exclusion. We only recorded one reason per publication.

1. Tethered cord syndrome as cause of spinal cord dysfunction. Lancet; 1996. p. 342-3. *Design*

2. Gene expression profiles of neurotrophic factors and their receptors in rat cultured spinal cord cells under cyclic tensile stress. Spine. 2009. *Population*

3. Effect of Acetazolamide & Position in CSF Leakage and Collection and Wound Dehiscence. 2013. *Outcome*

4. Fracture and migration of a retained microcatheter into the cauda equina after endovascular neurointervention for dural arteriovenous fistula as a rare cause of tethered spinal cord: case report. American Association of Neurological Surgeons & the Journal of Neurosurgical Publishing Group; 2019. p. 1-4. *Intervention*

5. Fetal lipomyelomeningocele: A closed neural tube defect diagnosed at second-trimester ultrasound examination. John Wiley & Sons, Inc.; 2019. p. 169-71. *Intervention*

6. Congenital Tethered Cord Presenting as Chronic Back Pain in a 29-Yr-Old Woman. Lippincott Williams & Wilkins; 2021. p. e162-e3. *Intervention*

7. Expert consensus on diagnosis and treatment of spina bifida. Zhongguo xiu fu chong jian wai ke za zhi = Zhongguo xiufu chongjian waike zazhi = Chinese journal of reparative and reconstructive surgery. 2021;35(11):1361-7. doi: 10.7507/1002-1892.202105099. *Language*

8. Rare case of human tail with tethered cord. Journal of Clinical Ultrasound. 2021;49(7):774-6. doi: 10.1002/jcu.23015. PMID: 151881157. Language: English. Entry Date: In Process. Revision Date: 20220901. Publication Type: Journal Article. Journal Subset: Biomedical. *Intervention*

9. In daytime (diurnal) incontinence, also consider the tethered cord syndrome. Journal fur Urologie und Urogynakologie. 2023;30(3):125-6. doi: 10.1007/s41972-023-00211-2. *Language*

10. Two cases of total syringomyelia caused by tethered spinal cord. Chinese Journal of Neurosurgery. 2023;39(9):950-2. doi: 10.3760/cma.j.cn112050-20220812-00403. *Language*

11. Surgical technique of spine-shortening vertebral osteotomy for adult tethered cord syndrome: a case report and review of the literature. BioMed Central; 2023. p. 1-5. *Duplicate*

12. Erratum: Tethered spinal cord among individuals with myelomeningocele: an analysis of the National Spina Bifida Patient Registry (J Neurosurg Pediatr. (2021) 28:1 (21-27) DOI: 10.3171/2023.5.PEDS20868). Journal of Neurosurgery: Pediatrics. 2023;32(6):750. doi: 10.3171/2023.5.PEDS20868a. *Population*

13. Abbott JF, Davis GH, Endicott B, et al. Prenatal diagnosis of vestigial tail. Journal of ultrasound in medicine. 1992;11(1):53-5. *Population*

14. . Pathophysiology and surgical treatment of syringomyelia associated with spinal dysraphism. 2nd International Symposium on Spina Bifida; 1997 Sep 27; Kobe, Japan. Springer-Verlag Tokyo. *Population*

15. Abe K. A tethered conus syndrome in an adult woman. Internal Medicine. 2006;45(7):489. doi: 10.2169/internalmedicine.45.1709. *Design*

16. Aboal C, Wilson D, Cibils D, et al. Tethered spinal cord surgery with intraoperative neurophysiological monitoring. Revista Medica Del Uruguay. 2006 May;22(2):152-6. PMID: WOS:000421472500010. *Language*

17. AbouZeid AA, Mohammad SA, Abolfotoh M, et al. The Currarino triad: What pediatric surgeons need to know. J Pediatr Surg. 2017 Aug;52(8):1260-8. doi: 10.1016/j.jpedsurg.2016.12.010. PMID: 28065719. *Population*

18. Abraham AP, Vora TK, Selvi BT, et al. Characterizing syringomyelia and its clinical significance in 140 patients with lipomyelomeningocele. Journal of Neurosurgery-Pediatrics. 2022 Sep;30(3):349-56. doi: 10.3171/2022.6.Peds2286. PMID: WOS:000863172200003. *Population*

19. Abu-Bonsrah N, Purvis TE, Goodwin CR, et al. Adult cervicothoracic lipomyelomeningocele. Journal of Clinical Neuroscience. 2016 Oct;32:157-9. doi: 10.1016/j.jocn.2016.04.005. PMID: WOS:000383525000038. *Intervention*

20. Adams JS, Caldecott-Johnson S. Surfer-s myelopathy in a young female cheerleader with tethered spinal cord syndrome: A case report. PM and R. 2014;6(9):S358. *Intervention*

21. Adamson AS, Gelister J, Hayward R, et al. Tethered cord syndrome: an unusual cause of adult bladder dysfunction. Br J Urol. 1993 Apr;71(4):417-21. doi: 10.1111/j.1464-410x.1993.tb15984.x. PMID: 8499985. *Intervention*

22. Adamson DC, Cummings TJ, Friedman AH, et al. Myxopapillary ependymoma and fatty filum in an adult with tethered cord syndrome: A shared embryological lesion? Case report. Neurosurgery. 2005;57(2):373. doi: 10.1227/01.NEU.0000166690.35246.DD. *Outcome*

23. Afshar K, Blake T, Jaffari S, et al. Spinal cord magnetic resonance imaging for investigation of nonneurogenic lower urinary tract dysfunction--can the yield be improved? J Urol. 2007 Oct;178(4 Pt 2):1748-50; discussion 50-1. doi: 10.1016/j.juro.2007.03.179. PMID: 17707435. *Intervention*

24. Agarwal N, Hansberry DR, Goldstein IM. Tethered Cord as a Complication of Chronic Cerebral Spinal Fluid Diversion. Int J Spine Surg. 2017;11(4):26. doi: 10.14444/4026. PMID: 29372130. *Outcome*

25. Ağırman M, Çalkın M, Güngören FZ, et al. Late-Onset Tethered Cord Syndrome in a Patient with Spina Bifida: A Case Report. Sisli Etfal Hastan Tip Bul. 2018;52(2):138-41. doi: 10.14744/semb.2017.64936. PMID: 32595388. *Design*

26. Agnarsson U, Warde C, McCarthy G, et al. Anorectal function of children with neurological problems. II: cerebral palsy. Dev Med Child Neurol. 1993 Oct;35(10):903-8. PMID: 8405719. *Population*

27. Agrawal A. Resolving clubfoot deformity misleading and delaying the diagnosis of tethered cord syndrome. Iranian Journal of Pediatrics. 2008;18(1):92-3. *Design*

28. Agrawal V, Velho V, Palande D, et al. “tethered Cord Syndrome” our experience. Child's Nervous System. 2011;27(10):1828-9. doi: 10.1007/s00381-011-1524-8. *Design*

29. Agubuzu O, Shaw ET. Intrathecal ziconotide for chronic pain due to tethered cord syndrome: A case report.

Neuromodulation. 2018;21(3):e1. doi: 10.1111/ner.12774. *Design*

30. Agushi R, De Saint Denis T, Zerah M, et al. Re-tethered cord syndrome in pediatric patients with conus lipoma: the second surgery. Child's Nervous System. 2021;37:1392. doi: 10.1007/s00381-021-05066-2. *Population*

31. Ahmed H, Almomani M, Strine AC, et al. Clinical urologic and urodynamic outcomes in patients with anorectal malformation and absent vagina after vaginal replacement. J Pediatr Surg. 2020 Sep;55(9):1834-8. doi: 10.1016/j.jpedsurg.2020.01.050. PMID: 32087935. *Intervention*

32. Ailawadhi P, Agrawal D, Mahapatra AK. Primary tethered cord syndrome-manifestations diagnosis and management: A prospective study. Child's Nervous System. 2011;27(10):1777. doi: 10.1007/s00381-011-1524-8. *Design*

33. Ailawadhi P, Kale SS, Agrawal D, et al. Primary Tethered Cord Syndrome - Clinical and Urological Manifestations, Diagnosis and Management: A Prospective Study. Pediatric Neurosurgery. 2012;48(4):210-5. doi: 10.1159/000345829. PMID: WOS:000324596900002. *Duplicate*

34. Akalin M, Demirci O, Kaygusuz E, et al. Prenatally diagnosed fetal thoraco-lumbar spine duplication associated with lipomyelomeningocele: An extremely rare case of split cord malformation. Turkish Journal of Obstetrics and Gynecology. 2022 Dec;19(4):333-7. doi: 10.4274/tjod.galenos.2022.85453. PMID: WOS:000921197500013. *Population*

35. Akay KM, Izci Y, Baysefer A, et al. Split cord malformation in adults. Neurosurgical Review. 2004 Apr;27(2):99-105. doi: 10.1007/s10143-003-0313-6. PMID: WOS:000220054400007. *Design*

36. Akutsu H, Takada T, Nakai K, et al. Surgical technique for idiopathic spinal cord herniation: the Hammock method. Technical note. Neurol Med Chir (Tokyo). 2012;52(4):238-42. doi: 10.2176/nmc.52.238. PMID: 22522340. *Population*

37. Al- Dahhan MH, Mnaather AA, Munshid BA. Evaluation Of Spina Bifida Occulta In Young Patients Presented With Low Back Pain. European Journal of Molecular and Clinical Medicine. 2020;7(10):4416-22. *Population*

38. Al-Habib A, Alhothali W, Albakr A, et al. Effects of compressive lesions on intraoperative human spinal cord elasticity. J Neurosurg Spine. 2021 Aug 20;35(6):807-16. doi: 10.3171/2021.1.SPINE201482. PMID: 34416718. *Population*

39. Al-Holou WN, Muraszko KM, Garton HJ, et al. The outcome of tethered cord release in secondary and multiple repeat tethered cord syndrome Clinical article. Journal of Neurosurgery-Pediatrics. 2009 Jul;4(1):28-36. doi: 10.3171/2009.2.Peds08339. PMID: WOS:000267384000011. *Duplicate*

40. Al-Mefty O, Kandzari S, Fox JL. Neurogenic bladder and the tethered spinal cord syndrome. J Urol. 1979 Jul;122(1):112-5. doi: 10.1016/s0022-5347(17)56279-5. PMID: 458974. *Outcome*

41. Al-Omari MH, Eloqayli HM, Qudseih HM, et al. Isolated lipoma of filum terminale in adults: MRI findings and clinical correlation. J Med Imaging Radiat Oncol. 2011 Jun;55(3):286-90. doi: 10.1111/j.1754-9485.2011.02266.x. PMID: 21696562. *Population*

42. Alabi NB, Thibadeau J, Wiener JS, et al. Surgeries and health outcomes among patients with spina bifida. Pediatrics. 2018;142(3). *Population*

43. Alam A, Teh J. MRI assessment of scoliosis. Imaging. 2005;17(3):226-35. doi: 10.1259/imaging/33022116. *Outcome*

44. Alatas I, Cetiner R, Ozer V, et al. Spina bifida with additional anomalies. Child's Nervous System. 2018;34(5):1069. doi: 10.1007/s00381-018-3756-3. *Design*

45. Alatas I, Ozel K, Tunc T, et al. Preoperative and postoperative urodynamic outcome of tethered cord syndrome in children. Child's Nervous System. 2014;30(4):760-1. doi: 10.1007/s00381-014-2389-4. *Design*

46. Alatas I, Ozel K, Tunc T, et al. Preoperative urodynamic findings of occult spinal dysraphisms in children. Child's Nervous System. 2014;30(4):761. doi: 10.1007/s00381-014-2389-4. *Duplicate*

47. Alawaji G, Alhothali W, Albakr A, et al. Shear wave elastography for intracranial epidermoid tumors. Clin Neurol Neurosurg. 2021 Aug;207:106531. doi: 10.1016/j.clineuro.2021.106531. PMID: 34182236. *Population*

48. Albakheet SS, Yoon H, Lee MJ, et al. Determining the optimal timing of screening spinal cord ultrasonography to detect filum terminale lipoma in infants. Ultrasonography. 2020;39(4):367-75. doi: 10.14366/usg.19061. *Outcome*

49. Aldaz Vallejo FA, Encalada Vasconez VS, Mosquera Moscoso J, et al. Resection of the extravertebral portion of the filum terminale with posterior internal sphincterotomy, a surgical technique for managing chronic constipation and encopresis in children. Salud, Ciencia y Tecnologia. 2023;3. doi: 10.56294/SALUDCYT2023576. *Population*

50. Aleem AW, Thuet ED, Padberg AM, et al. Spinal Cord Monitoring Data in Pediatric Spinal Deformity Patients With Spinal Cord Pathology. Spine Deform. 2015 Jan;3(1):88-94. doi: 10.1016/j.jspd.2014.06.011. PMID: 27927457. *Population*

51. Alexander E, Jr., Garvey FK, Boyce W. Congenital lumbosacral myelomeningocele with incontinence, a contribution to the understanding of bladder physiology. J Neurosurg. 1954 Mar;11(2):183-92. doi: 10.3171/jns.1954.11.2.0183. PMID: 13152569. *Intervention*

52. Alexiades NG, Shao BLD, Ahn ES, et al. High prevalence of gram-negative and multiorganism surgical site infections after pediatric complex tethered spinal cord surgery: a multicenter study. Journal of Neurosurgery-Pediatrics. 2022 Sep;30(3):357-63. doi: 10.3171/2022.6.Peds2238. PMID: WOS:000863172200004. *Outcome*

53. Alexiou GA, Prodromou N. Spinal dermal sinus tract. Child's Nervous System. 2010;26(5):597. doi: 10.1007/s00381-010-1084-3. *Population*

54. Ali A, Ali R, Ali G. TETHERED CORD SYNDROME IN ADULTS: EXPERIENCE OF 50 PATIENTS. Journal of Population Therapeutics and Clinical Pharmacology. 2023;30(18):337-43. doi: 10.53555/jptcp.v30i18.3075. *Population*

55. Aliredjo RP, de Vries J, Menovsky T, et al. The use of Gore-Tex membrane for adhesion prevention in tethered spinal cord surgery: technical case reports. Neurosurgery. 1999 Mar;44(3):674-7; discussion 7-8. doi: 10.1097/00006123-199903000-00139. PMID: 10069608. *Population*

56. Alriksson-Schmidt AI, Ong K, Reeder MR, et al. Site, frequency, and duration of pain in young children with spina bifida. Journal of Pediatric Rehabilitation Medicine. 2021;14(4):571-82. doi: 10.3233/PRM-190661. *Population*

57. Altiok H. Post-operative scoliotic curve progression following tethered cord release in children with myelodysplasia. Topics in Spinal Cord Injury Rehabilitation. 2013;19(2):160. doi: 10.1310/sci1902-152. *Outcome*

58. Altiok H, Riordan A, Graf A, et al. Response of Scoliosis in Children with Myelomeningocele to Surgical Release of Tethered Spinal Cord. Top Spinal Cord Inj Rehabil. 2016 Fall;22(4):247-52. doi: 10.1310/sci2204-247. PMID: 29339865. *Duplicate*

59. Altman NR, Altman DH. MR imaging of spinal dysraphism. AJNR Am J Neuroradiol. 1987 May-Jun;8(3):533-8. PMID: 3111214. *Population*

60. Ambartsumyan L, Nurko S. Review of organic causes of fecal incontinence in children: evaluation and treatment. Expert Rev Gastroenterol Hepatol. 2013 Sep;7(7):657-67. doi: 10.1586/17474124.2013.832500. PMID: 24070156. *Population*

61. Ambartsumyan L, Rodriguez L. Gastrointestinal motility disorders in children. Gastroenterol Hepatol (N Y). 2014 Jan;10(1):16-26. PMID: 24799835. *Population*

62. Ameri E, Andalib A, Tari HV, et al. The Role of Routine Preoperative Magnetic Resonance Imaging in Idiopathic Scoliosis: A Ten Years Review. Asian Spine J. 2015 Aug;9(4):511-6. doi: 10.4184/asj.2015.9.4.511. PMID: 26240707. *Population*

63. Amiri AR, Kanesalingam K, Srinivasan V, et al. Adult tethered cord syndrome resembling plantar fasciitis and peripheral neuropathy. BMJ Case Rep. 2013 Dec 5;2013. doi: 10.1136/bcr-2013-201437. PMID: 24311422. *Design*

64. Ammerman BJ, Henry JM, De Girolami U, et al. Intradural lipomas of the spinal cord. A clinicopathological correlation. J Neurosurg. 1976 Mar;44(3):331-6. doi: 10.3171/jns.1976.44.3.0331. PMID: 1249612. *Population*

65. Andar UB, Harkness WF, Hayward RD. Split cord malformations of the lumbar region. A model for the neurosurgical management of all types of 'occult' spinal dysraphism? Pediatr Neurosurg. 1997 Jan;26(1):17-24. doi: 10.1159/000121156. PMID: 9361113. *Population*

66. Andar UB, Harkness WFJ, Hayward RD. Split cord malformations of the lumbar region? Pediatric Neurosurgery. 1997;26(1):17-24. doi: 10.1159/000121156. *Population*

67. Anderson FM. Occult spinal dysraphism. Diagnosis and management. J Pediatr. 1968 Aug;73(2):163-77. doi: 10.1016/s0022-3476(68)80065-4. PMID: 4875770. *Population*

68. Anderson FM. Occult spinal dysraphism: a series of 73 cases. Pediatrics. 1975 Jun;55(6):826-35. PMID: 1094400. *Population*

69. Anderson RC, Ragel BT, Mocco J, et al. Selection of a rigid internal fixation construct for stabilization at the craniovertebral junction in pediatric patients. J Neurosurg. 2007 Jul;107(1 Suppl):36-42. doi: 10.3171/PED-07/07/036. PMID: 17644919. *Population*

70. Andro C, Pecquery R, De Vries P, et al. Split cervical spinal cord malformation and vertebral dysgenesis. Orthop Traumatol Surg Res. 2009 Nov;95(7):547-50. doi: 10.1016/j.otsr.2009.07.012. PMID: 19837020. *Population*

71. Angsanuntsukh C, Oto M, Holmes L, et al. Congenital vertical talus in multiple pterygium syndrome. J Pediatr Orthop. 2011

Jul-Aug;31(5):564-9. doi: 10.1097/BPO.0b013e31822108d0. PMID: 21654467. *Population*

72. Aoi M, Nagai M, Nakatsu D, et al. A case of tethered cord syndrome induced by head injury. Japanese Journal of Neurosurgery. 2012;21(10):808-11. doi: 10.7887/jcns.21.808. *Language*

73. Apaydin M. Tethered cord syndrome and transitional vertebrae. Surg Radiol Anat. 2020 Feb;42(2):111-9. doi: 10.1007/s00276-019-02341-5. PMID: 31538247. *Outcome*

74. Apkon SD, Grady R, Hart S, et al. Advances in the care of children with spina bifida. Adv Pediatr. 2014 Aug;61(1):33-74. doi: 10.1016/j.yapd.2014.03.007. PMID: 25037124. *Population*

75. Appignani BA, Jaramillo D, Barnes PD, et al. DYSRAPHIC MYELODYSPLASIAS ASSOCIATED WITH UROGENITAL AND ANORECTAL ANOMALIES - PREVALENCE AND TYPES SEEN WITH MR-IMAGING. American Journal of Roentgenology. 1994 Nov;163(5):1199-203. doi: 10.2214/ajr.163.5.7976901. PMID: WOS:A1994PQ81700033. *Population*

76. Arai H, Sato K, Okuda O, et al. Diagnosis and treatment of lumbosacral lipomas. Japanese Journal of Neurosurgery. 1998;7(8):484-90. doi: 10.7887/jcns.7.484. *Language*

77. Arbelo-Pérez P, de Ganzo-Suárez T, de Luis-Escudero JF. Prenatal Diagnosis of Diastematomyelia: a Case Report and Literature Review. Reprod Sci. 2023 Jul 25. doi: 10.1007/s43032-023-01307-8. PMID: 37491555. *Population*

78. Archer J, Jea A. Spinal Column Shortening for Secondary Tethered Cord Syndrome in Children: 2-Dimensional Operative Video. Oper Neurosurg (Hagerstown). 2019 Jun 1;16(6):E168. doi: 10.1093/ons/opy247. PMID: 30169877. *Population*

79. Arhan P, Faverdin C, Devroede G, et al. Anorectal motility after surgery for spina bifida. Dis Colon Rectum. 1984 Mar;27(3):159-63. doi: 10.1007/BF02555662. PMID: 6365486. *Population*

80. Arkin C, Swaroop V, Larson JE, et al. (14) tethered cord release: What are the orthopaedic indicators and when is orthopaedic surgery needed? Pediatrics. 2019;144(2). doi: 10.1542/peds.144.2-MeetingAbstract.803. *Population*

81. Arkin CM, Meyer T, Rosen C, et al. Orthopaedic red flags for tethered cord syndrome. Journal of Pediatric Rehabilitation Medicine. 2023;16:S75-S6. doi: 10.3233/PRM-239011. *Design*

82. Asakura Y, Kandatsu N, Hashimoto A, et al. Ultrasound-guided neuroaxial anesthesia: Accurate diagnosis of spina bifida occulta by ultrasonography. Journal of Anesthesia. 2009;23(2):312-3. doi: 10.1007/s00540-009-0742-7. *Design*

83. Atabay H, Ersahin Y, Mutluer S, et al. Occult intrasacral meningocele associated with tethered cord syndrome. Turkish Neurosurgery. 1994;4(4):176-9. *Population*

84. Atala A, Bauer SB, Dyro FM, et al. Bladder functional changes resulting from lipomyelomeningocele repair. J Urol. 1992 Aug;148(2 Pt 2):592-4. doi: 10.1016/s0022-5347(17)36662-4. PMID: 1640529. *Duplicate*

85. Atalay A, Ulus OS, Güven Z. Acutely presenting adult tethered cord syndrome due to thick filum terminale. Turkiye Fiziksel Tip ve Rehabilitasyon Dergisi. 2011;57:176. *Population*

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Appendix C. Evidence Tables

Table C.1. KQ1 evidence table

Index Test	Study ID	Population	Results
EP	Kamei, 2022[1] N = 103 Japan Sites: 1 Setting: Inpatient Retethering: NA	**Study population:** Tethered cord syndrome clearly diagnosed based on MRI findings; symptoms, such as dysuria or paralysis of the lower extremities; tip of the spinal cone located at the level of the sacrum; tight filum terminale group: tip of the conus medullaris is above the L2-3 disc in the mid-sagittal section of the lumber T2-weighted MRI; separation of the filum terminale from the cauda equina on lumbar T2-weighted MRI in prone position; symptoms like dysuria, spinal stiffness, back pain, or numbness/weakness in the lower extremities; at least one of the aforementioned symptoms improved by surgery to sever the filum terminale; patients did not present Chiari malformation or scoliosis **Other population:** Healthy volunteers with no signs/symptoms of neurological disease **Category:** Healthy volunteers **Comorbidity:** NA **Female:** 47% **Age:** Tight filum terminale group mean 15.7 (SD 7.4) , tethered cord syndrome group mean 36.7 (SD 17.9) **Age subgroup**: Mixed age sample **Ethnicity:** N/A	**Reference standard:** MRI Diagnosis based on MRI findings Timing: Prior diagnosis **Index test:** EP **Evoked potentials:** Motor evoked potential by transcranial magnetic stimulation, the cutoff value for CMCT to distinguish the TCS group from the control group was 15.8 ms Sensitivity: 83 Tight Filum Terminale Group: 72 Specificity: 97 Tight Filum Terminale Group: 91 AUC: Tethered Cord Syndrome Group AUC: 0.961, Tight Filum Terminale Group AUC: 0.860 Cost: N/A Misdiagnosis: N/A Clinical Impact: N/A **Subgroup**: NA **Diagnostic accuracy results:** Patients had a signifcantly longer MEP latency than healthy subjects. Using the cutof values for peripheral conduction time had a sensitivity of 72.0% and a specifcity of 91.4% for TSC patients.
EP	Leung, 2015[2] N = 28 Canada Sites: 1 Setting: Inpatient Retethering: First time	**Study population:** Patients with a fatty filum terminale who had undergone release of tethered cord **Other population:** Age- and sex-matched controls who had undergone surgical correction of idiopathic scoliosis **Category:** other : idiopathic scoliosis **Comorbidity:** NA **Female:** % NA **Age:** NA	**Reference standard:** Neurosurgeons Diagnosed based on neurosurgeon, all TCS patients had undergone surgical release of tethered cord Timing: Prior diagnosis **Index test:** EP **Evoked potentials:** Somatosensory evoked potentials and motor evoked potentials, P37 peak analyzed Sensitivity: 100 Concordance: There was 100% concordance with the neurosurgeon's diagnosis.

		Age subgroup: Age unclear **Ethnicity:** N/A	**Subgroup**: NA **Diagnostic accuracy results:** The width of the P37 response differed significantly between TCS and control patients and changed significantly during the surgical procedure. Nonsignificant trends were seen in somatosensory evoked potential and motor evoked potential latencies.
EP	Li, 1996[3] Trial ID NA N = 90 US Sites: multiple Setting: Inpatient Retethering: Retethering	**Study population:** Children with previous repairs were followed with serial peroneal somatosensory evoked potentials that experienced retethering **Other population:** Children with previous repairs were followed with serial peroneal somatosensory evoked potentials that did not experience retethering **Category:** NA **Comorbidity:** NA **Female:** % NA **Age:** NA **Age subgroup**: Age unclear **Ethnicity:** N/A	**Reference standard:** MRI Clinical evaluation with MRI if necessary Timing: Concurrent **Index test:** EP **Subgroup**: NA **Diagnostic accuracy results:** False-positive rate 71% and false-negative rate of 43%; serial SEPs do not appear to correlate well with clinical status and are not a useful modality for monitoring patients at risk for retethering.
EP	Polo, 1994[4] Trial ID NA N = 6 Italy Sites: 1 Setting: Inpatient Retethering: NA	**Study population:** Adults with TSC who developed symptoms in adulthood or who had childhood symptoms that became progressively worse in adulthood **Other population:** Healthy participants **Category:** Not tethered **Comorbidity:** NA **Female:** 83% **Age:** Mean 43 Min age: 33 Max age: 64 **Age subgroup**: Adults **Ethnicity:** N/A	**Reference standard:** MRI MRI showing spinal malformations Timing: Prior diagnosis **Index test:** EP **Evoked potentials:** Somatosensory evoked potentials recorded after square wave pulses were applied to posterior tibial nerve at the ankle **Subgroup**: NA **Diagnostic accuracy results:** The N22 lumbosacral potential was selectively affected, being rostrocaudally displaced and reduced in amplitude or even absent in patients with neurological signs indicating a segmental lower cord lesion. The data provide strong support for the clinical interpretation of electrophysiological findings.
EP	Roy, 1986[5] N = 22 US	**Study population:** Patients with symptoms suggestive of tethered spinal cord whose TSC was diagnosed radiologically and/or intraoperatively	**Reference standard:** Other Diagnosed based on low conus or the presence of large intraspinal space occupying lesions, or the combination of these

	Sites: 1 Setting: N/A Retethering: NA	**Other population:** Patients with symptoms suggestive of tethered spinal cord not diagnosed radiologically and/or intraoperatively **Category:** Not tethered **Comorbidity:** NA **Female:** 82% **Age:** Min age: 0 Max age: 22 **Age subgroup**: Mixed age sample **Ethnicity:** N/A	Timing: Prior diagnosis **Index test:** EP **Evoked potentials:** Posterior tibial nerve somatosensory evoked potential Clinical Impact: Relationship between evoked potentials and correct/incorrect clinical diagnoses is unclear **Subgroup**: NA **Diagnostic accuracy results:** Of 22 patients studied, 19 had operative or myelographic evidence of tethered cord syndrome. In patients with clinical symptoms but no myelographically demonstrable lesions, posterior tibial nerve somatosensory evoked potentials were within normal limits, suggesting normal physiologic function. In patients with myelographically and operatively confirmed tethering dysraphic lesions, posterior tibial nerve somatosensory evoked potential was predictive of the level and laterality of the lesion. Similarly, ranking the severity of neurological impairment and extent of dysraphism at operation, as well as the extent of abnormality of posterior tibial nerve somatosensory evoked potential, revealed a significant ($r = 0.81$, $p < 0.001$) correlation between clinical severity and posterior tibial nerve somatosensory evoked potential abnormalities. Postoperatively, in 8 patients, posterior tibial nerve somatosensory evoked potential also reflected improved function in relation to the level and type of dysraphic lesion present.
EP	Thomas, 2017[6] N = 31 Turkey Sites: 1 Setting: Outpatient Retethering: First time	**Study population:** Children with sacral stigmata, pathological neurological examination, or with fecal incontinence in addition to UI, no pathological findings on MRI, found to have no response after a total of 3 months of treatment for overactive bladder were included in this study and evaluated for spinal pathologies **Other population:** Children with sacral stigmata, pathological neurological examination, or with fecal incontinence in addition to UI, no pathological findings on MRI, found to have no response after a total of 3 months of treatment for overactive bladder, not found to have spinal pathologies	**Reference standard:** MRI Diagnosed based on MRI findings evaluated by pediatric neurosurgeon, tethering was accepted if the conus medullaris terminated below L1/2 disc or if there was a fatty filum or the presence of a thick filum terminale Timing: N/A **Index test:** EP **Evoked potentials:** Sensory evoked potentials Sensitivity: 88 After removing fusion defect (not indicative of tethered cord) patients: 100

		Category: Not tethered : with overactive bladder **Comorbidity:** Other : Treatment refractory overactive bladder **Female:** 51% **Age:** 8.3 (2.9) Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A	Specificity: 74 After removing fusion defect (not indicative of tethered cord) patients: 69 PPV: 54 After removing fusion defect (not indicative of tethered cord) patients: 100 NPV: 94 After removing fusion defect (not indicative of tethered cord) patients: 39 Accuracy: 77.4 95%, 60.2-88.8 After removing fusion defect (not indicative of tethered cord) patients: 74.2, 95% CI, 56.8-86.3 AUC: Cost: relatively cheaper to perform than MRI on small children Misdiagnosis: N/A Clinical Impact: N/A **Subgroup**: NA **Diagnostic accuracy results:** Somatosensory evoked potentials was abnormal in 41.9%, and MRI was abnormal in 25.8% patients; somatosensory evoked potential was found to have a sensitivity of 87.5%, a specificity of 73.9%, positive predictive value of 53.85%, and negative predictive value of 94.4%.
EP	Umur, 2007[7] N = 4 Turkey Sites: 1 Setting: Inpatient Retethering: NA	**Study population:** Tethered cord cases who initially applied with lumbar disk disease symptoms **Other population:** N/A **Category:** NA **Comorbidity:** NA **Female:** % NA **Age:** NA **Age subgroup**: Age unclear **Ethnicity:** N/A	**Reference standard:** MRI Diagnosed based on MRI findings Timing: N/A **Index test:** EP **Evoked potentials:** Somatosensory evoked potential **Subgroup**: NA **Diagnostic accuracy results:** Somatosensory evoked potential revealed pathological conduction values (either conduction bloc or delay of the spinal latencies) in all, and it was the main indicator for surgical sectioning in patients. Somatosensory evoked potential was particularly useful for diagnosing tethered cord in symptomatic patients with so-called normal fila in which MRI could not be used for diagnosis.

MRI	Barutcuoglu, 2015[8] N = 33 Turkey Sites: 1 Setting: Inpatient Retethering:	**Study population:** Patients with split cord malformations who were surgically treated **Other population:** N/A **Category:** NA **Comorbidity:** Fatty filum,Lipomyelomeningocele,Other : Split cord malformations (SCMs) **Female:** 70% **Age:** Mean 11.8 Min age: 0 Max age: 48 **Age subgroup**: Mixed age sample **Ethnicity:** N/A	**Reference standard:** Neurosurgeons Untethering surgery Timing: Later diagnosis **Index test:** MRI **MRI**: MRI findings **Subgroup**: NA **Diagnostic accuracy results:** 7/23 patients with fatty filum had normal appearance on MRI but was found tight at surgery.
MRI	Bischoff, 2019[9] N = 340 US Sites: 1 Setting: Inpatient Retethering: NA	**Study population:** Tethered group: abnormal spinal MRI, who underwent tethered cord release; Included patients needed a pre-operative MRI of the entire spine available for review; patients with more complex surgery or other surgical indications were excluded **Other population:** Normal (non-tethered) group: needed a MRI of the entire spine available for review **Category:** Not tethered **Comorbidity:** Anorectal malformation **Female:** 45% **Age:** 1.3 (1.6) Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A	**Reference standard:** Neurosurgeons Surgery Timing: Later diagnosis **Index test:** MRI **MRI**: Conus Medullaris Ratio: Determining the level of the conus medullaris using anatomiclandmarks to create a ratio that can differentiate between patients with normal and low-lying conus without the need to count vertebral body levels; Conus Medullaris Ratio is obtained by dividing the distance between the conus level and the iliac crest by the distance between the foramen magnum and the conus level; Study calculated in straight and curved fashion; high correlation between the straight and the curved ratio (r= 0.995) was found so straight ratio was used for the remainder of study Sensitivity: 79 Specificity: 81 AUC: 0.749 (0.65, 0.80) **Subgroup**: Age Those with abnormal spinal MRI were significantly older compared to those with normal spinal MRI, researchers subsetted data for age 0–2 years (majority of participants) and then no significant difference was found between age. AUC found was controlled for age as potential confounder. **Diagnostic accuracy results:** The mean ratio was significantly higher in the non-tethered group

			compared to the tethered patients (p 0.0001). The ratio proved to be a good discriminator between normal and abnormal patients, with AUC 0.749, meaning that at random, there is a 75% chance that the tethered cord patient will have a lower ratio than the non-tethered cord patient.
MRI	Brophy, 1989[10] N = 25 US Sites: 1 Setting: Inpatient Retethering: NA	**Study population:** Diagnosis of lipomyelomeningocele and/or tethered cord, underwent preop MRI at Children's Hospital of Philadelphia from 1985 to 1987 **Other population:** Effectiveness of MRI at diagnosing occult spinal dysraphisms, comparison of lipomyelomeningocele and tethered cord patients **Category:** Not tethered,Lipomyelomeningocele **Comorbidity:** Lipomyelomeningocele **Female:** 76% N/A **Age:** Mean 4.2 Min age: 0 Max age: 17 **Age subgroup**: Pediatrics **Ethnicity:** N/A	**Reference standard:** Neurosurgeons As proven at surgery Timing: Later diagnosis **Index test:** MRI **MRI**: MRI of lumbar spine **Subgroup**: Presentation Stratified by preop MRI Reading Groups (Groups A-E, lipoma size and its relationship to conus or flium terminale) and by Operative Findings Group (Groups A-E) **Diagnostic accuracy results:** In six patients, incidental intramedullary cystic lesions at the conus were identified by MRI scan. All eight postoperative (1 month to 2 years) scans demonstrated no change in the level of the conus from the preoperative study. MRI is an accurate screening modality in the initial diagnosis of occult spinal dysraphism. MRI was not useful in the postoperative evaluation of lipomyelomeningocele and the tethered cord, since the caudal, posterior displacement of the conus was unchanged in all studies. To identify abnormally low conus and the mechanis of tether ing, MRI is optimal with its excellent visualization of the spinal canal and sensitivity for the liopmatoous tissue frequently specific to the diagnosis of lipomyelomeningocele.
MRI	Cornips, 2010[11] N = 66 Netherlands Sites: multiple Setting: Outpatient Retethering: Mix	**Study population:** Children and the availability of at least 2 sagittal MRI studies, including one study obtained in the postnatal period, one study obtained at the time symptoms of TCS deteriorated and the decision was made to operate, and (whenever available) one study obtained 2 to 3 years postoperatively **Other population:** Children diagnosed with medulloblastoma, in whom the neuraxishad been screened for spinal metastases; children with metastatic disease were included only if their spinal	**Reference standard:** Other Retrospective study with clinical diagnosis of spinal dysraphism or medulloblastoma Timing: N/A **Index test:** MRI **MRI**: Lumbosacral angle measurement determined by the intersection of two straight lines drawn on a sagittal MRI of the lumbosacral region obtained in the supine position

		cord was not compressed, as cord compression may mimic a tethering mechanism. Again, at least 2 sagittal MRI studies had to be available **Category:** other : patients with medulloblastoma; no spinal dysraphisms **Comorbidity:** NA **Female:** 42% **Age:** Clinically progressive tethered cord syndrome: mean 5 (SD 11); Clinically stable tethered cord syndrome mean 2 (SD 4) Min age: 0 Max age: 18 **Age subgroup**: Pediatrics **Ethnicity:** N/A	**Subgroup**: NA **Diagnostic accuracy results:** No significant differences in measurements for children with clinically progressive TCS vs clinically stable TCS; lumbosacral angle measurement does not help to determine if there is significant spinal cord tethering, nor if surgical untethering is needed.
MRI	Filippi, 2010[12] N = 10 US Sites: 1 Setting: N/A Retethering:	**Study population:** Three adult patients with known lumbar diastematomyelia, and one adult patient with a history of myelomeningocele, cord release, and retethering **Other population:** Six normal volunteers **Category:** **Comorbidity:** Other : Lumbar diastematomyelia; myelomeningocele **Female:** 75% **Age:** Mean 49 Min age: 27 Max age: 67 **Age subgroup**: Adults **Ethnicity:** N/A	**Reference standard:** MRI Neuroradiologists readers compared cord morphology between the tractograms and conventional MR images Timing: Concurrent **Index test:** MRI **Subgroup**: NA **Diagnostic accuracy results:** In cases of tethered cord, tractography correlated with anatomical imaging. Tractography of patients 1 and 2 revealed differences between hemicords, with higher numbers of tracts drawn, as well as higher mean FA values of tracts, for the larger hemicord. In patients 3 and 4, the FA values of tethered cords were lower than those measured for the lower cord of any of the normal volunteers.
MRI	Hall, 1988[13] N = 30 US Sites: 1 Setting: Inpatient Retethering: First time	**Study population:** Children suspected of tethered cord, later diagnosed with TSC via MRI and intraoperative findings **Other population:** N/A **Category:** N/A **Comorbidity:** N/A **Female:** 43.3% **Age:** Median 6 Min age: 5 Max age: 20 **Age subgroup**: Pediatrics **Ethnicity:** N/A	**Reference standard:** Neurosurgeons Diagnosed based on intraoperative findings Timing: Later diagnosis **Index test:** MRI **MRI**: Pre-operative MRI images **Subgroup**: N/A **Diagnostic accuracy results:** There was an excellent correlation between MRI and the surgical findings.

MRI	McCullough, 1990[14] N = 21 US Sites: NA Setting: Inpatient Retethering: NA	**Study population:** Children from the Spina Bifida Service over 5 years of age volunteered for the clinical studies; 13 symptomatic children with MR demonstration of spinal cord tethering were studied preoperatively and six of them 3-12 months post-operatively; 8 asymptomatic previously operated patients with spinal dysraphism and MR images depicting tethered cords were also investigated **Other population:** Healthy adults and children volunteers were investigated to establish normal figures for spinal cord motion **Category:** Healthy volunteers **Comorbidity:** Lipomyelomeningocele **Female:** % N/A **Age:** Min age: 5 Max age: **Age subgroup**: Age unclear **Ethnicity:** N/A	**Reference standard:** MRI Traditional / Standard pre-operative MRI Timing: Prior diagnosis **Index test:** MRI **MRI**: Phase-motion MR (magnetic resonance), real-time, of the cervical cord was selectedfor study because cord pulsations associated with longitudinal tension arc best seen in the cervical region. Also the cord is larger in this region and less distorted by the scoliosis which is common in dysraphic patients; performed on a 0.5-tesla superconducting MR system. Velocity calibration was performed with a simple phantom study; a midline section through cervical cord and brain stem was determined by rapid images in the sagittal plane with a spin echo (SE 400/26) sequence ina transverse pilot image; midline sagittal section was imaged withcardiac gating with SE pulse sequences with a TE of 26 ms. All acquisitions were gated to the peak of the R wave of the electrocardiogram, and variable trigger delays were used. Images were first obtained at 200-ms intervals through the cardiac cycle, starting at 0-ms delay; subsequent additional images covered the range of 50- to 150-ms delays in 10- to 20-ms increments to ensure that peak cord velocity was sampled; the image matrix was 128x512 in the phase and frequency directions, respectively, with a field view of 25 cm and a section thickness of 5 mm; all phase measurements were made at the midcervical cord level; background phase was obtained by averaging phase measurements on either side of the spinal canal in stationary tissue; the final phase measurements were then calculated **Subgroup**: N/A **Diagnostic accuracy results:** Studies of cervical cord motion show a clear separation between results in patients with cord expansion from hydromyelia and those with pure tethering. Symptomatic patients with progressive deficit or pain have limited cervical cord motion which improves after surgical untethering. MR studies of cord motion have definite promise in the prediction of deficit from spinal cord tethering and

			should be further evaluated in comparison with ultrasound and electrophysiologic methods.
MRI	Moufarrij, 1989[15] N = 20 US Sites: 1 Setting: Inpatient Retethering: NA	**Study population:** Patients who have undergone MRI and then surgery for release of tethered spinal cord **Other population:** N/A **Category:** N/A **Comorbidity:** N/A **Female:** 35% **Age:** 16.1 (14.2) Min age: 0 Max age: 54 **Age subgroup**: Mixed age sample **Ethnicity:** N/A	**Reference standard:** Neurosurgeons Surgery Timing: Later diagnosis **Index test:** MRI **MRI**: One patient was examined with a resistive 0.15-Tesla Technicare system using a bodycoil to receive signal, another with a 0.5-Tesla Picker superconductive system using a body coil to receive signal; the remaining patients were examined with a 0.6-Tesla Technicare superconductive system using a surface coil to receive signal; MRI scans reviewed without knowledge of the surgical findings, but findings were noted for further comparison with the surgical findings **Subgroup**: N/A **Diagnostic accuracy results:** Correlative results support the use of MRI as the initial, and possibly only, imaging modality when a tethered spinal cord is suspected. Increased epidural fat was misdiagnosed as an intradural lipoma in one patient and a lipotamous stalk was not identified in 2 other patients. Scar tissue resulting from repair of a meningocele had tethered the cord in the remaining 8 patients. On MRI scans, the conus medullaris was located between L3 and S3; in 5 of the patients, scar tissue was apparent on the MRI scan.
MRI	O'Neil, 1990[16] N = 61 Ireland Sites: 1 Setting: Inpatient Retethering: Mix	**Study population:** Patients under 16 years of age with closed spinal dysraphism who had undergone surgery and were diagnosed with tethered spinal cord **Other population:** Patients under 16 years of age with closed spinal dysraphism who had undergone surgery and were diagnosed with diastematomyelia, lipomyelomeningocele, dermal sinus, dermal cyst, or neurenteric cyst **Category:** other : spinal dysraphism **Comorbidity:** N/A **Female:** % N/A **Age:**	**Reference standard:** Neurosurgeons Diagnosis was confirmed at surgery by neurosurgery Timing: Prior diagnosis **Index test:** MRI **MRI**: MRI, Siemens 1.5 Tesla superconducting magnet system (Magnetom), spine surface receiver coil was employed in all cases except in infants who could be examined in the head coil, patients were placed in the supine position, but those with severe disability **Subgroup**: N/A

		NA Min age: Max age: 15 **Age subgroup**: Pediatrics **Ethnicity:** N/A	**Diagnostic accuracy results:** MRI was found to have accurate correlation with surgical findings in all cases of tethered cord, and diastematomyelia. In cases of re-tethering at the site of previous myelomeningocele repair, while it was a significant advance on previous imaging techniques precise delineation of neural tissue and discrimination from post-operative fibrosis was frequently not possible. Imaging of dorsal lipomyelomeningoceles also correlated with surgical findings and provided accurate pre-operative information.
MRI	Raghavan, 1988[17] Trial ID NA N = 25 UK Sites: 1 Setting: Outpatient Retethering: NA	**Study population:** Patients with a suspected clinical diagnosis of tethered spinal cord **Other population:** N/A **Category:** N/A **Comorbidity:** N/A **Female:** 44% **Age:** Mean 18 Min age: 0 Max age: 65 **Age subgroup**: Mixed age sample **Ethnicity:** N/A	**Reference standard:** Neurosurgeons Surgical repair Timing: Concurrent **Index test:** MRI **MRI**: 1.5-T whole body superconductive magnet using surface receiving coils; two patients were studied on a O.35-T magnet **Subgroup**: N/A **Diagnostic accuracy results:** Spinal MRI is extremely useful in the evaluation of the suspected tethered spinal cord and can visualize conus medularis, assess the thickness of the filum terminale, idenity traction lesions, and evaluate associated bony dysraphism.
MRI	Sankhe, 2021[18] N = 56 India Sites: 1 Setting: Inpatient Retethering: Mix	**Study population:** Patients with clinical tethered cord syndrome who already underwent primary detethering surgery; patients who underwent re-exploration and had clinical worsening despite initial surgery due to arachnoid bands and/or filum or thickened/fatty filum not addressed in primary surgery; excluding those with asymptomatic low-lying conus **Other population:** Healthy patients, no tethered spinal cord **Category:** Not tethered **Comorbidity:** N/A **Female:** % N/A **Age:** Min age: Max age: 25	**Reference standard:** Neurosurgeons Intraoperative findings Timing: Concurrent **Index test:** MRI **MRI**: MRI with constructive interference in steady-state sequence Sensitivity: 99 AUC: 0.996 **Subgroup**: N/A **Diagnostic accuracy results:** The overall sensitivity of MRI with constructive interference in steady-state sequence was higher (99.17%) as compared with the T2W sequence (71.48%) especially in the detection of precise position/extent of tethered cord, assessment of filum terminale thickening, detection of a fibrous spur

		Age subgroup: Mixed age sample **Ethnicity:** N/A	in cases of split cord malformation, detection of dorsal dermal sinus, and evaluation of its precise extent and ramifications. The area under the ROC curve was higher with MRI with constructive interference in steady-state sequence (0.99) than with T2W sequence (0.85) which reflects its good predictive value as a screening test. This information was useful to the operating surgeon.
MRI	Singh, 2011[19] N = 49 US Sites: NA Setting: N/A Retethering: NA	**Study population:** Children with tethered cord documented at surgery **Other population:** Children with suspicions of TCS **Category:** Not tethered **Comorbidity:** Other : Voiding dysfunction, and sacral cutaneous abnormality **Female:** 64% **Age:** Median 6 Min age: 0 Max age: 18 **Age subgroup**: Pediatrics **Ethnicity:** N/A	**Reference standard:** Neurosurgeons Surgery and clinical follow up Timing: Later diagnosis **Index test:** MRI **MRI**: MRI protocol: sagittal T1 and FSE T2, axial T1 in the lumbar spine in the supineposition, sagittal T2 EPI in the prone position, and phase-contrast cine MR images in some cases; MRI assessment includes the conus level, filum thickness at L5-S1, presence of fatty infiltration, and any apparent tethering mass; children were clinically diagnosed with tethered cord syndrome based on criteria including skin abnormalities, abnormal muscle tone, gait abnormalities, urological issues, and back pain Sensitivity: 62 69-77% across two MRI readers Specificity: 61 94% for conus level PPV: 44 82-83% across two MRI readers NPV: 85 89-92% across two MRI readers Accuracy: 0.61 Rater agreement: Agreement of two evaluators (Cohen's kappa) 0.94 **Subgroup**: N/A **Diagnostic accuracy results:** 13/49 children had tethered cord documented at surgery. Reader 1, pronce MRI sensitivity 62%, specificity 61%, correct diagnosis 61%. Conus level had the highest diagnostic accuracy (sensitivity 69–77%, specificity 94%, PPV 82–83%, NPV 89–92%, correct diagnosis 88–90%) and highest between-reader concordance (98%).

			Prone and cine MRI did not add to the accuracy of the supine imaging.
MRI	Singh, 2019[20] N = 51 India Sites: 1 Setting: Inpatient Retethering: First time	**Study population:** Patients with spinal dysraphism with tethered cord (thick filum terminale, lumbar/lumbosacral meningomyelocoele, and lipomyelomeningocoele); patients who had already undergone a preoperative MRI, those with flaccid paraplegia with sphincteric involvement, those who were having an active cerebrospinal fluid leak from their posterior meningomyelocoele sac at the time of admission, and those with coexisting two-level cervical/upper thoracic cord tetheringalong with lumbar level tethering were excluded **Other population:** Patients without cord tethering who were undergoing and MRI for a posterior fossa tumor or congenital hydrocephalus **Category:** Not tethered, Patients with congenial lesions **Comorbidity:** Other : spinal dysraphism **Female:** 39% **Age:** Median TSC 14 months; Control median 78 months Min age: Max age: **Age subgroup**: Mixed age sample **Ethnicity:** N/A	**Reference standard:** Other Clinical diagnosis not further specified Timing: Prior diagnosis **Index test:** MRI **MRI**: 3-T MRIb machine, sagittal T1 and T2 and axial T1 and T2-weighted sequences of thelumbar spine in the supine position, with sagittal and axial T2W sequences also being repeated in the prone position; 2 radiologists independently measured the study parameters using the same MRI software, digital imaging and communications in medicine-advantage workstation **Subgroup**: N/A **Diagnostic accuracy results:** In the tethered group, significantly less movement at the level of conus (p 0.013) and one level above (p 0.03) and significant difference in ΔBA (p< 0.0) were observed in supine and prone positions, compared to controls. Ventral nerve root stretching resulted in sagittal/axial root angle changes. Median OF (p 0.04) in the lipomyelomeningocoele group was significantly less than that in control group (p 0.23). Median OF was also lesser in patients with thick filum terminale or meningomyelocele. Difference in median sagittal and axial root angles among the study and control groups was statistically significant (p<0.00). MRI parameter indicated a stretched cord that is vulnerable to exhibit symptoms of TCS, even when the lower level of cord is not below the conventionally defined level of L3.
MRI	Stamates, 2018[21] N = 71 US Sites: 1 Setting: Inpatient Retethering: Mix	**Study population:** Patients with occult spinal dysraphism: tethered cord was suspected clinically, imaging showed a conus below the inferior L-2 level and/or fatty filum terminale measuring greater than 2 mm in thickness, no prior surgery, surgical release of tethered cord performed Group 2: patients with a prior surgery for cord untethering: (etiologies included lipomyelomeningocele, myelomeningocele, fatty filum, lipoma, dermal sinus tract and lipoma, and diastematomyelia); presentation with clinical symptoms suggestive of	**Reference standard:** MRI Diagnosed based on MRI findings and surgical findings Timing: Concurrent **Index test:** MRI **MRI**: MRI in the prone position, using 10% canal width ventral motion Sensitivity: 93 Pediatric patients: 92 Specificity: 100

		retethering; recent MRI with prone sequence; and reoperation for surgical repeat untethering (group 1) **Other population:** Normal controls; consecutive patients with no or very low clinical suspicion of tethered cord, recently underwent lumbar spine MRI for isolated nonspecific symptoms (group 3) **Category:** Not tethered **Comorbidity:** N/A **Female:** 49% **Age:** Occult spinal dysraphism mean: 6 years; with a prior surgery mean 20.9 years; healthy controls mean 10.6 years Min age: Max age: **Age subgroup**: Mixed age sample **Ethnicity:** N/A	Pediatric patients: 100 Rater agreement: Paired t-tests to compare the measurements from the 2 observers in the overall sample and individually in Groups 1, 2, and 3, resulting in p values of 0.86, 0.45, 0.66, and 0.92. **Subgroup**: Age F Further analysis of only pediatric patients (< 21 years of age) was also performed,which included 24 patients from Group 1, 12 patients from Group 2, and 28 patients from Group 3. We found that 22 of 24 pediatric patients in Group 1 with an initial diagnosis of tethered cord had < 10% canal width motion, and 11 of 12 patients in the retethered Group 2 had < 10% motion. All 28 normal pediatric controls had > 10% canal width motion. For pediatric patients, sensitivity and specificity were thereby calculated as 91.7% and 100%, respectively. Using an alternate < 15% canal width threshold, the sensitivity increased to 97.2%, whereas the specificity decreased to 78.7%. **Diagnostic accuracy results:** Sensitivity and specificity were 92.7% and 100% across groups. Whereas 38/41 surgically treated patients with TCS had diminished (< 10% canal width) ventral motion on preoperative MRI, 30/30 controls had > 10% canal width motion. Sensitivity and specificity were thereby calculated as 92.7% and 100%, respectively.
MRI	Steinbrook, 1999[22] N = 77 Turkey Sites: 1 Setting: Inpatient Retethering: NA	**Study population:** Patients with tethered cord syndrome who underwent surgical detethering **Other population:** N/A **Category:** N/A **Comorbidity:** N/A **Female:** 45% **Age:** Primary tethered cord group mean 10.2; Secondary tethered cord group mean 6.3 Min age: Max age: **Age subgroup**: Age unclear **Ethnicity:** N/A	**Reference standard:** Neurosurgeons Surgery observation Timing: Later diagnosis **Index test:** MRI **MRI**: MRI and plain radiography **Subgroup**: NA **Diagnostic accuracy results:** Although 5 patients were reported to have filum terminale thicker than 2 mm in MRI, none appeared abnormally thick on surgery.
MRI	Warf, 1993[23] N = 26	**Study population:** Patients with signs of tethered cord who have various spinal cord malformations **Other population:** N/A	**Reference standard:** Neurosurgeons Surgery Timing: Later diagnosis

	US Sites: 1 Setting: Inpatient Retethering: First time	**Category:** N/A **Comorbidity:** Fatty filum,Lipomyelomeningocele,Scoliosis **Female:** % N/A **Age:** Min age: 0 Max age: 21 **Age subgroup**: Pediatrics **Ethnicity:** N/A	**Index test:** MRI **MRI**: Spinal MRI **Subgroup**: N/A **Diagnostic accuracy results:** In 4/19 patients the MRI impression differed from the intraoperative findings (2 patients with suspected lipomyelomeningocele had myelocystoceles with associated lipomans, 1 suspected dorsal lipoma in conjunction with a low lying conus did not contribute to spinal cord tethering but functional caudal nerve routs were foreshortened), 1 patient with progressive symptoms suggestive of tethering and a conus at teh L2-3 level with some fat signal in the filum on MRI had no identifiable abnormalility).
MRI	Witkam, 2001[24] N = 56 Netherlands Sites: 1 Setting: Outpatient Retethering: Mix	**Study population:** Consecutive patients in whom a tethered spinal cord was clinically suspected by a neurologist and a neurosurgeon (group 2) and 10 consecutive patients who had undergone surgery for a tethered cord and later presented with progressive neurologic deficits indicative of possible retethering (group 3) **Other population:** Healthy volunteers with a herniated disk or nonneurogenic micturition disturbances **Category:** Healthy volunteers **Comorbidity:** N/A **Female:** 43% **Age:** Healthy volunteers mean 15; tethered cord clinically suspected mean 14.7; symptoms indicative of retethering mean 12.7 Min age: 3 Max age: 46 **Age subgroup**: Mixed age sample **Ethnicity:** N/A	**Reference standard:** Other Tethering was considered to be present when (a) the medullary cone was lower thanthe L1-2 intervertebral disk and/or had an abnormal shape or (b) the terminal filum was thicker than 2 mm, regardless of the level of the cone. However, 1 patient in group 2 Timing: Prior diagnosis **Index test:** MRI **MRI**: MR imaging was performed in the supine and prone positions. T1-weighted spin-echoMR images (500/20 [repetition time msec/echo time msec], 3–5-mm section thickness, 350-mm field of view) in the sagittal and transverse planes were obtained. For groups 2 & 3, the lumbar spine was examined by obtaining sagittal T1-weighted (500/20, 3–5-mm section thickness, 350-mm field of view) and T2*-weighted gradient-echo (615/27, 25° flip angle) images and was completed by obtaining transverse T1- and T2*- weighted images through a region of interest, depending on the abnormality found on the sagittal images; patients were then placed in the prone position, and the same surface coil as that used for supine imaging (40 3 10 cm) was placed on the back of each patient; the acquisition of T1-weighted images in the sagittal and transverse planes of the lumbar spine was repeated in this position Concordance: 25 patients were clinically suspected to have TSC by neurologists/neurosurgeons, of these, in

			20 a definitive diagnosis of tethered cord syndrome was made on the basis of initial supine MRI findings showed no movement. **Subgroup**: N/A **Diagnostic accuracy results:** All healthy participants showed distinct and statistically significant medullary cone movement (range, 21%–41%); no patient in group 3 showed movement (P 0.001). In patients with suspected TSC in whom a definite diagnosis of tethered cord syndrome was made on the basis of initial supine MR image all 20 showed no movement, whereas 2/5 patients with normal supine MR images had abnormal and decreased cone movement at prone imaging.
MRI : prone position	Vernet, 1996[25] N = 51 Canada Sites: 1 Setting: Inpatient Retethering: Mix	**Study population:** Patients who had undergone MRI evaluations in supine and prone positions at MontrealChildren's Hospital, including patients with tethered cord secondary to occult spinal dysraphism who underwent spinal cord untethering (Group 2), and patients with secondary tethered cord who underwent detethering following prior myelomeningocele closure/reapair (Group 3) **Other population:** Control patients without cord tethering (Group 1), control patients had exhibited spinda bifida occulta on lumbar xrays but has normal MRI. These patients presented with neurogenic and urinary symptoms not due to tethered spinal cord **Category:** Not tethered **Comorbidity:** Other : Tethering s/p surgical repair for myelomeningocele: 26 **Female:** 53% **Age:** Range 1 month - 21 years; Control group median age at MRI: 9.0; Primary TC group median age at surgery: 2.4; Secondary TC group median age at surgery: 9.2 Min age: 0.083 Max age: 21 **Age subgroup**: Mixed age sample **Ethnicity:** N/A	**Reference standard:** MRI MRI of the lower spine was conducted with the patient positioned in supine and thenin prone position using a 1.5-Tesla superconducting magnet (GE Signa 1.5; General Electric Medical Systems, Milwaukee, Wisc., USA); sagittal T1 (repetition time = TR: 500-800 ms, echo time = TE: 10-30 ms) and T2 (TR: 3,000-4,000 ms, TE: 90-120 ms), as well as axial T1 (TR: 500-800 ms, TE: 10-30 ms) sequences were acquired routinely; the field of view ranged from 20 to 30 cm', with a data matrix ranging from 256 x 192 to 256 x 256 Timing: Prior diagnosis **Index test:** MRI : prone position **MRI**: MRI of the lower spine was conducted with the patient positioned in supine and then in prone position using a 1.5-Tesla superconducting magnet (GE Signa 1.5; General Electric Medical Systems, Milwaukee, Wisc., USA); sagittal T1 (repetition time = TR: 500- **Subgroup**: NA **Diagnostic accuracy results:** In patients with secondary tethered cord following prior myelomeningocele closure, MRI performed at a median interval of time of 11 months following untethering demonstrated resolution of the posterior cord tethering in only 8 out of the 24 patients who exhibited this feature pre-operatively. Anterior migration within the expanded dural sac was never

			noted in this group. Spine MRI is of limited value and that prone-positioned MRI is of no additional use in the evaluation of spinal cord retethering.
MRI : With VIBE/LAVA sequence	Rafiee, 2023[26] N = 66 US Sites: 1 Setting: Inpatient Retethering: NA	**Study population:** Patients younger than 20 years of age undergoing spine MRI for clinically suspected TCS **Other population:** N/A **Category:** N/A **Comorbidity:** N/A **Female:** 50% **Age:** 7.7 (5.7) Min age: 0 Max age: 18 **Age subgroup**: Pediatrics **Ethnicity:** N/A	**Reference standard:** Neurosurgeons Diagnosed based on intraoperative findings, from tethered cord release surgery to validate the presence of fatty intrathecal tissue Timing: Later diagnosis **Index test:** MRI : With VIBE/LAVA sequence **MRI**: MRI with volumetric interpolated breathhold examination / liver acquisition with volume acquisition sequence Sensitivity: 75 Specificity: 67 AUC: 0.810 Rater agreement: 2 different radiologists T1 FSE sequence AP diameter ICC 0.93, T1 FSE sequence RL diameter ICC 0.99, VIBE/LAVA sequence AP diameter ICC 0.89, VIBE/LAVA sequence RL diameter: 0.98, T1 FSE sequence FIL craniocaudal extension ICC 0.86, VIBE/LAVA 0.83 for T1 FSE and VIBE/LAVA sequen **Subgroup**: N/A **Diagnostic accuracy results:** T1 FSE sequences revealed fatty intrathecal lesions in 21/22 cases however, fatty intrathecal lesions on VIBE/LAVA were detected in 55%. Mean anterior-posterior and transverse dimensions of fatty intrathecal lesions measured larger on T1 FSE compared with VIBE/LAVA sequences (5.4 × 5.0 mm versus 1.5 × 1.6 mm, p 0.039 anterior-posterior, 0.027 transverse). While TI 3D gradient-echo MRI may have decreased the acquisition time and are more motion-resistant than conventional TI FSE, they are less sensitive and may miss small fatty intrathecal lestion (a cause of tethered cord).
MRI,EP	Barutcuoglu, 2016[27] N = 18 Turkey Sites: NA	**Study population:** Patients with progressive scoliosis due to tethered spinal cord **Other population:** N/A **Category:** N/A	**Reference standard:** MRI Compared MRI and evoked potentials Timing: Concurrent **Index test:** MRI,EP

	Setting: Inpatient Retethering: First time	**Comorbidity:** Scoliosis **Female:** 61.1% **Age:** Mean 14.72 Min age: 3 Max age: 42 **Age subgroup**: Mixed age sample **Ethnicity:** N/A	**MRI**: MRI normal conus medullaris level was accepted as between the lumbar 1st and 2nd disc spaces and the normal thickness of filum as taken as <2mm **Evoked potentials:** Somatosensorial evoked potentials, conducted at lumbal, thoracal, cervical levels and the somatosensorial cortex simultaneously **Subgroup**: NA **Diagnostic accuracy results:** 44.45% of patients had a normal appearance of filum terminale and normal level conus medullaris in MRI, but conduction delay and/or block was seen on EP.
MRI,Ultrasound,Urodynamic	Lavallee, 2013[28] Trial ID NA N = 123 Canada Sites: 1 Setting: N/A Retethering: NA	**Study population:** Patients referred for cutaneous stigmata of occult spinal dysraphism with tethered cord release surgery **Other population:** Patients referred for cutaneous stigmata of occult spinal dysraphism without tethered cord release surgery **Category:** NA **Comorbidity:** NA **Female:** 53.7% **Age:** Median 11 months; IQR 6.5–15.5 months Min age: 0 Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A	**Reference standard:** Other Selected for tethered cord release surgery Timing: Later diagnosis **Index test:** MRI,Ultrasound,Urodynamic **Subgroup**: NA **Diagnostic accuracy results:** Abnormal spinal magnetic resonance imaging was also significantly associated with operative intervention (p 0.05). Ultrasound of the spine (p 1.0), ultrasound of the abdomen/pelvis (p 0.68), history of urinary tract infections (p 1.0) and constipation (p 0.67) were not associated with intervention for tethered cord release.
Myelogram	Heinz, 1979[29] N = 16 US Sites: 1 Setting: Inpatient Retethering: NA	**Study population:** Postmeningomyelocele patients with tethered cord with a history and physical examination, increased latency on SSEP, one or more diagnostic radiological studies, and surgical or other proof **Other population:** N/A **Category:** N/A **Comorbidity:** Spina bifida,Lipomyelomeningocele **Female:** 50% **Age:** Boys mean: 8; Girls mean: 5 Min age: 1.5 Max age: 8 **Age subgroup**: Pediatrics **Ethnicity:** N/A	**Reference standard:** MRI Diagnosed based on MRI findings Timing: Concurrent **Index test:** Myelogram **Myelogram:** Water soluble and gas myelography Clinical Impact: **Subgroup**: N/A **Diagnostic accuracy results:** Metrizamide myelography with polytomography was superior to gas myelography in showing a low-lying cord, obtuse nerve root angles, and a thin subarachnoid space between the cord and the dorsal meninges cephalad

			to the tether; the space was easily seen on aqueous contrast medium but not clearly seen in any of the patients studied with gas (except for one in whom a lunbar puncture had pushed the cord forward).
other : computational fluid dynamics analysis	Gholampour, 2018[30] N = 59 Iran Sites: 1 Setting: N/A Retethering: NA	**Study population:** Patients presenting with both Chiari malformation type I and tethered cord syndrome **Other population:** Patients with Chiari malformation type I, patients with Chiari malformation type I and occipitoatlantoaxial joint instability, healthy control patients **Category:** Healthy volunteers,other : patients with chiari malformation type I **Comorbidity:** Other : Chiari malformation type I **Female:** 58% **Age:** CM-I mean 35.9 (SD 8.1); CM-I/OAAJI mean 31.3 (SD 4.3); CM-I/TCS mean 32.4 (SD 6.2); Normal mean 32.2 (SD 7.8) Min age: Max age: **Age subgroup**: Mixed age sample **Ethnicity:** N/A	**Reference standard:** MRI Diagnosed based on MRI findings Timing: Prior diagnosis **Index test:** other : computational fluid dynamics analysis Other tests: Computational fluid dynamics analysis, cerebrospinal fluid hydrodynamic parameters **Subgroup**: N/A **Diagnostic accuracy results:** Maximum changes in cerevrospinal fluid velocities in patients with CM-I, CM-I/OAAJI, and CM-I/TCS were 23.2%, 17.1%, and 18.3% higher than normal subjects.
other : Lumbosacral angle (LSA)	Tubbs, 2002[31] N = 50 US Sites: 1 Setting: Inpatient Retethering: First time	**Study population:** Patients with a myelomeningocele without a significant kyphotic, scoliotic or lordotic deformity, with symptoms indicative of TSC including: increased hip subluxation, increased incidence of cystitis, increased external deviation of the foot, increased ureteral reflux, increased scoliosis, increased spasticity in the lower extremities, increased back pain, syringomyelia, decreased lower extremity function, increased abnormality of urodynamics and increased incontinence of the bladder and or bowel **Other population:** Twenty controls chosen from hospital database because they were 8 years or younger, had had at least two lateral radiographs of the lateral lumbosacral region over time, and without diagnoses of spina bifida aperta, occult spinal dysraphism or diseases of the lumbobosacral vertebrae **Category:** other : patients from hospital database who had radiographs taken for other health conditions	**Reference standard:** Unclear Not stated how patients were ultimately diagnosed for TSC, likely by a neurosurgeon Timing: N/A **Index test:** other : Lumbosacral angle (LSA) **Subgroup**: NA **Diagnostic accuracy results:** At least two lateral radiographs over time were examined and the lumbosacral angle was measured; values were increased at the time of the second measurement in 26 of the total 30 patients and in all but 1 of the symptomatic patients. In 2 patients with a symptomatic tethered cord, there was no change in the angle; measured in children with a myelomeningocele is often increased for their age and often increases in caliber at the same time symptoms of a tethered spinal cord are brought to clinical attention -findings are not coincidental and a horizontally positioned sacrum will preate or be found upon presentation of a symptomatic tethered spinal cord in the population of

		Comorbidity: Lipomyelomeningocele **Female:** % NA **Age:** Mean 4.5 Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A	patients with myelomeningocele. LSA was often inappropriately increased at the time many of these patients presented with symptoms indicative of a tethered spinal cord.
other : Morphometric measurement	Milhorat, 2009[32] Trial ID NA N = 3276 US Sites: 1 Setting: Inpatient Retethering: NA	**Study population:** Patients found to have TCS from the study sample of Chiari malformation Type ! and Low-lying cerebellar tonsils. Diagnosis of TCS was based on the following nonspecific but generally accepted symptoms and signs: urinary dysfunction (including incontinence, urgency, sensory loss, incomplete emptying of the bladder), bowel incontinence, low back pain, leg and foot pain, numbness of the soles of the feet, gait disturbance, leg weakness, atrophy of calf muscles, loss of deep tendon reflexes in the lower extremities, thoracolumbar scoliosis, equinovarus or equinovalgus deformities of the feet, and spinal dysraphism **Other population:** Patients with Chiari malformation Type 1 and Low-lying cerebellar tonsils **Category:** other : Chiari malformation Type 1 and Low-lying cerebellar tonsils **Comorbidity:** Other : Chiari Malformation Type I and Low-lying cerebellar tonsils **Female:** 81% **Age:** 29.5 (4.1) Min age: 1 Max age: 60 **Age subgroup**: Mixed age sample **Ethnicity:** N/A	**Reference standard:** Neurosurgeons Diagnosis of TCS was based on the following nonspecific but generally accepted symptomsand signs: urinary dysfunction (including incontinence, urgency, sensory loss, incomplete emptying of the bladder), bowel incontinence, low back pain, leg and foot pain, numbness of the soles of the feet, gait disturbance, leg weakness, atrophy of calf muscles, loss of deep tendon reflexes in the lower extremities, thoracolumbar scoliosis, equinovarus or equinovalgus deformities of the feet, and spinal dysraphism Timing: Prior diagnosis **Index test:** other : Morphometric measurement Other tests: All morphometric measurements and volumetric calculations in this study were madeby a single experienced observer who was unaware of other study data to avoid interobserver variability; results were reviewed independently by two experienced observers, who oversaw the process and verified all calculations; constructed 2D CT and MR imaging **Subgroup**: N/A **Diagnostic accuracy results:** Morphometric measurements demonstrated elongation of the brain stem (mean, 8.3 mm; P < .001), downward displacement of the medulla (mean, 4.6 mm; P < .001), and normal position of the CMD except in very young patients. Compared to patients with generic CM-I, the FM was significantly enlarged (P < .001). The FT was typically thin and taut (mean transverse diameter, 0.8 mm). After SFT, the cut ends of the FT distracted widely (mean, 41.7 mm) and CSF flow in the lumbar theca increased from a mean of 0.7 cm/s to a mean of 3.7 cm/s (P < .001). Symptoms were improved or resolved in 69 children (93%) and 203

			adults (83%) and unchanged in 5 children (7%) and 39 adults (16%) and, worse, in 2 adults (1%) over a follow-up period of 6 to 27 months (mean, 16.1 months ± 4.6 SD). Magnetic resonance imaging 1 to 18 months after surgery (mean, 5.7 months ± 3.8 SD) revealed upward migration of the CMD (mean, 5.1 mm, P < .001), ascent of the cerebellar tonsils (mean, 3.8 mm, P < .001), reduction of brain stem length (mean, 3.9 mm, P < .001), and improvement of scoliosis or syringomyelia in some cases.
other : Needle electromyography and nerve conduction study	Shin, 2023[33] N/A N = 93 Korea Sites: 1 Setting: Outpatient Retethering: Retethering	**Study population:** Clinically suspected to have retethering, such as development of new urological symptoms or a change in the manual muscle test **Other population:** N/A **Category:** N/A **Comorbidity:** Lipomyelomeningocele : small subgroup under "other diagnoses",Other : Lumbosacral lipoma **Female:** 42% **Age:** Mean 4.9 Min age: 3.7 Max age: 17.3 **Age subgroup**: Pediatrics **Ethnicity:** N/A : Study was conducted in Korean hospital but no report of race/ethnicity	**Reference standard:** Neurosurgeons Electromyography: A single neurosurgeon with 30 years of experience in the field performed patient and caregiver interviews and physical examinations; lower extremity was evaluated for foot deformities and pain; muscle power of the ankle dorsiflexor and p Timing: Prior diagnosis **Index test:** other : Needle electromyography and nerve conduction study Other tests: Needle electromyography and nerve conduction study **Subgroup**: NA **Diagnostic accuracy results:** The appearance of abnormal spontaneous activity in new muscles was prominent in the retethered group (p < 0.01). The loss of abnormal spontaneous activity was more pronounced in the non-progression group (p < 0.01). Specificity and sensitivity of EMG for retethering were 80.4 and 56.5%, respectively. The positive predictive value was 57.1%, and negative predictive value was 65.0%. The area under the receiver operating characteristics curve analysis for the EMG deterioration was fairly large (0.713, p < 0.01).
Physical exam	Heji, 1996[34] N = 43 Netherlands Sites: NA Setting: Outpatient Retethering: NA	**Study population:** Patients with anorectal malformations who received a MRI of the lumbosacral region; high, low or Currariano's triad, 2 patients had a tethered cord (2/43) **Other population:** Patients with anorectal malformations who received a MRI of the lumbosacral region; high, low or Currariano's triad **Category:** NA	**Reference standard:** MRI MRI sequenced obtained included sagittal T! weighted imagine of the lumbosacraland pelvic areas; axial T1 wighted imaging of the lumbosacral and pelvic areas; corona T1 weighted imaging of the pelvis; axial T2 weighted imaging of the lumbosacral spine; attention was paid to the lumbrosacral spine, the medullary cone, and filum terminale, and the presence of an intraspinal lipoma

		Comorbidity: Anorectal malformation **Female:** 27.9% **Age:** NA Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A	Timing: N/A **Index test:** Physical exam **Physical examination:** Anorectal malformations and urological anomalies **Subgroup**: NA **Diagnostic accuracy results:** The MRI revealed one patient with tethered cord with urological anomalies present (1/43) and one patient with tethered cord without urological anomalies (1/43). Additionally, MRI found three patients with tethered cord and caudal regression syndrome with urological anomalies present (4/43) and no patients with tethered cord and caudal regression syndrome without urological anomalies (0/43).
Physical exam	Levitt, 1997[35] N = 111 US Sites: 1 Setting: Outpatient Retethering: First time	**Study population:** Patients with anorectal malformations who underwent MRI of the spine with MRI evidence of tethered spinal cord, some of which underwent surgical untethering **Other population:** Patients with anorectal malformations who underwent MRI of the spine without MRI evidence of tethered spinal cord **Category:** Not tethered **Comorbidity:** Anorectal malformation **Female:** % N/A **Age:** N/A Min age: Max age: **Age subgroup**: Age unclear **Ethnicity:** N/A	**Reference standard:** MRI MRI and follow up over time, some patients underwent surgery Timing: Later diagnosis **Index test:** Physical exam **Physical examination:** Urinary incontinence **Subgroup**: NA **Diagnostic accuracy results:** Patients with tethered cord had a lateral sacral ratio lower than that of patients without tethered cord (0.410 vs 0.702), fewer voluntary bowel movements (46 vs 70%), more fecal soiling (91 vs 63%), less constipation (21 vs 43%) and more urinary incontinence (86 vs 42%).
Physical exam	Tubbs, 2006[36] N = 50 US Sites: 1 Setting: N/A Retethering: NA	**Study population:** Patients who underwent repair of a lipomyelomeningocele with tethered spinal cord **Other population:** Patients who underwent repair of a lipomyelomeningocele without tethered spinal cord **Category:** Not tethered **Comorbidity:** Lipomyelomeningocele **Female:** 56% **Age:** mean 12.5 Min age: 4 Max age: 13 **Age subgroup**: Pediatrics	**Reference standard:** MRI Perinatal MRI Timing: N/A **Index test:** Physical exam **Physical examination:** Lumbosacral angle measured on radiograph or MRI **Subgroup**: NA **Diagnostic accuracy results:** 36% of patients were found to have corresponding LSA measurements greater than 70˚ and 28% of these presented with signs of a tethered spinal cord, such as decreased

		Ethnicity: N/A	lower-extremity function and bladder incontinence. The LSA measurements were statistically greater in symptomatic patients than in control patients (p 0.05).
Physical exam	Tubbs, 2007[37] N = 80 US Sites: 1 Setting: Outpatient Retethering: First time	**Study population:** Consecutive patients who underwent lipomyelomeningocele repair or myelomeningocele repair with tethered spinal cord **Other population:** Consecutive patients who underwent lipomyelomeningocele repair or myelomeningocele repair without tethered spinal cord **Category:** Not tethered **Comorbidity:** Lipomyelomeningocele **Female:** % N/A **Age:** Min age: 4 Max age: 13 **Age subgroup**: Pediatrics **Ethnicity:** N/A	**Reference standard:** Other Appropriate imaging and further observation Timing: Later diagnosis **Index test:** Physical exam **Physical examination:** Lumbosacral angle **Subgroup**: N/A **Diagnostic accuracy results:** No single sign or symptom of a tethered spinal cord appeared to correlate with any degree of increase in the lumbosacral angle. 36% of patients were found to have corresponding lumbosacral angle measurements of greater than 70˚ with 28% presenting with signs of a tethered spinal cord (e.g., decreased lower-extremity function and bladder incontinence); measurements were statistically (p 0.05) greater in the symptomatic patient population than in controls.
Physical exam,X ray	Arikan, 1999[38] N = 81 Turkey Sites: 1 Setting: N/A Retethering: NA	**Study population:** Children with complicated voiding dysfunction, including a history of diurnal incontinence, frequency, urgency, urge incontinence, incomplete bladder emptying, recurrent urinary tract infection, and persistent vesicoureteral reflux despite formal bladder retraining programs, anticholinergic medication, and clean intermittent catheterization if required; with tethered cord on MRI **Other population:** Children with complicated voiding dysfunction, including a history of diurnal incontinence, frequency, urgency, urge incontinence, incomplete bladder emptying, recurrent urinary tract infection, and persistent vesicoureteral reflux despite formal bladder retraining programs, anticholinergic medication, and clean intermittent catheterization if required; without tethered cord on MRI **Category:** N/A **Comorbidity:** N/A **Female:** 64% **Age:**	**Reference standard:** MRI Dynamic MRI was used to improve accuracy in the diagnosis of tethering using phase motion studies to calculate peak spinal cord velocity to distinguish patients with true tethered spinal cord from those with an abnormal location of the conus. Timing: Later diagnosis **Index test:** Physical exam,X ray **Physical examination:** Neuro-orthopedic examinations **X-rays:** Spinal x-ray **Subgroup**: Other,NA **Diagnostic accuracy results:** 43.2% of patients were diagnosed as having primary tethered cord syndrome with positive neurocutaneous and/or x-ray findings, in this group, 6 patients (7.4%) with abnormal neuro-orthopedic examinations had normal spinal x-rays, and 7patients (8.6%) with normal neuro-orthopedic examinations had abnormal spinal x-rays.

		Mean 8.7 Min age: 4 Max age: 17 **Age subgroup**: Pediatrics **Ethnicity:** N/A	
Ultrasound	Ben-Sira, 2009[39] Trial ID NA N = 254 Israel Sites: 1 Setting: Inpatient Retethering: NA	**Study population:** Infants under the age of 6 months with suspicious dorsal midline skin stigmata and tethered cord syndrome **Other population:** Infants under the age of 6 months with suspicious dorsal midline skin stigmata without tethered cord syndrome **Female:** 50% **Age:** Mean 7 (SD 5) weeks Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A	**Reference standard:** Neurosurgeons Consecutive infants up to age 6 months referred either directly for US screening or for neurosurgical consultation due to suspicion of MSS by a primary care physician, each examining physician completed the relevant parts of a standard questionnaire Timing: Concurrent **Index test:** Ultrasound **Ultrasound**: Sensitivity: 96 Specificity: 96 PPV: 96 **Subgroup**: Presentation Although US had high specificity for all criteria, it had low sensitivity for dermalsinus (46%). Six cases of dermal sinus were identified on MRI but not on US. This lack of US sensitivity did not affect appropriate management, however; all of the infants with dermal sinus missed by US had skin lesions that were more severe than those of the low-risk group, and thus of less relevance to our low-risk MSS analysis. **Diagnostic accuracy results:** US and MRI concordance with a sensitivity of 96%, a specificity of 96%, and a PPV: 96%.
Ultrasound	Cowley, 2022[40] N = 79 US Sites: 1 Setting: Inpatient Retethering:	**Study population:** Patients with Esophageal Atresia/Tracheoesophageal Fistula referred to clinic within 6 year period who were also later then diagnosed with TSC, clinically significant spinal anomalies suggestive of TCS were those that either required additional follow-up or surgical intervention from neurosurgeons, neurologists, or rehab physicians for the spinal anomaly **Other population:** Patients with Esophageal Atresia/Tracheoesophageal Fistula **Category:** other : Esophageal Atresia/Tracheoesophageal Fistula **Comorbidity:** Other : EA/TEF **Female:** % N/A	**Reference standard:** MRI Diagnosed based on MRI and clinical findings Timing: N/A **Index test:** Ultrasound **Subgroup**: Age Of the patients who received MRI screening, 41.3% demonstrated an anomaly consistentwith suspected TCS. 57.7% of MRIs in patients 0-1 y and 50.0% of MRIs in patients 1- 2y detected these lesions, demonstrating a high rate of detecting these spinal anomalies in younger patients. In patients greater than 2 y, however, only 11.1% of MRIs demon- strated an anomaly consistent with TCS. Vertebral anomalies had a high association with tethering lesions on MRI

		Age: 4.9 (2.38) Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A	(64.7%) as did an increased number of VACTERL (vertebral, anal atresia, cardiovascular, tracheosophageal fistula, esophageal atresia, renal, lib deffects) anomalies: patients with three or more VACTERL anomalies had TCS lesions on MRI at a rate of 56.3%. **Diagnostic accuracy results:** Of the patients who had normal reported ultrasounds, 22% had an MRI reading suggestive of TCS later in life; this calls into question the sensitivity of US screening for TCS particularly for patients with vertebral anomalies. Nine patients with normal reported ultrasounds received MRIs later in life; 22% had signs of cord tethering (low lyingconus) on MRI; one additional patient had normal conus position terminating at L2/L3 level but received neurosurgical intervention due to clinical symptoms. Of the patients who received MRI screening, 41.3% demonstrated ananomaly consistent with suspected TCS.
Ultrasound	He, 2016[41] Trial ID N/A N = 548 China Sites: 1 Setting: N/A Retethering: First time	**Study population:** Fetuses with TSC **Other population:** Consecutive healthy fetuses **Category:** other : Healthy fetuses **Comorbidity:** **Female:** % **Age:** Mean gestational age 27.30 (SD 3.5) weeks Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A	**Reference standard:** Neurologists Autopsies, ultrasound (post-delivery), and neurological examinations after delivery Timing: Later diagnosis **Index test:** Ultrasound **Ultrasound**: Ultrasonographic measurement of the conus distance in fetuses ICC: 0.977 Rater agreement: For intraobserver reliability assessment data were collected and analyzed by the same operator twice with an interval of half an hour, data were collected 3 times, mean value was used. For interobserver reliability assessment, the same data were collected Intraobserver (ICC 0.977, CI, 0.995–0.998); interobserver (ICC 0.995, CI 0.990–0.997) with 95% limits of agreement of −2.2 to 2.6 mm and −3.7 to 3.1 mm. **Subgroup**: N/A **Diagnostic accuracy results:** The conus distance was significantly less in TCS fetuses than in healthy fetuses. Ultrasonographic measurement of conus

			distance is an easy and reliable method to evaluate the position of the conus medullaris and, therefore, can be helpful in the prenatal diagnosis of TCS.
Ultrasound	Jehangir, 2020[42] N = 44 Australia Sites: multiple Setting: Inpatient Retethering: First time	**Study population:** Neonates with anorectal malformations then found to also have TSC **Other population:** Neonates with anorectal malformations **Category:** other : children with anorectal malformations **Comorbidity:** Anorectal malformation **Female:** 48% **Age:** neonates Min age: 0 Max age: 0 **Age subgroup**: Pediatrics **Ethnicity:** N/A	**Reference standard:** MRI Diagnosed based on MRI findings Timing: Later diagnosis **Index test:** Ultrasound **Ultrasound**: Spinal Ultrasound Sensitivity: 36 Overall sensitivity spinal anomalies: 91 Specificity: 84 Overall specificity spinal anomalies: 75 **Subgroup**: NA **Diagnostic accuracy results:** Sensitivity for tethered spinal cord was 36% with corresponding specificity 85%. No child who was reported to have a normal spinal US required de-tethering at a later stage. 60% underwent neurosurgical operation out of all children with an abnormal MRI – 1 child had meningomyelocoele repair, 1 an anterior meningocoele repair and 17 (9%) had laminectomy and de-tethering of cord with or without excision of lipoma.
Ultrasound	Karrer, 1988[43] N = 14 US Sites: 1 Setting: Inpatient Retethering: Mix	**Study population:** Patients with anorectal malformations associated with spinal cord lesions (all having tethered cord) with radiographs and medical records, including high imperforate anus (4), low lesions (4), and cloacal exstrophy (6) **Other population:** N/A **Category:** N/A **Comorbidity:** N/A **Female:** 71.4% **Age:** NA Min age: 0 Max age: 15 **Age subgroup**: Pediatrics **Ethnicity:** N/A	**Reference standard:** Other Clinical follow up or surgery revealed tethered spinal cord Timing: Later diagnosis **Index test:** Ultrasound **Ultrasound**: Spinal sonography **Subgroup**: N/A **Diagnostic accuracy results:** Spinal sonography was highly accurate in the neonatal period. The application of ultra- sonography can be of great advantage in early screening of patients with anorectal malformations and, in some cases, may eliminate the need for invasive imaging techniques.
Ultrasound	Kerensky, 2024[44] N = 6 US	**Study population:** Patients with neurological symptoms and deficits after previous detethering surgeries, diagnosed with recurrent TCS, and scheduled for posterior vertebral column	**Reference standard:** Other Tension measurement after spinal column shortening Timing: Concurrent

	Sites: multiple Setting: Inpatient Retethering: Retethering	subtraction osteotomy , all presenting with lower extremity weakness, decreased sensation, and bladder deficits **Other population:** N/A **Category:** N/A **Female:** % N/A **Age:** Min age: Max age: **Age subgroup**: Age unclear **Ethnicity:** N/A	**Index test:** Ultrasound **Ultrasound**: Sensitivity: 89 Specificity: 86 AUC: 0.962 92-100 **Subgroup**: N/A **Diagnostic accuracy results:** The ROC AUC was 96.2% (CI 92%–100%). The SWV value that maximized Youden's index was 1.795 m/s. This threshold had a single-image sensitivity and a single-image specificity of 89%. Ultrasound-derived shear wave velocity proves to be an effective tool for intraoperative feedback, enhancing diagnosis, treatment, and monitoring of tethered cord syndrome.
Ultrasound	Keykhosravi, 2023[45] Trial ID NA N = 30 Iran Sites: 1 Setting: Inpatient Retethering: NA	**Study population:** Children under the age of two, who were referred to and diagnosed with TCS by an expert neurosurgeon; patients with open neural tube defects or spinal canal masses were excluded **Other population:** Healthy patients matched on age and sex **Category:** NA **Comorbidity:** NA **Female:** 53% **Age:** 7.67 (6.39) Min age: 0 Max age: 1.92 **Age subgroup**: Pediatrics **Ethnicity:** N/A	**Reference standard:** MRI TSC diagnosed based on low-lying conus medullaris and a filum terminal measurement of more than 2 mm Timing: Prior diagnosis **Index test:** Ultrasound **Ultrasound**: Patients were placed in a prone position and a B-mode gray-scale ultrasound examinationof the spinal cord was performed using a Samsung WS80A device equipped with an 8-12 MHz linear-array transducer; the maximum distance of the spinal cord from the posterior wall of the spinal canal at T12-L2 levels (except the inflated conus medullaris region), was measured with B-mode ultrasonography. B-mode ultrasonography was also used to determine the endpoint location of conus medullaris **Subgroup**: NA **Diagnostic accuracy results:** TCS patients had a significantly shorter maximum distance of the spinal cord from the posterior wall of the spinal canal than the control group (1.75±0.62 mm vs. 2.79±0.76, P<0.001).
Ultrasound	Lam, 2004[46] Trial ID NA N = 124	**Study population:** Children with spinal cord lesions (6 children with suspected tethered cord syndrome and 10 postoperative cases of known tethered cord syndrome)	**Reference standard:** MRI MRI of the spine was performed by other radiologists in the department without theknowledge of the ultrasound findings either before or after the

	Hong Kong Sites: 1 Setting: Inpatient Retethering: Mix	**Other population:** Neurologically normal and asymptomatic infants and children; none manifested neurologic abnormalities, and all were referred to the hospital for ultrasound examinations requested for other parts of the body **Category:** Healthy volunteers **Comorbidity:** NA **Female:** 56.3% **Age:** Mean 3.9 Min age: 0 Max age: 11 **Age subgroup**: Pediatrics **Ethnicity:** N/A	ultrasound examinations, the radiologists performing the ultrasound did not know the MRI findings beforehand; findings were classified as follows: normal cord, low tethered cord only, tethered cord and terminal anomaly (e.g., lipoma or syrinx) Timing: Concurrent **Index test:** Ultrasound **Ultrasound**: Ultrasound of the lumbosacral spine performed on the normal and spinal legion groupusing a 5-12-MHz linear-array transducer; images were obtained by paramedian scan in left lateral decubitus position with the lumbosacral spine flexed, sagittal and axial scans of the spinal cord obtained; location of the conus medullaris recorded; all exams performed by 2 radiologists independently; posterior/anterior subarachnoid spaces, and diameter of filum terminale were measured just below the conus medullaris and at the L5/S1 dural sac; the posterior /anterior subarachnoid space just below conus medullaris was defined as the maximum distance between the posterior/anterior thecal sac and the tip of the conus medullaris, the posterior/anterior subarachnoid space at the L5/S1 dural sac was defined as the max distance between the posterior/anterior thecal sac and the cauda equina near the thecal sac at the L5/S1 level, respectively; m-mode was applied at these 2 levels to document cerebrospinal fluid pulsation of cauda equina; the oscillation rate and amplitude were measured; the oscillation amplitude was defined by the maximal displacement of the cauda equina in anterior-posterior direction; all measurements were taken 3 times, and an average was obtained; the ratio of posterior to anterior subarachnoid spaces was calculated Sensitivity: In 6 cases with suspected tethered cord, there was 1 of low tethered cord with sacrallipomaand 5 with simple low tethered cord without other abnormality detected by ultrasound; the abnormal findings determined on ultrasound yielded 100% correlation with MRI findings. ICC: 0.949

			Rater agreement: Intraclass correlation coefficient was of the two radiologists in observing 10 patients in the normal group **Subgroup**: Age,Other : Sex The absolute measurements and ratio of different spaces, oscillation rate, and amplitude for the normal group were correlated with age and sex using correlation analysis **Diagnostic accuracy results:** Any oscillation amplitude of less than 0.3 mm in a symptomatic patient should alert the clinician to possible cord abnormality, cord tethering, or retethering in postoperative cases. Postoperative US findings matched MRI findings in all 10 cases of known TSC.
Ultrasound	Mottet, 2016[47] Trial ID NA N = 169 France Sites: multiple Setting: Inpatient Retethering: First time	**Study population:** Fetuses with prenatal diagnosis of tethered cord **Other population:** Singleton fetuses without malformations **Category:** Healthy volunteers **Comorbidity:** NA **Female:** % NA **Age:** Range 23.5-32 weeks Min age: 0 Max age: 0 **Age subgroup**: Pediatrics **Ethnicity:** N/A	**Reference standard:** Other Prenatal diagnosis of tethered cord Timing: N/A **Index test:** Ultrasound **Ultrasound**: Sonographic evaluation of the fetal conus medullaris Rater agreement: Different sonographers Inter-observer variability intradural FT distance ICC 0.97, Intra-observer variability intradural FT distance ICC 0.987, Inter-observer variability CM-S1 distance ICC 0.974. Intra-observer variability CM-S1 ICC 0.985, Bland-Altman analysis inter-observer **Subgroup**: NA **Diagnostic accuracy results:** In cases of tethered cord, the mean CM-S1 distance and the mean intradural FT distance were both below the 5th percentile.
Ultrasound	Scottoni, 2014[48] N = 82 Italy Sites: 1 Setting: Outpatient Retethering: First time	**Study population:** Patients with anorectal malformations who underwent spinal ultrasound and MRI, 3% with occult spinal dyraphism **Other population:** Patients with anorectal malformations who underwent spinal ultrasound and MRI **Category:** NA	**Reference standard:** MRI Diagnosed based on MRI findings, pediatric radiologist Timing: Later diagnosis **Index test:** Ultrasound **Ultrasound**: Spinal ultrasound

		Comorbidity: Anorectal malformation **Female:** 41% **Age:** NA Min age: Max age: **Age subgroup**: Age unclear **Ethnicity:** N/A	**Subgroup**: NA **Diagnostic accuracy results:** Forty-seven patients (57, 3 % of total, 18 females, 29 males) had some occult spinal dysraphism (tethered spinal cord, spinal lipoma, syringomyelia) at MRI. Only 7 (14, 8 %) patients of those with spinal anomalies at MRI had pathological US studies. Sensitilvity and specificity of US for diagnosis of occult spinal dysraphism were 14, 8 and 100 %.
Ultrasound	Teo, 2012[49] Trial ID NA N = 101 Singapore Sites: 1 Setting: Inpatient Retethering: NA	**Study population:** Children with anorectal malformations evaluated with low lying cord, then found to have tethered cord as well **Other population:** All children who had a lumbar US performed and who were diagnosed with and underwent surgery for anorectal malformations **Category:** other : Patient with anorectal malformations (ARM) and low lying cord (LLC) **Comorbidity:** Anorectal malformation **Female:** % LLC group: 47% female **Age:** NA Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A	**Reference standard:** MRI MR images included axial and sagittal T1- and T2-weighted images; patients werereviewed by the paediatric neurosurgeon, who confirmed the radiologic diagnosis of low-lying spinal cord; diagnosis of TCS was made based on the presence of any urodynamic dysfunction in urodynamic studies performed by a paediatric general surgeon or the presence of neurological signs, including urinary incontinence on clinical examination performed by the paediatric neurosurgeon Timing: Concurrent **Index test:** Ultrasound **Ultrasound**: The presence of LLC on US and MR imaging was evaluated and reported by a radiologist **Subgroup**: NA **Diagnostic accuracy results:** 70.6% patients had abnormal US and MR imaging findings. 29.4% had normal US but abnormal MR imaging results; in these patients, MR imaging was performed due to new symptoms and equivocal US findings.
Ultrasound : Lumbar spine ultrasound	Kucera, 2015[50] Trial ID NA N = 3884 US Sites: multiple Setting: Inpatient Retethering: First time	**Study population:** Patients with tethered cord who received a screening lumbar spine ultrasound with the indication of a simple sacral dimple; patients with other conditions such as congenital abnormalities were excluded **Other population:** 1 patients without tethered cord who received a screening lumbar spine ultrasound with the indication of a simple sacral dimple **Category:** Not tethered **Comorbidity:** NA	**Reference standard:** Neurosurgeons Intraoperative confirmation Timing: Later diagnosis **Index test:** Ultrasound : Lumbar spine ultrasound **Ultrasound**: Standard ultrasound examinations of the lumbar spine; high-resolution, 8- to 14-MHzlinear-array transducers were used (from various machines); a sonogram was considered abnormal for any of the following reasons: a conus medullaris terminating below the L2–L3 disc space, decreased motion of the

		Female: % Detethering group: 60 **Age:** NA Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A	conus or nerve roots, a fat-containing filum terminale or a filum thickened >2 mm, or the presence of an intraspinal mass, osseous dysraphism (best evaluated for on transverse US images), or a subcutaneous tract leading to the thecal sac; in children with transitional anatomy with a discrepancy between the level of the conus when counted from the last rib versus when counted from the sacrum, the lowest conus position was assumed; normal variants such as a filar cyst, ventricularis terminalis, or a pilonidal tract (defined as a residual cord-like region composed of fibrous tissue extending from the skin dimple to the coccyx without connection to thecal sac) were notconsidered abnormal **Subgroup**: NA **Diagnostic accuracy results:** Only 5/3,884 (0.13%) infants underwent surgical intervention, and 4/5 were found to have a tethered cord intraoperatively.
Ultrasound : Percutaneous ultrasonography	Brezner, 1999[51] Trial ID NA N = 106 Israel Sites: 1 Setting: Outpatient Retethering: First time	**Study population:** Patients ultimately diagnosed with tethered cord **Other population:** Children, adolescents, and adults with myelomeningocele who visited the spina-bifida clinic and underwent percutaneous ultrasonography of their spinal cord at the level of the bony defect **Category:** other : Myelomeningocele **Comorbidity:** Lipomyelomeningocele **Female:** 49.1% **Age:** Median 6 years and 6 months Min age: 0 Max age: 29 **Age subgroup**: Mixed age sample **Ethnicity:** N/A	**Reference standard:** MRI Diagnosed based on MRI findings Timing: Concurrent **Index test:** Ultrasound : Percutaneous ultrasonography **Ultrasound**: Percutaneous ultrasonography to determine cord pulsation Misdiagnosis: Of the 53 patients who underwent MRI of their cord, 20 patients exhibited clinicalsigns of deterioration and 33 did not. There was a strong correlation between the presence of these clinical signs and the availability of MRI of the cord (Spearman r=0.402, P<0.001), indicating that patients with clinical signs were over-represented among the patients who underwent MRI examinations (20 of 22 with clinical signs versus 33 of 84 without clinical signs). **Subgroup**: Age,Presentation There was no significant correlation between sonographic grading and age (r 0.039) nor between sonographic grading and height (r 0.076). There was no significant correlation between sonographic grading and age (r 0.039) nor between

			sonographic grading and height (r 0.076). The probability of there being no pulsation among patients with clinical signs was found to be significantly high (P<0.001) **Diagnostic accuracy results:** The absence of cord pulsation correlated with the presence of symptoms but this relation may be explained by MRI findings of certain structural cord malformations and not by tethering per se. The relation between spinal cord pulsation and MRI findings is presented in a 2 × 2 contingency table. As the number of patients in each MRI category was too small, we grouped patients for statistical analysis. Two groups were formed: those with NC, TC, or TC+TA, and those with TC+LA, TC+EA. The χ2 test indicates that the probability of having no pulsation is higher in the presence of a syrinx, without relation to the presence of tethering of the cord (χ2=8.589, df=1, P<0.01)
Ultrasound,Physical exam : Presence of cutaneous lesions	Sasani, 2008[52] Trial ID NA N = 612 Iran Sites: multiple Setting: Inpatient Retethering: First time	**Study population:** Live-born neonates diagnosed with TSC **Other population:** Healthy neonates and neonates with other spinal conditions **Category:** Fatty filum,Lipomyelomeningocele,Healthy volunteers,other : Diastematomyelia; dermal sinus tract **Comorbidity:** NA **Female:** % NA **Age:** N/A Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A	**Reference standard:** Neurologists Results evaluated by two neurologists Timing: N/A **Index test:** Ultrasound,Physical exam : Presence of cutaneous lesions **Ultrasound**: Spinal ultrasonography **Physical examination:** Uroneurological symptoms **Subgroup**: NA **Diagnostic accuracy results:** The discordance between ultrasonography and MRI was 16.58%. The mean incidence of agreement between ultrasonography and MRI was 83.42. MRI scans are more reliable and give an exact diagnosis of tethered cord. The correlation between urodynamic assessment and cutaneous lesions with a tethered cord found by MRI examination allow for an early diagnosis and the possibility of prompt treatment. Four children presented with the neurological or uroneurological findings of a tethered cord syndrome; however, there was disagreement between the clinical examination and radiological evidence; in all 4 children, the conus medullaris had a normal anatomical ending; 1 patient had clubfeet and

			paraparesis with a cutaneous appendage (human tail), 3 patients had uroneurological findings with 1 of 3 patients having a dimple over the sacrum, while 2 of 3 patients had a lipoma and a normal anatomical ending. 33.82% of children had uroneurological symptoms, including all TSC patients.
Urodynamic	Broderick, 2015[53] N = 38 US Sites: 1 Setting: Inpatient Retethering: First time	**Study population:** Asymptomatic patients with MRI diagnosis of tethered cord; excluded any neurologic or urologic dysfunction or associated syndromes, and other significant comorbidities **Other population:** N/A **Category:** N/A **Comorbidity:** N/A **Female:** 68.4% **Age:** Mean 3 Min age: 0.2 Max age: 16.3 **Age subgroup**: Pediatrics **Ethnicity:** N/A	**Reference standard:** MRI Diagnosed based on MRI and neurosurgical evaluation Timing: Prior diagnosis **Index test:** Urodynamic **Urodynamics:** Urodynamic studies consisted of cystometrography, fluoroscopic voiding cystourethrography,and electromyography of the urinary sphincter; EMG action potentials were measured either via needle insertion or via patch electrode, depending on the urologist's preference. Urodynamic study was performed after transurethral catheterization with 6 French dual-lumen catheter for measurement of intravesical pressure, and a 9 French rectal catheter for measurement of intra-abdominal pressure with the child in supineposition, without sedation or analgesia **Subgroup**: NA **Diagnostic accuracy results:** 82 % of children had normal baseline urodynamics, yet 68 % of these patients still underwent neurosurgical intervention; 7/7 patients with abnormal baseline had normal renal ultrasound findings and had no other significant differences in presentation from the patients with normal UDS. In children with asymptomatic tethered cord, abnormal preoperative urodynamic studies may prompt intervention, while normal urodynamic studies do not appear to prevent intervention. There is no significant correlation between abnormal preoperative UDS and abnormal preoperative imaging. Further study is needed to evaluate the utility of this procedure in the preoperative setting in an asymptomatic patient population.
Urodynamic	Meyrat, 2003[54] N = 53	**Study population:** Children with primary TCS who underwent spinal cord untethering	**Reference standard:** MRI Preoperative spinal MRI Timing: Concurrent

	Switzerland Sites: 1 Setting: Inpatient Retethering: NA	**Other population:** Pediatric patients who were evaluated with UDS during the same period of time for primary or secondary enuresis and preoperative work-up for anorectal malformations **Category:** other **Comorbidity:** N/A **Female:** 33.33% **Age:** 5 (4) Min age: 0 Max age: 15 **Age subgroup**: Pediatrics **Ethnicity:** N/A	**Index test:** Urodynamic **Urodynamics:** Preformed preoperatively. Microtip transducers were used for pressure measurements. Assessment of the activity of the external urethral sphincter was made by recording the EMG activity of the external anal sphincter with perineal surface electrodes. Concordance: 100% concordance. All patients had TCS. **Subgroup**: N/A **Diagnostic accuracy results:** There was a statistically significant difference in the preoperative urodynamic study (UDS) scores between the control group and the study group (p<0.001). Postoperatively, there was a statistically significant improvement (p<0.001) in UDS scores. UDS score is a reliable tool for identifying and quantifying neurourological disorders in patients with TCS. Postoperatively, this score was useful in the early diagnosis of spinal cord retethering.
Urodynamic	Tamura, 2017[55] Trial ID NA N = 103 Japan Sites: 1 Setting: Inpatient Retethering: First time	**Study population:** Children with sacrococcygeal dimples and functional or anatomical TSC (caudal end of the conus medullaris is lower than the inferior border of the L2–3 intervertebral disc) **Other population:** Children with sacrococcygeal dimples **Category:** Not tethered : anatomica TSC **Comorbidity:** NA **Female:** 52% **Age:** Mean 9.2 months Min age: 0 Max age: 6 **Age subgroup**: Pediatrics **Ethnicity:** N/A	**Reference standard:** MRI MRI diagnosis of anatomical tethered spinal cord characterized by patholigical fixation of the spinal cord resulting in an abnormally low conus medullaris Timing: Concurrent **Index test:** Urodynamic **Urodynamics:** Presence of neurogenic bladder (urinary tract dysfunction) Sensitivity: 67 Specificity: 56 **Subgroup**: NA **Diagnostic accuracy results:** The prevalence of neurogenic bladder was not signficantly different between groups with or without anatomical tethered spinal cord (p 0,64).
Urodynamic	Yarandi , 2019[56] Trial ID NA N = 110 Iran Sites: 1	**Study population:** Patients referred to neurosurgery clinic with Idiopathic Scoliosis or Congenital Scoliosis later identified to have TSC, exclusion criteria include: patients aged less than 5 years; those with myelomeningocele or meningocele, prior history of spine surgery, any	**Reference standard:** MRI Diagnosed based on the presence of at least one of the following: a low-lying filumterminale at any place below the L2/L3 disk space, neurologic manifestations of cord tethering and placement of the tip of the filum at any level below L1/L2, SCM I, or any other tethering

	Setting: N/A Retethering: First time	contraindication to MRI, neuromuscular or other degenerative diseases, psychologic illnesses that affect history taking and examination reliability, paralysis, and degenerative and reactive scoliosis; and those who are unable to perform UDS due to any reasonable cause, TCS or anomalies that could cause cord tethering were found on the MRI images of 26.3% and 38.2% of patients with ISC and CSC **Other population:** Patients without TSC **Category:** other : Idiopathic or Congenital Scoliosis **Comorbidity:** Scoliosis : ISC and CSC **Female:** 65.5% **Age:** 15.9 (7.2) Min age: 3 Max age: 40 **Age subgroup**: Mixed age sample **Ethnicity:** N/A	pathologies of the spine, including sinus tract or tumors, or a tight filum terminale on MRI, further confirmed in surgery by two neurosurgeons Timing: Prior diagnosis **Index test:** Urodynamic **Urodynamics:** Standard urodynamic study, abnormal finding were defined as the presence of impaired capacity/compliance (mild impairment) and overactivity of the bladder or dyssynergia **Subgroup**: NA **Diagnostic accuracy results:** TCS or anomalies that could cause cord tethering were found on the MRI images of 26.3% and 38.2% of patients with idiopathic and congenital scoliosis. 61.8% of patients had normal urodynamic study findings. In the idiopathic group, a significantly abnormal finding indicated that the risk of TCS increased from 26.3% to 50% (odds ratio [OR], 4.2), urodynamic studies may be performed as additional examination for the evaluation of TCS in selected patients within this subgroup.
X ray	Mahapatra, 2005[57] Trial ID NA N = 254 India Sites: 1 Setting: N/A Retethering: NA	**Study population:** Patients with split cord malformations with tethered spinal cord **Other population:** Patients with split cord malformations without tethered spinal cord **Category:** other : split cord malformation **Comorbidity:** Other : split cord malformations **Female:** 60.3% **Age:** 7.3 Patients with neurological deficits: mean 6.66 years; asymptomatic patients mean 6.7 years Min age: 0.04 Max age: 35 **Age subgroup**: Mixed age sample **Ethnicity:** N/A	**Reference standard:** MRI Magnetic resonance imaging of the spine (for type and level of split, level of theconus medullaris, thickness of the terminal filum, presence of other associated tethering elements, and syringomyelia) was performed, along with a screening MR imaging study of the brain and craniovertebral junction to look for hydrocephalus, Chiari malformation, and syringomyelia Timing: Later diagnosis **Index test:** X ray **X-rays:** Plain x-ray films of the spine were obtained to assess for kyphoscoliosis and vertebral or rib anomalies **Subgroup**: NA **Diagnostic accuracy results:** Magnetic resonance imaging revealed an additional lesion causing tethering in 47% of cases.

X ray,CT	Kaplan, 1980[58] N = 12 US Sites: 1 Setting: N/A Retethering: NA	**Study population:** Adults with clinically occult tethered conus **Other population:** N/A **Category:** N/A **Comorbidity:** N/A **Female:** % N/A **Age:** Min age: 20 Max age: 55 **Age subgroup**: Adults **Ethnicity:** N/A	**Reference standard:** Other Myelography Timing: Later diagnosis **Index test:** X ray,CT **X-rays:** Plain radiograph **CT:** CT of the spinal canal **Subgroup**: N/A **Diagnostic accuracy results:** Twelve adults presented with tethered conus syndrome which had gone undiagnosed throughout childhood. Seven patients had had surgery directed toward the presenting symptoms or cutaneous abnormalities because the true underlying pathology was not appreciated. Although plain radiographs of the lumbosacral spine were abnormal, it was myelography that established the diagnosis. Computed tomography was performed in 4 cases and optimally showed the point of tethering, the nature and extent of the tethering masses, and the course of the intradural bands.
X ray,Myelogram : Conventional & CT	Merx, 1989[59] N = 30 Netherlands Sites: 1 Setting: Inpatient Retethering: First time	**Study population:** Patients with external signs of occult spinal dysraphia and osseous abnormalities in the lumbar region **Other population:** N/A **Category:** N/A **Comorbidity:** Spina bifida : Plain x-rays showed a form of spina bifida or dysplasia **Female:** % N/A **Age:** N/A Min age: Max age: **Age subgroup**: Mixed age sample **Ethnicity:** N/A	**Reference standard:** Neurosurgeons Diagnosis by surgical inspection Timing: Later diagnosis **Index test:** X ray,Myelogram : Conventional & CT **X-rays:** Plain x-ray films **Myelogram:** Conventional lumbar myelography was done under general anesthesia in patients youngerthan 10 years of age; older patients received the usual premedication; paramedian lumbar punctures were done in lateral decubitus with a short bevelled puncture needle at the lowest possible level, because of the expected low position of the conus Sensitivity: 82 Specificity: 96 PPV: 0.94 NPV: 0.85 **Subgroup**: N/A

			Diagnostic accuracy results: All patients showed lumbar or sacral osseous malformations on the plain X-ray films - this means a high diagnostic sensitivity although the specificity for TSC is low. Conventional myelography had a sensitivity of 0.82 and positive predictive value of 0.94, while the specificity and negative predictive value are respectively 0.96 and 0.85. The positive predictive value of the total diagnostic procedure of plain X-ray films and lumbar myelography for TSC may be estimated at 1.

Notes: N/A not available or not applicable; CT computed tomography; MRI magnetic resonance imaging; EP evoked potentials; IONM intra operative neurophysiological monitoring; PPV positive predictive value; NPV negative predictive value; AUC area under the curve; ICC intra class correlation;

Table C.2. KQ2 evidence table

Study	Population	Intervention	Results
Li, 2022[60] Cohort study N = 85 China Sites: 1 Setting: Inpatient	**Study population:** Infants with congenital neural tube defects, children with bladder and rectal dysfunction were excluded **Other population:** N/A **Comorbidity:** Other : Neural tube defects and meningocele **Female:** 38% **Age:** Mean in months: 0.79 (0.11) Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Asymptomatic	**Intervention:** Other Meningocele repair combined with tethered cord release within 6 hours to 30 days after birth, general anesthesia with tracheal intubation and underwent a lumbosacral incision; surgical procedures involved 2 main steps: relieving spinal cord compression and releasing the spinal cord from traction sources; specific techniques were used, including removing tissue causing compression, separating nerves, and repairing the dura. Care was taken to avoid damage, and space was reserved during the procedure to prevent secondary adhesions **Control:** NA **Comparator:** Other Meningocele repair combined with tethered cord release after 30 days after birth, general anesthesia with tracheal intubation and underwent a lumbosacral incision; surgical procedures involved 2 main steps: relieving spinal cord compression and releasing the spinal cord from	Gross motor function The immediate surgery group had significantly higher gross motor function comparedto the delayed group at the longest follow-up (4 years postoperatively) (p <0.001). Subgroup: NA

		traction sources; specific techniques were used, including removing tissue causing compression, separating nerves, and repairing the dura. Care was taken to avoid damage, and space was reserved during the procedure to prevent secondary adhesions **Comparator 2:** NA **Follow-up:** 72 weeks	
Ogiwara, 2015[61] Cohort study N = 354 Japan Sites: 1 Setting: Inpatient	**Study population:** Patients diagnosed with tethered cord syndrome, either clinically with neurological symptoms or through MRI radiology, exhibited either a low-lying conus (below the caudal edge of L-2) or a conus in its usual position, 18% were asymptomatic **Other population:** Symptomatic patients diagnosed with tethered cord syndrome, either clinically with neurological symptoms or through MRI radiology, exhibited either a low-lying conus (below the caudal edge of L-2) or a conus in its usual position **Comorbidity:** Fatty filum **Female:** 32.8% **Age:** 72 hr group: 43 months (range 3-226 months); 8 day group: 27 months (range 3-138 months) Min age: Max age: **Age subgroup**: Mixed age sample **Ethnicity:** N/A **Indication**: Mixed sample	**Intervention:** Other Postoperative flat bed rest for 72 hours after untethering the spinal cord using intraoperative monitoring, closing the dura primarily with 4–0 Neurolon and interlocking stitches, and then closing the muscles with sutures **Control:** NA **Comparator:** Other Postoperative flat bed rest for 8 days after untethering the spinal cord using intraoperative monitoring, closing the dura primarily with 4–0 Neurolon and interlocking stitches, and then closing the muscles with sutures **Comparator 2:** NA **Follow-up:** 92 weeks	Postoperative complications None of the asymptomatic or symptomatic patients developed a CSF leak. Pseudomeningocele, which was confirmed by MRI, developed in 1 patient who had been kept flat for 8 days (unclear whether this was a symptomatic or asymptomatic patient). No intraoperative complications across asymptomatic or symptomatic patients and both treatment groups. Subgroup: NA

Byrne, 1995[62] Cohort study N = 100 US Sites: multiple Setting: Inpatient	**Study population:** Patients who are asymptomatic with lumbosacral skin lesions and congenital anomalies **Other population:** Patients who experienced neurological and urological symptoms, along with orthopedic abnormalities and skin lesions, received a confirmed diagnosis through various diagnostic methods such as myelography, computed tomography, CT/myelography, ultrasound, and MRI **Comorbidity:** Lipomyelomeningocele **Female:** 55% **Age:** mean 0.33 Min age: 0 Max age: 1 **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Mixed sample	**Intervention:** Other surgery Untethering with laser resection of lipoma or untethering without laser; the goal of these primary procedures was spinal cord untethering and debulking of the lipoma but not necessarily a complete resection of the lipoma **Control:** NA **Comparator:** Other Cosmetic procedures in which the lipoma was debulked but no attempt was made to resect the lipoma to the interface between the lipoma and the neural tissue, thereby untethering the spinal cord **Comparator 2:** NA **Follow-up:** 60 weeks	Motor, urologic or orthopedic symptoms No asymptomatic infant deteriorated postoperatively and 93% of these children remained symptom-free at follow-up (mean follow-up was 44 months). Of the infants that presented with motor, urologic or orthopedic symptoms, 39% improved, 58% stabilized, while 3% worsened as a result of surgery. Deterioration No asymptomatic infant deteriorated postoperatively and 93% of these children remained symptom-free at follow-up (mean follow-up was 44 months). Of the infants that presented with motor, urologic or orthopedic symptoms, 39% improved, 58% stabilized, while 3% worsened as a result of surgery. If a spinal lipoma is detected, a dethering of the spinal cord and debulking of the lipoma should be performed (prompt surgery is recommended since there is considerably more risk in waiting for the infant to become progressively symptomatic than there is in performing a spinal cord untethering). Postoperative complications There were no cases of abscess formation or meningitis. Early postoperative complications occurred in 16% across symptompatic and asymptomatic infants. These consisted of CSF leaks and superficial wound infections. All complications were treated successfully. All 12 children who had an initial cosmetic procedure all required a second operation for symptomatic cord tethering. Subgroup: NA

Goldstein, 2019[63] Cohort study N = 208 US Sites: multiple Setting: Inpatient	**Study population:** Children who were under 21 years of age with a history of myelomeningocele repair and who underwent scoliosis surgery with or without prophylactic detethering **Other population:** N/A **Comorbidity:** Scoliosis,Other : Myelomeningocele **Female:** 52% **Age:** 9.4 Min age: 1 Max age: 17 **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Asymptomatic	**Intervention:** Surgical detethering Scoliosis corrective surgery and concomitant prophylactic untethering **Control:** Other Surgery for myelomeningocele and scoliosis repair without untethering **Comparator:** Surgical detethering Prophylactic spinal cord untethering prior to scoliosis surgery **Comparator 2:** NA **Follow-up:** 3 weeks	Urologic function Only 2 patients, both in the concomitant prophylactic untethering group had improved urologic function (p 0.03), with most patients requiring straight catheterization at baseline. Change in motor/sensory function No change in motor/sensory function in any group. CSF leaks, surgical site infection, wound complications, or ventriculo-peritoneal shunt malfunctions Surgical site infection, were seen in 31% of patients undergoing concomitant untethering, 29% undergoing prior untethering, 12% without untethering (p 0.01). CSF leaks, wound complications, or ventriculo-peritoneal shunt malfunctions did not differ between groups Subgroup: NA
Oi, 2009[64] Cohort study N = 261 Japan Sites: multiple Setting: Inpatient	**Study population:** Asymptomatic and symptomatic patients with spinal lipoma **Other population:** **Comorbidity:** NA **Female:** % NA **Age:** NA Min age: Max age: **Age subgroup**: Age unclear **Ethnicity:** N/A **Indication**: Asymptomatic	**Intervention:** Surgical detethering Untethering performed by expert pediatric neurosurgeons; prophylactic for some of the asymptomatic patients **Control:** Other Conservative observation without surgery **Comparator:** NA **Comparator 2:** NA **Follow-up:** 31 weeks	Urinary retention In asymptomatic patients, urinary retention was seen 0.7% postoperatively but the deficit resolved resolved after a few weeks. Varus 4.3% of asymptomatic conservatively managed patients presented with varus in the follow up period but symptoms were mild and did not affect daily activities, the other 95.7% had stable neurological states. 20% of symptomatic patients improved immediately after surgery, and the improvement rate increased to 44% at the final follow-up; worsening of symptoms was seen in 9% of patients immediately postoperatively but decreased to 6% at the final follow-up; the 2 symptomatic patients that were conservatively managed had stable neurological states. Subgroup: NA

Tu, 2016[65] Cohort study N = 44 Canada Sites: 1 Setting: Inpatient	**Study population:** Infants with lumbosacral lipomas or congenital deficits noted during infancy, aligned with anatomical abnormalities observed through MRI imaging; patients underwent untethering at an average age of 4.7 months **Other population:** N/A **Comorbidity:** Other : Muscle bulk discrepancies, orthopedic limb abnormalities, and Scoliotic deformities **Female:** % NA **Age:** NA Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Asymptomatic	**Intervention:** Surgical detethering Prophylactic detethering; patients who showed no deficits during infancy and had no neurological issues underwent prophylactic untethering at an average age of 9 months; included monitoring (free-running electromyography with neural stimulation), surgical goals included achieving maximal safe removal of the lipoma guided by intraoperative ultrasound, stimulating the placode and root, and reconstructing the subarachnoid space with the use of a dural graft **Control:** NA **Comparator:** Other Delayed detethering; surgical procedures included monitoring (free-running electromyography with neural stimulation), surgical goals included achieving maximal safe removal of the lipoma guided by intraoperative ultrasound, stimulating the placode and root, and reconstructing the subarachnoid space with the use of a dural graft **Comparator 2:** NA **Follow-up:** 154 weeks	Complications 33% of patients undergoing successful untethering surgery experienced a complication. Requiring further surgery Of 10 infants undergoing prophylactic untethering, 4 required further surgery after 124 months. Ten further underwent observation with 8 requiring surgery later. Two required repeat untethering after 154 months. Subgroup: NA
van der Meulen, 2002[66] Cohort study N = 41 Netherlands Sites: NA Setting: N/A	**Study population:** Spina bifida occulta patients with a tethered cord: 12 asymptomatic tethered cord patients **Other population:** Spina bifida occulta patients with a tethered cord: 10 with progressive symptoms, 9 treated conservatively at first, but underwent surgery after further	**Intervention:** Surgical detethering Surgery (prophylactic or to address symptoms) **Control:** TAU Conservative treatment only **Comparator:** Surgical detethering Surgical treatment after symptom progression **Comparator 2:** Surgical detethering	Neurological symptoms All patients in the prophylactic surgery group remained stable during the follow-up period. Neurological symptoms improved more markedly after operation in the patients with early surgery compared to later surgery (improved 22%, stabilised 44%, deteriorated 33%). Patients in the early intervention group show 60% improvement at the first postoperative examination and at the end of follow-up improvement was 40%. Patients in the late intervention group show less improvement immediately after operation (44%)

	progression of symptoms; 10 patients treated conservatively **Comorbidity:** Spina bifida **Female:** 59% **Age:** Prophylactic surgery group mean: 7.7 (range 1.7–20); Progressive symptoms then surgery group mean: 27.5 (range 5.2–54.6); Surgical treatment after conservative treatment and progressive symptoms mean: 28.3 (range 8.9–49.7); Conservative treatment group mean: 34.4 (range 9.0–54.5) Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Mixed sample	Surgical treatment after conservative treatment and progressive symptoms **Follow-up:** 68 weeks	and at the end of follow-up the improvement rate is down to 33%. The no surgery group showed 10% deteriorated during follow-up. Surgical complications Prophylactic surgery: 4/12 patients developed surgical complications, 3 had CSF leakage from the wound (in 1, re-exploration was necessary, 1 had a temporary bladder retention; all complications resolved during the early postoperative period. Conservative treatment: 0/10 Surgery after progressive symptoms: 3/10 patients developed postoperative complications, 1 patient had a CSF leakage requiring re-exploration,1 patient had urinary problems, and 1 patient had a partial caudal syndrome; all complications resolved during the early postoperative period. Surgery after conservative treatment and progressive symptoms: 3/9 patients developed postoperative complications, 1 patient had CSF leakage (resolved spontaneously), 1 patient had voiding problems, and 1 patient had liquor hypotension complaints, all complications were resolved during the early postoperative period. Subgroup: NA
Xenos, 2000[67] Cohort study N = 59 UK Sites: 1 Setting: Inpatient	**Study population:** Children with spinal lipomas, some asymptomatic **Other population:** Children with spinal lipomas, symptomatic **Comorbidity:** Other : Spinal lipoma **Female:** 68% **Age:** Mean 44.6 Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Mixed sample	**Intervention:** Surgical detethering Surgery, in some cases prophylactic, the spinal cord lipoma was disconnected from its dural and subcutaneous attachments, and subtotally excised; no attempt was made for a complete excision of the lipoma; the dura and muscle layers were carefully reconstituted **Control:** Other No prophylactic surgery (approach varies between the neurosurgeons) **Comparator:** NA **Comparator 2:** NA	Bladder function 1 out of 5 asymptomatic patients had sphincter function disturbances at latest follow up. Bladder function did not change in 71% of all patients (asymptomatic and symptomatic). After surgery, 12 patients improved, 5 deteriorated, and no patients returned to normal bladder function. Most of the improvements are due to children with bladder dysfunction becoming old enough to self-catheterize, and thus being assigned a higher score. At latest follow-up, 51% were normal, 2% had stress incontinence/dysuria, 30% required intermittent catheterization, 7% had nocturnal incontinence, and 10% were incontinent day and night. Anal sphincter function did not change in 44 patients (74%). After surgery, 10 patients improved, 5 deteriorated, and no patients returned

		Follow-up: 61.8 weeks	to normal sphincter function. At latest follow-up, 73% were normal, 10% had painful constipation, and 17% were incontinent. Deterioration Sensory function did not change in 74% of patients (across symptomatic and asymptomatic patients). After surgery, 12 patients improved, 3 patients deteriorated, and 6 patients returned to normal function; improvements are mainly due to 9/10 patients with limb pain being cured with surgery. At latest follow-up, 76% were normal, 22% had sensory deficit, and 2% had pain. Walking Motor function did not change in 73% of patients. After surgery, 9 patients improved, 7 patients deteriorated, and only 1 patient returned to normal function. At latest follow-up, 71% were normal, 7% had fatigue on walking, 18% required minor orthoses, 2% required major orthoses, and 2% were wheelchair bound. Pain After surgery, 12 patients improved, including 9/10 patients with limb pain being cured with surgery. At latest follow-up, 76% were normal, 22% had sensory deficit, and 2% had pain. Operative complications The overall operative complication rate was 18% (11 operations across symtpmatic and asymtomatic patients). This consisted of 2 wound infections, 4 CSF leaks and 5 wound breakdowns. Surgical repair was required in 54% to treat local wound problems. 91% with complications presented with a conus spinal lipoma, and 9% patient with CSF leak had a filum spinal lipoma. There was no operative mortality. Second operation of repeat division of filum One asymptomatic filum lipoma patient with thickened filum had a partial untethering in the context of a myelomeningocele repair at first operation and required a second operation of

			repeat division of filum due to progressive tethered spinal cord. Subgroup: NA
Li, 2022[60] Cohort study N = 85 China Sites: 1 Setting: Inpatient	**Study population:** Infants with congenital neural tube defects, children with bladder and rectal dysfunction were excluded **Other population:** N/A **Comorbidity:** Other : Neural tube defects and meningocele **Female:** 38% **Age:** Mean in months: 0.79 (0.11) Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Asymptomatic	**Intervention:** Other Meningocele repair combined with tethered cord release within 6 hours to 30 days after birth, general anesthesia with tracheal intubation and underwent a lumbosacral incision; surgical procedures involved 2 main steps: relieving spinal cord compression and releasing the spinal cord from traction sources; specific techniques were used, including removing tissue causing compression, separating nerves, and repairing the dura. Care was taken to avoid damage, and space was reserved during the procedure to prevent secondary adhesions **Control:** NA **Comparator:** Other Meningocele repair combined with tethered cord release after 30 days after birth, general anesthesia with tracheal intubation and underwent a lumbosacral incision; surgical procedures involved 2 main steps: relieving spinal cord compression and releasing the spinal cord from traction sources; specific techniques were used, including removing tissue causing compression, separating nerves, and repairing the dura. Care was taken to avoid damage, and space	Gross motor function The immediate surgery group had significantly higher gross motor function comparedto the delayed group at the longest follow-up (4 years postoperatively) (p <0.001). Subgroup: NA

		was reserved during the procedure to prevent secondary adhesions **Comparator 2:** NA **Follow-up:** 72 weeks	
Ogiwara, 2015[61] Cohort study N = 354 Japan Sites: 1 Setting: Inpatient	**Study population:** Patients diagnosed with tethered cord syndrome, either clinically with neurological symptoms or through MRI radiology, exhibited either a low-lying conus (below the caudal edge of L-2) or a conus in its usual position, 18% were asymptomatic **Other population:** Symptomatic patients diagnosed with tethered cord syndrome, either clinically with neurological symptoms or through MRI radiology, exhibited either a low-lying conus (below the caudal edge of L-2) or a conus in its usual position **Comorbidity:** Fatty filum **Female:** 32.8% **Age:** 72 hr group: 43 months (range 3-226 months); 8 day group: 27 months (range 3-138 months) Min age: Max age: **Age subgroup**: Mixed age sample **Ethnicity:** N/A **Indication**: Mixed sample	**Intervention:** Other Postoperative flat bed rest for 72 hours after untethering the spinal cord using intraoperative monitoring, closing the dura primarily with 4–0 Neurolon and interlocking stitches, and then closing the muscles with sutures **Control:** NA **Comparator:** Other Postoperative flat bed rest for 8 days after untethering the spinal cord using intraoperative monitoring, closing the dura primarily with 4–0 Neurolon and interlocking stitches, and then closing the muscles with sutures **Comparator 2:** NA **Follow-up:** 92 weeks	Postoperative complications None of the asymptomatic or symptomatic patients developed a CSF leak. Pseudomeningocele, which was confirmed by MRI, developed in 1 patient who had been kept flat for 8 days (unclear whether this was a symptomatic or asymptomatic patient). No intraoperative complications across asymptomatic or symptomatic patients and both treatment groups. Subgroup: NA

Notes: N/A not available or not applicable

Table C.3. KQ3 evidence table

Study	Population	Intervention	Results
Baldia, 2020[68] Trial ID NA Cohort study N = 16	**Study population:** Patients with postoperative cerebrospinal fluid leak **Comorbidity:** Fatty filum,Lipomyelomeningocele **Female:** %	**Intervention:** Other Conservative management of cerebrospinal fluid leak, additional sutures and continuation of prone positioning with foot end	Complications None of the conservatively managed patients had any complications like pneumonia/deep veinthrombosis related to the 7days of bedrest. Subgroup: NA

India Sites: 1 Setting: N/A	**Age mean:** NA Min age: Max age: **Age subgroup**: Mixed age sample **Ethnicity:** N/A **Indication**: Symptomatic **Retethering:** NA	elevation beyond the initial 1 week, continued for a median of 7 days (range 3-17 days) **Control:** NA **Comparator:** Other Different wound management, including ventriculoperitoneal shunt, shunt and acetazolamide, wound repair and acetazolamide, or wound repair **Comparator 2:** NA **Follow-up:** weeks	
Chern, 2011[69] Trial ID NA Cohort study N = 222 US Sites: multiple Setting: Inpatient	**Study population:** Patients who underwent tethered cord release due to a tight filum terminale; patients with myelomeningoceles, lipomyelomeningoceles, meningoceles, and intraspinal space-occupying lesions such as dermoid tumors and neurenteric cysts, cases that involved reoperations, or had incomplete medical records were excluded **Comorbidity:** NA **Female:** 51.8% **Age mean:** Mean 4.5, median 2.8 Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: NA **Retethering:** First time	**Intervention:** Other Patients lying flat for 24 hours and discharged them on postoperative day 1, with instructions to the parents to keep their child lying flat at home for an additional 48 hours after tethered spinal cord release operation, to prevent cerebrospinal fluid leak **Control:** NA **Comparator:** Other Patients lying flat for 48 hours and discharged on postoperative day 2 after tethered spinal cord release operation, to prevent cerebrospinal fluid leak **Comparator 2:** Other Patients lying flat for 72 hours and discharged on postoperative day 3 after tethered spinal cord release operation, to prevent cerebrospinal fluid leak	Cerebrospinal fluid leak A longer hospital stay for maintaining patients flat after a simple tethered cord release does not prevent cerebrospinal fluid leakage, the post-surgery intervention effect was not statistically significant; a leak occurred in 13/222 patients, 11 of whom were taken to the operating room for wound revision, 2 were oversewn at the bedside; pseudomeningocele was noted in 9/222 patients; local wound infection was documented in 7/222 patients, but none had meningitis; complication rates for CSF leakage, pseudomeningocele formation, and local wound infection were 5.9%, 4.1%, and 3.2%, there were no permanent neurological consequences due to these complications; univariate analysis was used to correlate different variables with the occurrence of CSF leakage and/or pseudomeningocele formation Subgroup: Age,Technique,Presentation,NA None of the independent variables, including age reached statistical significance. None of the independent variables (use of microscope, use of dural sealant) reached statistical significance. None of the independent variables (no. of episodes, operating time) reached statistical significance.

Fekete, 2019[70] Trial ID NA Cohort study N = 91 Hungary Sites: NA Setting: N/A	**Study population:** Patients with tethered spinal cord, underlying pathologies: resection of intraspinal lipoma; transection of a specific bundle; scar tissue release; scar tissue release with lipoma resection; dyastematomyelia; epidermoid tumour resection; dermoid tumour resection; meningicele reconstruction **Comorbidity:** NA **Female:** 49% **Age mean:** Mean: 8.44; Range: 0-59.43 Min age: Max age: **Age subgroup**: Mixed age sample **Ethnicity:** N/A **Indication**: Mixed sample **Retethering:** Mix	**Intervention:** Other Intraoperative electrophysiological monitoring during surgical untethering **Control:** Other Surgical detethering without intraoperative electrophysiological monitoring **Comparator:** NA **Comparator 2:** NA	Neurological progression Neurological progression was significantly lower in the intra-operative monitoring group (11.3% vs 30.8%, p 0.03341). Improvement was present in 13.9%: in the monitoring group and 18.9% and in the control group (p 0.06995). Progression-free follow-up was 82.3%, significantly better with electrophysiology (88.7% vs 69.2%, p 0.03341). Surgery-related complication rate The permanent surgery-related complication rate was 2.9% in the intra-operative monitoring group and 9.4% in the control group (p < 0.001). The electrophysiological group was associated with significantly lower rates of reoperation (8.6% vs 23.8%, p 0.02567). Subgroup: NA
Hayashi, 2018[71] Cohort study N = 88 Japan Sites: 1 Setting: Inpatient	**Study population:** 49 pediatric patients received interlaminar approach between 2007-2012 and were diagnosed with film terminals lipoma based on MRI studies; 38 patients were in control group who received standard one level laminectomy/laminotomy up until 2007 **Other population:** N/A **Comorbidity:** Anorectal malformation,Other : Filum lipoma **Female:** 47% **Age mean:** interlaminar approach group: 2.9 (3.2); laminectomy/laminotomy group: 2.0 (2.8) Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** Other : Study was conducted in Japan, but no report of race/ethnicity **Indication**: Mixed sample **Retethering:** NA	**Intervention:** Other Surgical untethering, minimally invasive surgical approach to filum terminals lipoma sectioning, interlaminar approach: minimal skin incision to expose the unilateral ligamentum flavum in the lower lumbar region; ligamentum flavum incision to expose the dural sac, and dural incision followed by identification and sectioning of the filum; postoperatively, no bed rest was required **Control:** TAU Standard one level laminectomy/laminotomy with more than 1 week of postsurgical bed rest **Comparator:** NA N/A **Comparator 2:** NA **Follow-up:** 60 weeks	Walking independently All cases can walk independently. Postsurgical pain All patients who underwent interlaminar approach complained of minimal postsurgical back pain, but none of them were confined to bed rest postoperatively, while patients who underwent laminectomy/laminotomy need bed rest for several days because of postsurgical back pain. Surgical complications Surgical complications that need additional surgical procedure were seen only in one patient who developed CSF leak in the early postoperative period that need repair of dural sac in LL patients. No retethering or additional neurological symptoms were seen during follow-up in both groups (ILA group: range, 60–121 months; mean, 88.8 ± 20.5 months, LL group: range 116–160 months; mean 137.5 ± 13.4 months). All patients remained stable or showed improvement of preoperative symptoms in the follow-up period. Total hospital stays of the patients who underwent ILA and LL was 8.1 ± 2.1 days (range, 3–10 days) and 10.9 days ±

			2.2 days (range, 8–20 days). There was a statistically significant difference in the hospital stays between both groups (P < 0.001). Subgroup: NA
Jiang, 2019[72] Trial ID NA Cohort study N = 100 China Sites: 1 Setting: Inpatient	**Study population:** Children aged between 3 months and 12 years who exhibit symptoms of tethered cord, including neurological, urinary, and bowel abnormalities, along with additional malformations such as spina bifida, hydronephrosis, hydromyelia, and diastematomyelia, had their diagnosis clinically and radiologically (MRI+CT) confirmed by a neuroradiologist and a neurosurgeon **Comorbidity:** Spina bifida,Other : Hydrops of upper urinary tract, congenital hip dislocation, hydromyelia, diastematomyelia **Female:** 44% **Age mean:** Monitoring mean: 9.2 years (range 3 months to 12 years); No monitoring mean: 8.4 years (range: 3 months to 12 years) Min age: 0 Max age: 12 **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Symptomatic **Retethering:** NA	**Intervention:** Other Tethered spinal cord release with intra-operative neurophysiological monitoring; anesthesia administered with propofol with an initial dose of 2.0 mg/kg of propofol, followed by maintenance controlled at 8 mg/kg/h, and the surgical procedure involves carefully exposing the spinal structures, dissecting the dura mater, removing a lipoma through cavitron ultrasonic surgical aspirator, addressing tissue adhesions, and closing the wound layer by layer, with continuing monitoring of neurophysiological parameters (motor-evoked potentials, sensory-evoked potentials, and nerve conduction velocities) during surgery, and postoperative administration of prophylactic antibiotics for 3-5 days **Control:** Other Tethered spinal cord release without intra-operative monitoring **Comparator:** NA **Comparator 2:** NA **Follow-up:** Mean: 29; range: 6-60 weeks	Complete recovery or significant improvement More children in the monitoring group (76%) achieved complete recovery or significant improvement than those in the no monitoring group (54%), P < 0.05. More children in monitoring group (39, 80%) achieved total release than no monitoring group (36, 71%). New complications Fewer new complications were found in the monitoring (18%) than the no monitoring group (37%), P < 0.05). Subgroup: Unclear

Kanematsu, 2020[73] Trial ID NA Cohort study N = 313 Japan Sites: 1 Setting: Inpatient	**Study population:** Patients at a single institution who underwent untethering/sectioning of a tight filum terminale and fatty filum **Other population:** **Comorbidity:** Fatty filum **Female:** % **Age mean:** 72 hour group mean: 26.7 month (range: 3-138), 0 hour group mean: 21.8 month (range: 3-144) Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Mixed sample **Retethering:** NA	**Intervention:** Other Horizontal decubitus position for 72 hours following transection of a tight filum terminale, one-level laminectomy at L-4 in younger patients or partial laminectomy of lowerL-4 and upper L-5 in older patients **Control:** NA **Comparator:** Other Not in horizontal decubitus position following transection of a tight filum terminale, one-level laminectomy at L-4 in younger patients or partial laminectomy of lowerL-4 and upper L-5 in older patients **Comparator 2:** NA	Overall postoperative complications Maintaining patients without restriction of their position does not change the rate of postoperative leakage (0/144 vs 1/169, n.s.), pseudomeningocele (1/144 vs 1/169, n.s.), in group B, one patient had CSF leakage the day after the operation (patient was maintained in the prone position until the day after suture removal and no CSF leakage was observed after this time); the rate of overall complications was 0.7% vs 1.2%. Subgroup: NA
Lalgudi, 2021[74] Cohort study N = 80 Multiple countries Switzerland & Israel Sites: multiple Setting: Inpatient	**Study population:** Children aged 0 to 18 years who received treatment for the release of Filum terminale lipomas **Comorbidity:** Other : VACTER/Curarino **Female:** 55% **Age mean:** 38.15 (51.15) Min age: 0 Max age: 18 **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Mixed sample **Retethering:** NA	**Intervention:** Other In surgery procedure without intra-operative neuromonitoring, patients were placed prone and underwent laminectomy at the lowest feasible level to avoid nerve roots and the conus, followed by midline durotomy under microscopic view to identify and separate the filum terminale lipomas, ensuring no ventrally attached nerve roots by flipping the filum terminale lipomas, and then untethered through a 'cauterise—cut' technique, with the dura and other layers closed in a water-tight manner **Control:** TAU Surgery without intraoperative neuromonitoring	Stable neurological outcome Neurological outcome was stable at short-term and long-term folow up in the entire cohort. Neurological morbidity There was no neurological morbidity associated with surgery. The intraoperative monitoring was not associated with any complications. Need for repeat surgery None of the patients required repeat surgery during the follow up. Subgroup: NA

		Comparator: Surgical detethering **Comparator 2:** NA **Follow-up:** 48 weeks	
Ogiwara, 2015[61] Trial ID NA Cohort study N = 354 Japan Sites: 1 Setting: Inpatient	**Study population:** Patients diagnosed with tethered cord syndrome, either clinically with neurological symptoms or through MRI radiology, exhibited either a low-lying conus (below the caudal edge of L-2) or a conus in its usual position, 18% were asymptomatic **Other population:** Symptomatic patients diagnosed with tethered cord syndrome, either clinically with neurological symptoms or through MRI radiology, exhibited either a low-lying conus (below the caudal edge of L-2) or a conus in its usual position **Comorbidity:** Fatty filum **Female:** 32.8% **Age mean:** 72 hr group: 43 months (range 3-226 months); 8 day group: 27 months (range 3-138 months) Min age: Max age: **Age subgroup**: Mixed age sample **Ethnicity:** N/A **Indication**: Mixed sample **Retethering:** NA	**Intervention:** Other Postoperative flat bed rest for 72 hours after untethering the spinal cord using intraoperative monitoring, closing the dura primarily with 4–0 Neurolon and interlocking stitches, and then closing the muscles with sutures **Control:** NA **Comparator:** Other Postoperative flat bed rest for 8 days after untethering the spinal cord using intraoperative monitoring, closing the dura primarily with 4–0 Neurolon and interlocking stitches, and then closing the muscles with sutures **Comparator 2:** NA **Follow-up:** 92 weeks	Postoperative complications None of the asymptomatic or symptomatic patients developed a CSF leak. Pseudomeningocele, which was confirmed by MRI, developed in 1 patient who had been kept flat for 8 days (unclear whether this was a symptomatic or asymptomatic patient). No intraoperative complications across asymptomatic or symptomatic patients and both treatment groups. Subgroup: NA
Pan, 2023[75] Cohort study N = 340 US Sites: multiple Setting: Inpatient	**Study population:** Patients with tethered spinal cord syndrome and secondary retethering after pediatric tethered cord release surgery **Other population:** **Comorbidity:** Lipomyelomeningocele,Other : Dermal sinus, lipoma, **Female:** % **Age mean:** Mean age 70.7 months Min age: Max age: **Age subgroup**: Age unclear **Ethnicity:** N/A **Indication**: Symptomatic	**Intervention:** Other Detethering with operative microscope and intraoperative neuromonitoring, with simple tethered cord release cases undergoing primary closure and complex cases involving skin or muscle flaps, along with potential lumbar drain placement; simple tethered cord release patients lay flat for ony 1 night and were dischaged the next day, patients who underwent complex tethered cord release	Complications, 60 days For simple tethered cord release cases, there was no significant increase in total 60-day complication rates. The mean hospital length of stay was shorter after the practice change (1.71 vs 3.88 days, p<0.001), as expected by shortening the number of days the patient was required to lie flat. For complex tethered cord release, lumbar drain placement rates were significantly higher (64.4% vs 9.5%, p <0.001). However, despite more aggressive lumbar drainage, the overall hospital length of stay was not significantly affected (p 0.487). There were no significant differences in the total 60-day complication rate (p 0.461).

	Retethering: Mix	had routine placement of lumbar drains if technically feasible with most cases involving duraplasties and patients without prior cerebrospinal fluid diversion; postoperative management was determined by the treating surgeon's discretion **Control:** NA **Comparator:** Surgical detethering Detethering with operative microscope and intraoperative neuromonitoring, with simple tethered cord release cases undergoing primary closure and complex cases involving skin or muscle flaps, along with potential lumbar drain placement, followed by 72 hour **Comparator 2:** NA **Follow-up:** 2 weeks	Subgroup: Presentation,NA There were no significant differences in the total 60-day complication rate (p 0.461) for simple versus complex tethered cord release.
Shahjouei, 2016[76] NCT01867268 RCT N = 161 Iran Sites: 1 Setting: Inpatient	**Study population:** Children undergoing untethering surgery **Female:** 55.9% **Age mean:** Mean: 1146.5 (1385.6) days Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Mixed sample **Retethering:** NA	**Intervention:** Other Acetazolamide administration and prone positioning for 10 days after surgery, routine protocol of wound care; operative sites were cleaned with Povidone-iodine and a compressive dressing was applied daily, acetazolamide administration for 10 days **Control:** No intervention Routine protocol of wound care only; operative sites were cleaned with Povidone-iodine and a compressive dressing was applied daily **Comparator:** Other Acetazolamide administration for 10 days only, routine	Postoperative complications CSF leakage and collection rates were significantly lower in patients who underwent prone positioning (p 0.042 and 0.036). The administration of acetazolamide, either isolated or in combination with prone positioning, not only could not significantly lower the complication rates, but also added the burden of side effects. The analyses of complications through each intervention group (A–D) yielded a borderline difference in CSF leak and significant difference in CSF collection rates among categories of intervention (p = 0.06 and 0.02, respectively). Rates of complications in patients taking acetazolamide were not significantly different from others. Among all those who received acetazolamide, 2 (2.56%) patients experienced diarrhea without bacteria growth in stool examination, 3 (3.84%) had acidosis, 2 (2.56%) experienced electrolyte imbalance, and

		protocol of wound care; operative sites were cleaned with Povidone-iodine and a compressive dressing was applied daily **Comparator 2:** Other Prone positioning for 10 days after surgery, routine protocol of wound care; operative sites were cleaned with Povidone-iodine and a compressive dressing was applied daily **Follow-up:** 0.33 weeks	4 (5.12%) had loss of appetite. One patient needed admission to the intensive care unit due to severe acidosis and electrolyte imbalance. Applying both modalities (prone positioning and acetazolamide administration) simultaneously did not mitigate the rate of complications Subgroup: Age,Presentation No correlation between target outcomes and age No correlation between target outcomes and sex, weight, or indications for surgery
Udayakumaran, 2018[77] Trial ID NA Cohort study N = 25 India Sites: 1 Setting: N/A	**Study population:** Patients who underwent surgery for TCS and a CSF leak or significant pseudomeningocele within the first 30 days after surgery **Comorbidity:** Other : CSF leak; pseudomeningocele **Female:** 52% **Age mean:** Range: 10 days - 4 years Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Symptomatic **Retethering:** NA	**Intervention:** Other Cystoperitoneal shunt for cerebrospinal fluid leak; patient is placed lateral, strapped well, to access the abdomen for the peritoneal tube insertion by tilting the table; the implant used for CPS is a valveless lumboperitoneal shunt, the thecal end of the shunt implant is placed in the pseudomeningocele and the distal end into the peritoneal cavity; a flank incision is used to access the pseudomeningocele, using a Tuohy needle and also to pass a tunneler towards the abdomen for the insertion of the peritoneal end; using a flank incision gives the advantage of being away from the macerated leaking wound and allows simultaneous tunneling towards the abdomen; a second incision on the abdominal wall leads the catheter into the peritoneum; the tubes are connected in the flank and fixed to the	Cerebropsinal fluid leak and complications CPS treatment successfully resolved all CSF leaks or pseudomeningocele without any secondary complications, the implant was removed after 3 months and no patients experienced leak development after CPS removal; 5 patients who underwent primary wound revision experienced a leak and required asecondary intervention, but none of the patients who underwent CPS had any complications. Subgroup: NA

		subcutaneous tissue with silk 2.0 suture; because this is a low-pressure system, CSF is diverted passively, and no valve other than the peritoneal slit-valve is used; after a thorough rinse with antibiotic solution, the wounds are closed; antibiotics are used preoperatively until CSF culture results are obtained; after at least 3 months, the implant is electively removed **Control:** NA **Comparator:** Other surgery Primarywound revision for cerebrospinal fluid leak **Comparator 2:** NA	
Abdallah, 2018[78] Cohort study N = 25 Turkey Sites: 1 Setting: Inpatient	**Study population:** Randomly selected adult cases of congenital tethered cord syndrome treated at the department of neurosurgery **Comorbidity:** NA **Female:** 64% **Age mean:** 30.1 (10.3) Min age: 18 Max age: 61 **Age subgroup**: Adults **Ethnicity:** N/A **Indication**: NA **Retethering:** NA	**Intervention:** Other surgery Hemilaminectomy **Control:** NA **Comparator:** Surgical detethering Laminectomy **Comparator 2:** Surgical detethering Laminotomy	Laminoplasty leads to mean hospital stay of 3.9 ± 2.2 (28) days. This is shorter than the hospital stay related to hemilaminectomy and laminectomy approaches which led to meanstays of 4 ± 2.2 (2–7) and 6.4 ± 3.3 (3–12) days,
Byrne, 1995[62] Trial ID NA Cohort study N = 100 US Sites: multiple Setting: Inpatient	**Study population:** Patients who are asymptomatic with lumbosacral skin lesions and congenital anomalies **Other population:** Patients who experienced neurological and urological symptoms, along with orthopedic abnormalities and skin lesions, received a confirmed diagnosis through various diagnostic methods such as myelography, computed tomography, CT/myelography, ultrasound, an	**Intervention:** Other surgery Untethering with laser resection of lipoma or untethering without laser; the goal of these primary procedures was spinal cord untethering and debulking of the lipoma but not necessarily a complete resection of the lipoma **Control:** NA	Motor, urologic or orthopedic symptoms No asymptomatic infant deteriorated postoperatively and 93% of these children remained symptom-free at follow-up (mean follow-up was 44 months). Of the infants that presented with motor, urologic or orthopedic symptoms, 39% improved, 58% stabilized, whil Deterioration No asymptomatic infant deteriorated postoperatively and 93% of these children

	Comorbidity: Lipomyelomeningocele **Female:** 55% **Age mean:** mean 0.33 Min age: 0 Max age: 1 **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Mixed sample **Retethering:** NA	**Comparator:** Other Cosmetic procedures in which the lipoma was debulked but no attempt was made to resect the lipoma to the interface between the lipoma and the neural tissue, thereby untethering the spinal cord **Comparator 2:** NA **Follow-up:** 60 weeks	remained symptom-free at follow-up (mean follow-up was 44 months). Of the infants that presented with motor, urologic or orthopedic symptoms, 39% improved, 58% stabilized, while 3% worsened as a result of surgery. If a spinal lipoma is detected, a dethering of the spinal cord and debulking of the lipoma should be performed (prompt surgery is recommended since there is considerably more risk in waiting for the infant to become progressively symptomatic than there is in performing a spinal cord untethering). Postoperative complications There were no cases of abscess formation or meningitis. Early postoperative complications occurred in 16% across symptompatic and asymptomatic infants. These consisted of CSF leaks and superficial wound infections. All complications were treated successfully. All 12 children who had an initial cosmetic procedure all required a second operation for symptomatic cord tethering. Subgroup: NA
Caldarelli, 1995[79] Trial ID NA Cohort study N = 72 Italy Sites: multiple Setting: Inpatient	**Study population:** Myelodysplastic children who showed worsening neurological symptoms after myelomeningocele repair: 26 **Comorbidity:** Other : Chiari II malfolrnation, Hydrocephalus, Hydro/syringomyelia **Female:** 50% **Age mean:** Min age: 1 Max age: 9 **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Mixed sample **Retethering:** NA	**Intervention:** Other surgery Surgical treatment, including correcting associated anomalies, revising malfunctioning CSF shunts, draining hydromyelia cavities, and performing posterior fossa decompression for symptomatic Chiari II malformation, and untethering of the conus medullaris and spinal cord, involving re-opening the previous surgical scar, separating the conus and spinal cord from the dura, and dividing arachnoid adhesions **Control:** No intervention No surgical procedures after myelomeningocele repair for	Improvement of clinical picture Eleven children underwent detethering of the fixed conus with an improvement of their clinical picture from mild to good, the remaining 11 subjects improved following the correction of the associated abnormalities (malfunctioning CSF shunt: 5 cases; hydromyelia: 4 cases; symptomatic Chiari II malformation: 2 cases). Subgroup: NA

		myelodysplastic children who did not display any neurological deterioration and had routine MRI scans as part of the follow-up care **Comparator:** NA **Comparator 2:** NA **Follow-up:** 95 weeks	
Erkan, 1999[80] Trial ID NA Cohort study N = 132 Turkey Sites: 1 Setting: Inpatient	**Study population:** A total of 132 patients with 32 having both tethered cord syndrome and terminal syringomyelia, characterized by conditions such as thick filum terminale, lumbosacral lipomas, diastematomyelia, and repaired lipomyelomeningocele and 100 patients who presented only with tethered cord syndrome. All patients exhibited a spectrum of associated symptoms, including neurological issues, urinary problems, bowel dysfunction, and scoliosis based on CT scans, MRIs, as well as results from urodynamic studies (cystometric, uroflowmetric, and electromyographic exams) **Comorbidity:** Fatty filum,Scoliosis,Other : Lumbosacral lipomas, diastematomyelia **Female:** % **Age mean:** Range: 4 months to 82 years Min age: 1 Max age: 82 **Age subgroup**: Mixed age sample **Ethnicity:** N/A **Indication**: Symptomatic **Retethering:** NA	**Intervention:** Other surgery Combined untethering plus concurrent syrinx drainage; release of the tethered spinal cord was followed by additional procedures to address the syrinx problem, randomly terminal ventriculostomy was performed when the syrinx extended to the conus, while dorsal midline myelotomy was chosen to facilitate syrinx drainage; a multiseptated syrinx, syringosubarachnoid shunting was employed, involving the insertion of a silastic T-tube to facilitate drainage into the rostral subarachnoid space **Control:** Other Simple untethering of the spinal cord **Comparator:** NA **Comparator 2:** NA **Follow-up:** Mean: 36; range: 9-72 weeks	Neurological deficits The better clinical outcomes observed after successful syrinx drainage emphasized the importance of recognition and treatment of the associated syrinx Subgroup: NA
Erkan, 2000[81] Trial ID NA RCT N = 30 Turkey Sites: 1	**Study population:** Patients presenting with tethered spinal cord conditions attributed to thick filum terminale, diastematomyelia, and terminal lipoma, as determined by CT and MRI scans; they also exhibited severe neurological symptoms and experienced dysfunction in urinary and bowel control, which was assessed through urodynamic	**Intervention:** Other surgery Combing detethering with with syrinx decompression; primary untethering of spinal cord surgery with drainage approach, classical terminal ventriculostomy for syrinx extending to the conus	Clinical follow-up evaluation revealed that surgical drainage of the syrinx, when combined with spinal cord untethering, resulted in better outcomes in terms of resolution of sensory deficits (p = 0.036) and bladder dysfunction (p =0.05). The improvement in clinical outcome correlated with the radiologically documented resolution of the syrinxcavity; however,

Setting: Inpatient	studies, including cystometrography, uroflowmetry, and pelvic electromyography **Comorbidity:** Fatty filum,Lipomyelomeningocele,Other : Congenital vertebral anomalies, diastematomyelia, terminal lipoma **Female:** 63% **Age mean:** 6.2 (4.4) Min age: 1 Max age: 16 **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Symptomatic **Retethering:** First time	medullaris, while simple drainage through dorsal midline myelotomy for segmental unilocular thoracic cavities with maximal cyst dilation **Control:** Other Standard untethering compared to the same procedure using Syrinx drainage **Comparator:** Surgical detethering Dividing the thickened fatty filum terminale through a focused laminectomy, and if needed, excising any lesions like bony spurs or terminal lipomas; additionally, the procedure included dissecting arachnoidal adhesions to restore a patent and roomy thecal **Comparator 2:** **Follow-up:** 12 weeks	response rates of symptoms differed for each tethering subgroup. Subgroup: Technique Patients with tethered cords due to thick filum terminale , diastematomyelia, and previously operated lipomyelomeningocele with reduced syrinx size experienced improvement compared to unchanged syrinx size
Hoffman, 1985[82] Cohort study N = 97 Canada Sites: multiple Setting: Inpatient	**Study population:** Patients presented with cosmetic concerns or neurological symptoms like urinary incontinence and leg weakness, and underwent surgical treatment for lipomyelomeningoceles **Comorbidity:** Fatty filum,Lipomyelomeningocele,Scoliosis **Female:** 61% **Age mean:** Min age: 0 Max age: 18 **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Symptomatic **Retethering:** First time	**Intervention:** Other surgery Detethering of the spinal cord, both from the overlying fatty connection to the skin and the dura; a thickened ilium must be divided or an associated diastematomyelia repaired; the dura must be closed and yet adequate space left for neural tissue and any remaining fat, which usually rquires a dural graft; lipomyelomeningocele patients first received diagnostic myelographic or CT metrizamide myelography to identify the extent of intraspinal lipoma and associated CNS abnormalities, followed by	Deterioration from inially grade 0 Following appropriate repair, there was no significant deterioration and several patients improved in function. 50% of patients had a preoperative grade of 0, but only 8% remains in grade 0. Surgical complications 3/97 patients devoloped temporary leakage of CSF into the subcutaneous tissues leading to formation of a pseudomeningocele (successfully managed), 2/97 patients developed a superficial wound infection (responded to antibiotic therapy); treatment group unclear. Subgroup: NA

		surgical repair involving magnification, dural opening, and lipoma removal, and concluded with dural sac reconstruction using graft materials to facilitate cerebrospinal fluid flow and prevent adhesions **Control:** NA **Comparator:** Other surgery Cosmetic repair without conus untethered and dura freed or patients with associated lesions such as distematomyelia or epidermoid cysts that were not recognized and treated **Comparator 2:** NA **Follow-up:** 48 weeks	
Jun , 2016[83] Cohort study N = 82 China Sites: multiple Setting: Inpatient	**Study population:** Adult patients, aged between 18 and 47 years, experiencing symptoms of tethered cord syndrome **Comorbidity:** Other : Simple filum terminal thickening, lipoma, dermoid, epidermoid cyst **Female:** 59% **Age mean:** Min age: 18 Max age: 47 **Age subgroup**: Adults **Ethnicity:** N/A **Indication**: Symptomatic **Retethering:** NA	**Intervention:** Other surgery Complete release of tethered spinal cord, patients underwent surgery with general anesthesia and prone positioning, involving neural electrophysiological monitoring, varied incisions, exposure and removal of tumors, and closure techniques; for cases with subcutaneous giant lipomas, tumor removal, drainage tube placement, pressurized dressing, and vacuum aspiration were performed in the lumbosacral region **Control:** NA No release of tethered spinal cord, patients underwent surgery with general anesthesia and prone positioning, involving neural electrophysiological	Bladder dysfunction improvement The effective rate for bladder dysfunction was 86% for complete release, 33% for no release, and 50% for partial release. The effective rate for defecation dysfunction was 93% for complete release, 33% for no release, and 57% for partial release. Motor dysfunction Effective rate were 78% for complete release, 33% for no release, and 60% for partial release. Postoperative complications 5% with spinal fluid leakage, 2 patients were cured following vacuum aspiration and pressurized dressing; 7% showing delayed wound healing mainly caused by spinal fluid leakage or fat liquefaction; no case of infection or new onset of nerve injury. No second tethered cord syndrome. Subgroup: NA

		monitoring, varied incisions, exposure and removal of tumors, and closure techniques; for cases with subcut **Comparator:** NA Partial release of tethered spinal cord, patients underwent surgery with general anesthesia and prone positioning, involving neural electrophysiological monitoring, varied incisions, exposure and removal of tumors, and closure techniques; for cases with s **Comparator 2:** NA **Follow-up:** 30 weeks	
Kunes, 2022[84] Trial ID NA Cohort study N = 38 US Sites: multiple Setting: Other	**Study population:** Patients diagnosed with tethered cord and scoliosis, as confirmed by MRI, and with an average patient age ranging from 5 to 7 years at the time of spinal deformity correction **Comorbidity:** Fatty filum,Lipomyelomeningocele,Other : low lying conus **Female:** 57.9% **Age mean:** NA Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Symptomatic **Retethering:** NA	**Intervention:** Other surgery Simultaneous detethering and spinal and deformity correction surgery on the same day under a single anesthesia event **Control:** NA **Comparator:** Surgical detethering Staged approach separated surgeries: detethering and spinal and deformity correction surgery into two separate surgeries **Comparator 2:** Other The combined surgeries approach demonstrated a lower incidence of complications or no significant difference in complications compared to the staged approach **Follow-up:** 6 weeks	Within 90 days postoperatively, 16 complications in 11 patients (44.0%) occurred in the staged group, whereas no complications occurred in the simultaneous cohort ($p = 0.006$). From 90-days to 180-days postoperatively, 4 additional complications in 3 patients (12.0%) occurred in the staged group, with no complications reported in the same timeframe for the simultaneous cohort. Subgroup: NA

Mehta, 2010[85] N/A Cohort study N = 54 US Sites: 1 Setting: Inpatient	**Study population:** Patients who experienced symptomatic tethering following an initial repair of myelomeningocele repair were identified from an original pool of patients who underwent first-time untethering due to any tethered cord syndrome cause **Other population:** N/A **Comorbidity:** Scoliosis,Other : Duraplasty **Female:** 56% **Age mean:** 10.3 (4.9) Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Symptomatic **Retethering:** First time	**Intervention:** Other surgery Duraplasty surgery spinal cord tethering following myelomeningocele repair **Control:** NA **Comparator:** NA Primary dural repair spinal cord tethering following myelomeningocele repair **Comparator 2:** NA **Follow-up:** 47 weeks	Bowel/bladder dysfunction The mean time to improvement in symptoms was 3.5 months for urinary dysfunction across duraplasty and nonduraplasty procedures. Stabilization of preoperative urinary symptoms was observed in 76%, with 17% experiencing improvement and 7% experiencing worse Motor function Improvement in motor function was reported in 26%, with maintenance or worsening in 62% and 11% across duraplasty and nonduraplasty procedures. Pain / pain improvement The mean time to improvement in symptoms for pain relief was 3.21 months across duraplasty and nonduraplasty procedures. Pain improvement was observed in 28% of patients, maintenance of preoperative state in 65%, and worsening in 7%. Retethering Symptomatic retethering occurred in 17 (31%) of 54 patients at a mean of 51 ± 33 months (range 10–133 months). Retethering was observed in 8 (36%) of 22 patients who underwent primary dural closure, and 9 (28%) of 32 who underwent closure with a dural gra Complications No significant difference in retethering-free survival based on type of dural closure Subgroup: Age,Presentation The average patient age at the time of surgery was not significantly different in those who experienced retethering (9.26 years) compared with those who did not undergo retethering (10.66 years; p 0.345). There was no significant difference in preoperative symptom duration in patients who experienced retethering (6.94 months) compared with those who did not undergo retethering (7.21 months; p 0.877).

Mehta, 2011[86] Trial ID NA Cohort study N = 36 US Sites: 1 Setting: Inpatient	**Study population:** Patients with tethered cord associated scoliosis and/or kyphosis; patients who underwent a concurrent pediatric spinal cord deformity correction and tethered cord release (single-staged approach) were considered to be high-risk subgroup based on evidence of rapid deformity progression and/or curves >40 degrees **Comorbidity:** Scoliosis,Other : Kyphosis **Female:** 66.6% **Age mean:** Mean: 9.6 (range 1-15) Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Symptomatic **Retethering:** Mix	**Intervention:** Other surgery Concurrent pediatric spinal cord deformity correction and tethered cord release (single-staged approach) **Control:** NA **Comparator:** Other Untethering surgery followed by a staged scoliosis correction (two-staged approach) **Comparator 2:** NA	AE One-stage vs 2-stage: dural tear 0%, 9.5% (p < 0.041); cerebrospinal fluid leak 0%, 0% (ns); New postoperative neurologic deficit 0%, 19% (p<0.022); persistent postoperative deficit (>1 month) 0%, 4.8% (p<0.038); wound infection 0%, 26.3% (p < 0.006); wound dehiscence 0%, 14.3% (p<0.009). Percent retethered One-stage patients vs two-stage patients (0% vs 9.5%, p<0.041). Deformity correction (kyphosis) one-stage 27% vs two-stage 21% (ns); requiring revision fusion one-stage 7%, two-stage 9.50% (ns) Subgroup: NA
Oda, 2012[87] Trial ID NA Cohort study N = 10 US Sites: 1 Setting: Inpatient	**Study population:** Patients with a diagnosis of progressive early onset scoliosis (congenital, infantile, juvenile) and preoperative MRI scan documenting a tethered cord; patients with neural axis abnormalities (i.e., concomitant syringomyelia, Chiari malformation, diastematomyelia, or tumor) or the absence of distalneurological function (i.e., myelomeningocele) were excluded **Comorbidity:** Scoliosis **Female:** % **Age mean:** Study group mean: 5.7; Control group mean: 6.1 Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: NA **Retethering:** NA	**Intervention:** Other surgery Concurrent tethered cord release and growing-rod insertion; in the prone positionon a radiolucent Jackson table over gel bolsters to allow the belly to hang freely; neurophysiological monitoring modalities employed included somatosensory evoked potentials, motor evoked potentials, and triggered electromyography stimulation of neural elements and pedicle screws; fine needle electrodes were placed in bilateral upper- and lower-extremity musculature; anal sphincter fine needle leads also were placed to monitor sacral nerve root integrity; anesthetized intravenously, preoperative antibiotics; cord exploration and release were performed	No adverse neurological events. Subgroup: NA

		first by a pediatric neurosurgeon via an L5 or S1 laminectomy; care was taken to minimize damage to the posterior vertebral structures, including the facet joints and interspinous ligament; the dura was opened, and the nerve roots and the thickened filum terminale were identified; triggered EMG to differentiate the fibrous cord tether from the surrounding nerve roots, spinal cord was noted to be under tension with a distinct fibrous tether; once the fibrous cord was identified, it was cut, and the dura was closed; dual submuscular growing-rod instrumentation was then placed by a pediatric orthopedic surgeon. Initial distraction of the growing-rod construct was performed gradually, over at least 10 minutes, under constant neurological surveillance; distraction was not forceful, and did not attempt maximal correction of the scoliosis; patients were extubated immediately postoperatively and were admitted to the pediatric intensive care unit overnight for monitoring; all patients were allowed to be weightbearing as tolerated and encouraged to be out of bed as much as possible; the use of a postoperative brace was left to the operating surgeon's discretion **Control:** NA	

		Comparator: Surgical detethering Staged tethered cord release and growing rod instrumentation insertion **Comparator 2:** NA	
Samuels, 2009[88] Trial ID NA Cohort study N = 110 US Sites: 1 Setting: Inpatient	**Study population:** Children (<18 years old) with cases of first-time release of a symptomatic tethered cord who underwent untethering after they had failed conservative management of symptoms in the setting of a radiographically confirmed tethered cord, including symptoms of motor or urinary dysfunction, pain, or scoliotic progression. 26 patients were neurologically asymptomatic infants (less than 2 years of age), who had demonstrated either radiological evidence of cord tethering, worsening scoliosis, or abnormal urodynamic results and for whom it was determined appropriate to receive a preventative untethering procedure by the attending surgeon **Comorbidity:** NA **Female:** 63% **Age mean:** 5.7 (4.8) Duraplasty: 5.9 (4.7), Non-duraplasty: 5.6 (4.9) Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Mixed sample **Retethering:** First time	**Intervention:** Other surgery Duraplasty in the surgical detethering operation **Control:** NA **Comparator:** Surgical detethering Primary dural closure/non-duraplasty in surgical detethering operation **Comparator 2:** NA	Surgical site infection Incidence of postoperative CSF leak, surgical site infection, or median [IQR] length of stay were similar in patients receiving primary dural closure [5%),9%, 4–6] days vs duraplasty (9%, 9%, 5–8 days; p>0.05) Symptomatic retethering Twenty-nine (26%) patients had symptomatic retethering a median postoperatively, 41% had received a duraplasty, 59% primary dural closure (p=0.19). There was no difference in median [IQR] time to retethering after duraplasty (25 [23–26] months postoperati Subgroup: Presentation Patients presenting with a postmyelomeningocele repair demonstrated a statically significant higher likelihood of duraplasty use (p 0.0026), while fatty filum cases more frequently received primary dural closure (p 0.015); Of the cases of symptomatic rete
Strong, 2015[89] Trial ID NA Cohort study N = 248 US Sites: 1 Setting: Inpatient	**Study population:** Consecutive patients undergoing tethered cord release by filum terminale transection at a single academic pediatric hospital; patients with more complex forms of tethered spinal cord, such as myelomeningocele, lipomyelomeningocele, and meningocele, and patients with incomplete records were excluded **Comorbidity:** NA	**Intervention:** Other surgery Tethered cord release by filum terminale transection using laminotomy **Control:** NA **Comparator:** Surgical detethering	Improvement of pre-operative symptoms 97.1% of patients demonstrated clinical improvement (defined as an improvement in the presenting symptom(s) with no difference between operative techniques (p 0.183). 3.6% patients experienced complications, there was no association between surgical revision and operative technique (p 0.174). 5/9 patients who experienced complications underwent revision surgery for repair of CSF leak (n=2) or

	Female: 54.4% **Age mean:** Mean: 5.2 Min age: 0.3 Max age: 16.8 **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Mixed sample **Retethering:** NA	Tethered cord release by filum terminale transection using laminoplasty **Comparator 2:** NA **Follow-up:** 3 weeks	surgical management of suprafascial infection (n=3); there was no association between surgical revision and operative technique (p 0.174). Subgroup: Age,Technique,Presentation A multiple logistical regression including age with the incidence of post-operative complications; none of the independent variables reached statistical significance A multiple logistical regression including surgical technique, bed rest, and length of stay with the incidence of post-operative complications; none of the independent variables reached statistical significance A multiple logistical regression including sex, conus level, MR imaging variables, with the incidence of post-operative complications; none of the independent variables reached statistical significance
Tao, 2019[90] Trial ID NA Cohort study N = 41 China Sites: 1 Setting: Inpatient	**Study population:** Patients diagnosed with congenital scoliosis and tethered cord syndrome based on CT scans revealing a conus medullaris position below the L2 level, or an MRI showing a filum terminale diameter exceeding 2 mm, with confirmation provided by 2 experienced spine surgeons, some patients were asymptomatic **Other population:** N/A **Comorbidity:** Scoliosis **Female:** 73% **Age mean:** NA Min age: Max age: **Age subgroup**: Age unclear **Ethnicity:** N/A **Indication**: Asymptomatic **Retethering:** NA	**Intervention:** Other surgery Spinal deformity correction without prophylactic intradural detethering; posterior Spinal Fusion for moderate curves with intact neurological status, Pedicle Subtraction Osteotomy for neurological symptoms with smaller curves, and Vertebral Column Resection for severe curves or limited flexibility with or without neurological symptoms) all performed by a single senior surgeon under general anesthesia with meticulous pedicle screw placement, laminectomy, facet excision, osteotomy, lateral vertebral body wall removal, and subsequent correction using an in situ bender followed by spinal fusion with bone graft, while closely monitoring somatosensory-evoked and motor-evoked	Neurological symptoms 0/15 patients in posterior spinal fusion group had neurological symptoms preoperatively and there were no post-operative neurological changes during mean follow up of 47 months. All patients with neurological symptoms in the posterior spinal fusion and pedicle subtraction osteotomy group improved to varying degrees. For neurologically symptomatic patients in the pedicle subtraction osteotomy group, the neurological score improved slightly (p 0.024) with a mean difference of 1.7. For neurologically symptomatic patients in vertebral column resection group, the neurological score improved slightly (p 0.009) with a mean difference of 1.1. Major complications Seven patients in those three groups experienced major complications, including blood loss more than 5000 mL, temporary neurological symptoms, cerebrospinal fluid leakage, and infection. The most severe complications included one patient in the vertebral column resection group who had

		potentials to ensure neural safety **Control:** NA **Comparator:** Other Pedicle Subtraction Osteotomy without intradural detethering for neurological symptoms with smaller curves, without neurological symptoms all performed by a single senior surgeon under general anesthesia with meticulous pedicle screw placement, laminectom **Comparator 2:** Other Vertebral column resection without intradural detethering for severe curves or limited flexibility with or without neurological symptoms) all performed by a single senior surgeon under general anesthesia with meticulous pedicle screw placement, laminectom **Follow-up:** 47 weeks	temporarily decreased strength in the lower limb, and one patient in the pedicle subtraction osteotymy group with temporary numbness in the lower limb. Subgroup: NA
Duz, 2008[91] Trial ID NA Cohort study N = 22 Turkey Sites: 1 Setting: Inpatient	**Study population:** Patients admitted for management of caudal spinal cord tethering **Comorbidity:** NA **Female:** 5% **Age mean:** Mean: 22.3; Range: 20-29 Min age: 20 Max age: 29 **Age subgroup**: Adults **Ethnicity:** N/A **Retethering:** NA	**Intervention:** Surgical detethering Detethering surgery, patients with lipomyelomeningocele and myelomeningocele, as much dissection as possible was performed around the dorsal cord; in the patient with diastematomyelia, the bony septum was removed; in 2 other patients with split cord malformation, fibrous bands and attachments were excised; dermal sinuses were excised when present **Control:** No intervention	Bladder dysfunction Of 10 patients who chose surgery, 6 had preoperative urgency and 4 of them improved after surgery. Case 1, a patient with spina bifida occulta who presented with urgency, gradually improved to normal bladder function 6 months after surgery. Case 5, who ha Of the 8 of 10 patients who presented with preoperative progressive back pain, 4 were improved after operation. Of the 2 of 10 patients who presented with preoperative progressive leg pain, all who underwent surgery were improved after operation.

		Patients who declined surgery **Comparator:** NA **Comparator 2:** NA	Cerebrospinal fluid leakage occurred in 1 patient after operation; this was controlled with reinforcement sutures. Subgroup: NA
Jalai, 2017[92] Trial ID NA Cohort study N = 6457 US Sites: multiple Setting: Inpatient	**Study population:** Patients with tethered cord syndrome **Comorbidity:** NA **Female:** % **Age mean:** Dethethering mean: 16.17; Spinal fusion mean: 32.65 Min age: Max age: **Age subgroup**: Mixed age sample **Ethnicity:** N/A **Indication**: NA **Retethering:** NA	**Intervention:** Surgical detethering Detethering **Control:** NA **Comparator:** Other surgery Spinal fusion	Detethering cases only had an increased prevalence of nervous system procedure-related complications (2.46% vs.1.79%,p=0.029) compared to fusion. The approach was also an independent risk factor for increased nervous system (OR:1.34,CI:1.001–1.78;p=0.049) Subgroup: NA
Klekamp, 2011[93] Trial ID NA Cohort study N = 85 Germany Sites: multiple Setting: Inpatient	**Study population:** Patients with a tethered cord not diagnosed in childhood were included; excluding patients with surgically treated myelomeningoceles and Chiari Type II malformations who presented with signs of a retethered cord and patients with spinal hamartomas (lipoma or dysraphic cyst) without a tethered cord. Two categories of patients were defined: Group A: Patients with either a low-positioned conus medullaris below L-2, a thick filum terminale, or a splitcord malformation (that is, a tethered cord syndrome only) and Group B: patients with a combination of a tethered cord and a hamartoma **Comorbidity:** Other : Hamartoma in Group B **Female:** 72% **Age mean:** 46 (13) Range: 23–74 ; Group A mean (SD): 51 (15); Group B mean (SD): 42 (12) Min age: Max age: **Age subgroup**: Adults **Ethnicity:** N/A **Indication**: Mixed sample	**Intervention:** Surgical detethering Surgical strategies depended on pathology; for tethered cord due to a thick filum terminale the filum was transected; for split cord malformation, resected the tethering components at the level of the split cord and transected the filum in cases with a low-lying conus; extent of untethering was evaluated intraoperatively and considered successful if all tethering components could be released; for dysraphic cysts a complete resection, including the capsule, was intended; whenever possible a lipoma was left untouched to avoid arachnoid adhesions; a lipoma mass was reduced only if the spinal cord and lipoma would not fit comfortably in the spinal canal and dural sac or if the lipoma had extradural extension; in such cases, intra-	Bladder dysfunction clinical score Hypesthesia Gait ataxia Karnofsky Performance Scale Pain Recurrence rate at 10 years Recurrence rate at 10 years 0.22 vs 0.21. Subgroup: Other : Tethered cord vs. tethered cord + hamartoma

	Retethering: First time	and extradural components of the lipoma were separated from each other at the level of the dura, the extradural part in the subcutaneous space was left in place to avoid problems of wound healing, and the intradural part was reduced to accommodate the cord and the rest of the lipoma in the reconstructed dural sac; whenever partially resected a lipoma, attempted closure of the capsule to avoid recurrent tethering; duraplasty was performed to avoid retethering; except for 3 patients treated early in the series with fascia lata grafts, artificial materials were used; the duraplasty graft was lifted off the spinal cord by means of tenting sutures to minimize the risk of retethering **Control:** No intervention No surgery **Comparator:** NA **Comparator 2:** NA **Follow-up:** 60 weeks	
Lagae, 1990[94] Cohort study N = 41 Belgium Sites: 1 Setting: N/A	**Study population:** Children who regularly attend spina bifida clinic with conus medullaris below L 2-L 3 and lower lumbosacral dysraphic lesions (all normal ambulators) **Comorbidity:** NA **Female:** % **Age mean:** NA Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Symptomatic **Retethering:** NA	**Intervention:** Surgical detethering Neurosurgical repair for one of the subtypes of spina bifida occulta associated with a tethered cord, neurosurgery implied removal of excellsive adipose tissue, sectioning of the filum terminale and a dura plasty **Control:** No intervention No surgical release of the tethered cord **Comparator:** NA	Surgery: preoperatively, 9 of the 20 children needed clean intermittent bladdereatheterisation, associated with oxybutynin in 5 out of the 9; 7/9 children were socially continent with dry periods in between the catheterisations; 1 childwas kept continent Pain improvement Surgery: 2 patients operated for backpain became symptom-free postoperatively, in the other children, improvement was never observed and all preoperative medical treatment had to be continued.

		Comparator 2: NA	No surgery: 1 boy complained of increasing pain in the back. Signs for retethering Surgery: 3/20 patients had signs of retethering. Subgroup: NA
Liu, 2023[95] Trial ID NA Cohort study N = 80 China Sites: 1 Setting: Inpatient	**Study population:** TSC patients with who were clinically and radiologically (MRI) confirmed, and patients who underwent neurophysiological monitoring during surgery; patients with previous lumbar surgery, tumor, trauma, and other neurological diseases were excluded **Comorbidity:** NA **Female:** 46% **Age mean:** Less than 1 year: 42.5%; 1-5 years: 46.2%; >5 years: 11.3%; Post-term birth: 16.2% Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Unclear (check with Grady) **Retethering:** First time	**Intervention:** Surgical detethering Untethering in the first 3 months after diagnosis; all children underwent general anesthesia in the prone position, in order to prevent excessive loss of cerebrospinal fluid due to the gravity; sacrococcygeal region was raised by putting an air pillow at the hip joint and the lumbosacral mass was gently cut; needle electrodes were then implanted in the anal sphincter, bilateral quadriceps femoris, anterior tibial and gastrocnemius muscle to assess neurophysiological condition of patients during the surgery; thickened filum terminale was explored and the spinal cord adhesion was peeled under electrophysiological monitoring; for the assessment of myelomeningocele type and lipoma type, the neck of the bulging capsule was fully exposed, and a longitudinal dural incision was made from top to bottom in order to expose the bulging spinal nerve; electromyographic activity was measured using an electrophysiological probe after stimulation and resting potential; among the	Surgical intervention benefits Duration of diagnosis (timing of intervention after diagnosis) showed that early intervention was associated with surgical intervention benefits. Subgroup: NA

		lipomatous infiltrations, filar lipoma is relatively simple to remove; for the lipomyelocele type, a cavitron ultrasonic surgical aspirator was applied for sharp segmented resection of lipoma under electrophysiological monitoring; this device was safe enough to protect the spinal nerve, avoiding repeated pulling and sharp damage; the spinal cord wound was tightened and sutured appropriately to prevent re-adhesion **Control:** NA **Comparator:** Surgical detethering Untethering 3 months or longer after diagnosis; all children underwent general anesthesia in the prone position, in order to prevent excessive loss of cerebrospinal fluid due to the gravity; sacrococcygeal region was raised by putting an air pillow at the **Comparator 2:** NA **Follow-up:** 3 weeks	
Nakashima, 2016[96] Trial ID NA Cohort study N = 14 Japan Sites: multiple Setting: Inpatient	**Study population:** Adults >18 years old at the time of surgery, underwent spinal surgery for TCS **Female:** 29% **Age mean:** 37.7 (12.5) Range: 19-53 Min age: 18 Max age: **Age subgroup**: Adults **Ethnicity:** N/A **Indication**: Symptomatic **Retethering:**	**Intervention:** Surgical detethering Untethering surgery: Lumbosacral laminectomies were performed to obtain adequate exposure of the conus medullaris and cauda equina. Surgeries were performed under continuous electrophysiologic neuromonitoring with somatosensory-evoked potentials, combined with	Bladder and/or fecal dysfunction Bladder and/or fecal dysfunction occurred in 11.1% in the untethering and in 50% of the spine shortening group (p 0.20). Altered sensation; muscle weakness Overall clinical improvement was significantly greater in the spine shortening surgery (90.0%) than in the untethering group (33.3%, p 0.003). Improvement in gait disturbance Gait disturbance improved in 50% of the untethering and 100% of the spine shortening group (p 0.39).

		motor-evoked potentials, and electromyography with direct nerve root stimulation. After identification of the terminal filum, we confirmed electromyography activity on bipolar stimulation before clip ligation and definitive sectioning. Tethering lesions due to lipomas were maximally debulked, and occasionally the Cavitron Ultrasonic Surgical Aspirator was used (Valleylab, Boulder, Colorado, United States). In the patients who had undergone myelomeningocele repair during infancy or previous untethering surgery, meticulous dissection was required to ensure complete release of the spinal cord because of extensive arachnoidal adhesions. Duraplasty using substitute materials was performed at the close of surgery **Control:** NA **Comparator:** Spine-shortening vertebral osteotomy Spine-shortening osteotomy was performed at the level of T12 or L1; the laminae and transverse processes of the vertebrae at T12 and L2 were resected, and the pedicle screws were placed bilaterally at these vertebrae. Then, temporary rods were fixed in pl **Comparator 2:** NA	Improvement in back pain Back and leg pain improved in 20% and 43% of patients after untethering and 100% after spine shortening. Untethering surgery: CSF leakage, urinary infection; Spine-shortening osteotomy: significant blood loss (>3 L) CSF leakage and urinary infection each occurred in 1 patient in untethering surgery cases, and massive intraoperative bleeding (more than 3,000 mL) was observed in 1 patient in the SSO group. One patient in the untethering surgery group underwent SSO 11because the symptoms worsened 1 year after untethering Subgroup: NA

Oi, 2009[64] Cohort study N = 261 Japan Sites: multiple Setting: Inpatient	**Study population:** Asymptomatic and symptomatic patients with spinal lipoma **Comorbidity:** NA **Female:** % **Age mean:** NA Min age: Max age: **Age subgroup**: Age unclear **Ethnicity:** N/A **Indication**: Asymptomatic **Retethering:** First time	**Intervention:** Surgical detethering Untethering performed by expert pediatric neurosurgeons; prophylactic for some of the asymptomatic patients **Control:** Other Conservative observation without surgery **Comparator:** NA **Comparator 2:** NA **Follow-up:** 31 weeks	Urinary retention In asymptomatic patients, urinary retention was seen 0.7% postoperatively but the deficit resolved resolved after a few weeks. Varus 4.3% of asymptomatic conservatively managed patients presented with varus in the follow up period but symptoms were mild and did not affect daily activities, the other 95.7% had stable neurological states. 20% of symptomatic patients improved immediately after surgery, and the improvement rate increased to 44% at the final follow-up; worsening of symptoms was seen in 9% of patients immediately postoperatively but decreased to 6% at the final follow-up; the 2 symptomatic patients that were conservatively managed had stable neurological states. Subgroup: NA
Potts, 2010[97] Trial ID NA Cohort study N = 6 US Sites: 1 Setting: N/A	**Study population:** Patients with symptomatic TCS **Comorbidity:** NA **Female:** % **Age mean:** Mean: 47.7 (range 31-64) Min age: Max age: **Age subgroup**: Adults **Ethnicity:** N/A **Indication**: Symptomatic **Retethering:** NA	**Intervention:** Surgical detethering Minimally invasive approach using an expandable tubular retractor **Control:** NA **Comparator:** Surgical detethering Traditional open laminectomies for detethering **Comparator 2:** NA	1/3 patient in the mini-open group developed a pseudomeningocele, requiring readmission for surgical revision while 0/3 patients in the open group suffered surgical complications Subgroup: NA
Sadrameli, 2019[98] Trial ID NA Cohort study N = 22 US Sites: 1 Setting: Inpatient	**Study population:** Patients with tethered spinal cord **Comorbidity:** NA **Female:** 50% **Age mean:** Open tethered cord mean: 9.5 (4.5); Minimally invasive tethered cord mean: 10.1 (4.6) Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Unclear (check with Grady)	**Intervention:** Surgical detethering Minimally invasive muscle-sparing tethered cord release; after induction of general endotrachealanesthesia, patients were placed in a prone position and fluoroscopy was used for appropriate level localization; a vertical linear incision was marked about 2	Improvement or resolution of symptoms Among patients who underwent minimally invasive detethering, 10 experienced improvement or resolution of symptoms (91%) and 1 patient was stable in the first postoperative visit (9%, patient was later lost to follow up); in the open cohort, all patients expressed improvement or resolution of symptoms.

	Retethering: NA	cm off midline and was opened through the fascia, METRx tube similar to standard tubular microdiscectomy technique; superior iliac crest used to anatomically approximate the location of L4-5 disc space, an 18-gauge spinal needle confirmed this level on fluoroscopy; the tip of the first dilator was then used to palpate the bony edges of the laminae of L4 and L5 and another shot was used to confirm placement of the initial dilator in L4-5 interlaminar space; serial METRx tube dilation was then utilized to create a muscle splitting exposure of the interlaminar space at L4-5 and a final fluoroscopy image was taken to ensure appropriate docking of the tube, bringing the typical number of fluoroscopy images to 3; the length of the METRx tube has correlation with body habitus and body mass index of the patient; the range of length of tube used in this case series was 30 mm to 70 mm; under the microscope, a high-speed drill and a Kerrison rongeur were used for a laminotomy in the L4 and L5 interlaminar space without disruption of interspinous ligaments or the posterior tension band; the dura was opened sharply with a number 11 blade and intradural dissection was carried down to isolate the fatty filum; the filum was isolated with a cottonoid patty; intraoperative stimulation	There were no postoperative complications (CSF leak, infection, neurologic injury) in either cohort. Subgroup: NA

		of the nerve roots produced responses in the bilateral lower extremities and anal sphincter, whereas stimulation of the filum did not produce any response, the filum was then cauterized and divided; the dura was primarily closed in a water-tight fashion with CV7 Gore-Tex ribbon sutures using Scanlan minimally invasive instruments and a Valsalva maneuver was performed to ensure no CSF leakage; the METRx tube was then withdrawn, and fascia was closed primarily with 2e0 Vicryl suture followed by subdermal layer closure using 3e0 Vicryl suture; skin was then approximated using 4e0 Monocryl **Control:** NA **Comparator:** Surgical detethering Open surgical detethering **Comparator 2:** NA **Follow-up:** 5.6 weeks	
Steinbok, 2016[99] NCT00124046 RCT N = 21 Canada Sites: multiple Setting: Inpatient	**Study population:** Urological criteria: Including: 1) Primary or secondary daytime urinary incontinence that persisted during 12 months of medical treatment at the discretion of a pediatric urologist, including a combination of timed voiding, biofeedback, anticholinergics, a-antagonists, laxatives and prophylactic antibiotics. An abnormal voiding diary compiled for 3 weeks was used to confirm BBD as defined by 2 or more episodes of incontinence per week despite compliance with scheduled voids and stools, and medication/dietary recommendations. 2) A normal renal/bladder ultrasound was required. If ultrasound showed more than	**Intervention:** Surgical detethering Surgical filum section plus standard medical managment; surgical technique at surgeon discretion, section was achieved via an interspinous approach at a single level with no or minimal removal of laminae and spinous processes, level of transection could be from just below the conus to the termination of the filum in the sacral area, appearance of the filum and	Uryodynamic score The average urodynamics change did not statistically significantly differ between the surgical and medical groups (p 0.80). Pediatric Enuresis Module on Quality of Life (PEMQOL) Child Impact Score The median change in the surgical arm was 19.64 (range 0-56.50) and 10.71 (range -10-50) did not statistically significantly differ between the surgical and medical groups (p 0.19). Subgroup: NA

	minimal bladder thickening (greater than 3.0 mm at 50% or greater expected capacity), a voiding cystourethrogram was required to exclude bladder outlet obstruction. 3) Abnormal UDS testing was defined by any 1 of certain criteria detailed, including low bladder capacity as expected for age, abnormal bladder compliance as determined by standard formulas, detrusor overactivity as evidenced by an involuntary pressure increase during the filling phase associated with urgency and abnormal bladder sensation with volume at first sensation less than 20% of expected bladder capacity. Excluding: 1) bladder outlet obstruction demonstrated on voiding cystourethrogram and/or cystoscopy, 2) alternative diagnoses known to be associated with neuropathic bladder dysfunction (eg spinal dysraphism, spinal cord injury, cerebral palsy or other traumatic brain injury), 3) anorectal malformations, 4) alternative urological diagnoses with other defined treatment options besides further medical therapy as described, not including filum section (eg radiation cystitis, Eagle-Barrett, etc), 5) insufficient mental capacity to gain continence within 1 year, 6) noncompliance with medical management, 7) unwillingness to undergo initial and follow up UDS, and 8) UDS evidence of an atonic bladder, defined as capacity greater than 125% of EV. Radiological criteria: Including: 1) a normally positioned conus on spinal MRI (above the inferior L2 end plate), 2) any size filum, 3) any amount of fat in the filum, 4) terminal syringomyelia of less than 1 bony level was acceptable and 5) lumbar bifid spinal lamina was acceptable. Excluding: 1) recognized spinal dysraphism such as lipomyelomeningocele, myelomeningocele, dermal sinus, diastematomyelia and caudal regression, and 2) other spinal cord abnormalities explaining symptoms (tumor, etc). Neurological criteria: Including: 1)	whether the cut ends sprung apart when transected was recorded; as soon as possible postoperatively the child resumed a medical regimen similar to that used preoperatively **Control:** Other Standard medical treatment; followup visits at 3, 6 and 12 months, voiding diaries completed for the previous 3 weeks were reviewed and the treatment plan was reconfirmed with the urology team; therapy was weaned gradually if improvement occurred accordin **Comparator:** NA **Comparator 2:** NA	

	Lumbar cutaneous markings without MRI evidence of dysraphism. Excluding: 1) Evidence of progressive lower extremity motor/sensory deficits **Comorbidity:** NA **Female:** 76% **Age mean:** Mean: 9.3 Min age: 6 Max age: 18 **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Unclear (check with Grady) **Retethering:** NA		
van der Meulen, 2002[66] Trial ID NA Cohort study N = 41 Netherlands Sites: NA Setting: N/A	**Study population:** Spina bifida occulta patients with a tethered cord: 12 asymptomatic tethered cord patients **Other population:** Spina bifida occulta patients with a tethered cord: 10 with progressive symptoms, 9 treated conservatively at first, but underwent surgery after further progression of symptoms; 10 patients treated conservatively **Comorbidity:** Spina bifida **Female:** 59% **Age mean:** Prophylactic surgery group mean: 7.7 (range 1.7–20); Progressive symptoms then surgery group mean: 27.5 (range 5.2–54.6); Surgical treatment after conservative treatment and progressive symptoms mean: 28.3 (range 8.9–49.7); Conservative treatment group me Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Mixed sample **Retethering:** NA	**Intervention:** Surgical detethering Surgery (prophylactic or to address symptoms) **Control:** TAU Conservative treatment only **Comparator:** Surgical detethering Surgical treatment after symptom progression **Comparator 2:** Surgical detethering Surgical treatment after conservative treatment and progressive symptoms **Follow-up:** 68 weeks	Neurological symptoms All patients in the prophylactic surgery group remained stable during the follow-up period. Neurological symptoms improved more markedly after operation in the patients with early surgery compared to later surgery (improved 22%, stabilised 44%, deteriorated 33%). Patients in the early intervention group show 60% improvement at the first postoperative examination and at the end of follow-up improvement was 40%. Patients in the late intervention group show less improvement immediately after operation (44%) and at the end of follow-up the improvement rate is down to 33%. The no surgery group showed 10% deteriorated during follow-up. Surgical complications Prophylactic surgery: 4/12 patients developed surgical complications, 3 had CSF leakage from the wound (in 1, re-exploration was necessary, 1 had a temporary bladder retention; all complications resolved during the early postoperative period. Conservative treatment: 0/10 Surgery after progressive symptoms: 3/10 patients developed postoperative complications, 1 patient had a CSF leakage requiring re-exploration,1 patient had urinary problems, and 1 patient had a partial caudal syndrome; all

			complications resolved during the early postoperative period. Surgery after conservative treatment and progressive symptoms: 3/9 patients developed postoperative complications, 1 patient had CSF leakage (resolved spontaneously), 1 patient had voiding problems, and 1 patient had liquor hypotension complaints, all complications were resolved during the early postoperative period. Subgroup: NA
Xenos, 2000[67] Trial ID NA Cohort study N = 59 UK Sites: 1 Setting: Inpatient	**Study population:** Children with spinal lipomas, some asymptomatic **Other population:** Children with spinal lipomas, symptomatic **Comorbidity:** Other : Spinal lipoma **Female:** 68% **Age mean:** Mean 44.6 Min age: Max age: **Age subgroup**: Pediatrics **Ethnicity:** N/A **Indication**: Mixed sample **Retethering:** Mix	**Intervention:** Surgical detethering Surgery, in some cases prophylactic, the spinal cord lipoma was disconnected from its dural and subcutaneous attachments, and subtotally excised; no attempt was made for a complete excision of the lipoma; the dura and muscle layers were carefully reconstituted **Control:** Other No prophylactic surgery (approach varies between the neurosurgeons) **Comparator:** NA **Comparator 2:** NA **Follow-up:** 61.8 weeks	Bladder function 1 out of 5 asymptomatic patients had sphincter function disturbances at latest follow up. Bladder function did not change in 71% of all patients (asymptomatic and symptomatic). After surgery, 12 patients improved, 5 deteriorated, and no patients returned Deterioration Sensory function did not change in 74% of patients (across symptomatic and asymptomatic patients). After surgery, 12 patients improved, 3 patients deteriorated, and 6 patients returned to normal function; improvements are mainly due to 9/10 patients with limb pain being cured with surgery. At latest follow-up, 76% were normal, 22% had sensory deficit, and 2% had pain. Walking Motor function did not change in 73% of patients. After surgery, 9 patients improved, 7 patients deteriorated, and only 1 patient returned to normal function. At latest follow-up, 71% were normal, 7% had fatigue on walking, 18% required minor orthoses, 2% Pain After surgery, 12 patients improved, including 9/10 patients with limb pain being cured with surgery. At latest follow-up, 76% were normal, 22% had sensory deficit, and 2% had pain. Operative complications The overall operative complication rate was 18% (11 operations across symtpmatic and

			asymtomatic patients). This consisted of 2 wound infections, 4 CSF leaks and 5 wound breakdowns. Surgical repair was required in 54% to treat local wound problems. 91% with complications presented with a conus spinal lipoma, and 9% patient with CSF leak had a filum spinal lipoma. There was no operative mortality. Second operation of repeat division of filum One asymptomatic filum lipoma patient with thickened filum had a partial untethering in the context of a myelomeningocele repair at first operation and required a second operation of repeat division of filum due to progressive tethered spinal cord. Subgroup: NA
Baldia, 2020[68] Trial ID NA Cohort study N = 16 India Sites: 1 Setting: N/A	**Study population:** Patients with postoperative cerebrospinal fluid leak **Comorbidity:** Fatty filum,Lipomyelomeningocele **Female:** % **Age mean:** NA Min age: Max age: **Age subgroup**: Mixed age sample **Ethnicity:** N/A **Indication**: Symptomatic **Retethering:** NA	**Intervention:** Other Conservative management of cerebrospinal fluid leak, additional sutures and continuation of prone positioning with foot end elevation beyond the initial 1 week, continued for a median of 7 days (range 3-17 days) **Control:** NA **Comparator:** Other Different wound management, including ventriculoperitoneal shunt, shunt and acetazolamide, wound repair and acetazolamide, or wound repair **Comparator 2:** NA	Complications None of the conservatively managed patients had any complications like pneumonia/deep veinthrombosis related to the 7days of bedrest. Subgroup: NA

Notes: NA not available or not applicable

Table C.4. KQ4 evidence table

Study	Population	Intervention	Results

Haberl, 2004[100] Trial ID NA Cohort study N = 115 Germany Sites: 1 Setting: N/A	**Study population:** Children with spina bifida who underwent tethered cord release after initial repair or previous release operations performed in other hospitals, excluding those who underwent prophylactic surgery, had simultaneous posterior rhizotomy, and had missing urologic data **Comorbidity:** Spina bifida **Female:** % **Age mean:** NA Min age: Max age: **Age subgroup**: Pediatrics	**Intervention:** Repeat detethering Bilateral dural incision, undercutting arachnoid adhesions along the tethered area; after macroscopic midline access and identification of the dura at the level of the first intact vertebral lamina above the malformation, extradural dissection of the lateral borders of the spinal canal was performed down to the end of the spina bifida; after laminectomy and dural incision slightly above the site of pathology progressive microscopic dural dissection was performed following the midline and keeping stricly epiarachnioidally; after having reached the area of arachnoid adhesions, the further line of incision diverged and continued laterally on both sides towards the foramen intervertebrale, undercutting the dorsal fibrosis; after completion of the basal circumcision, the dissected lateral and dorsal mass of scar tissue, still embedding the former placode, was diminished gradually, terminating at the level of dorsal root entry; entered the subarachnoid space using a rigid endoscope in 31 procedures immediately after the first small dural incision, taking advantage of the initially vast space between the ventral dura and the spinal cord provided by dorsal tethering; following the course of the nerve roots within the cavum leptomeningicum on each side in a caudal view allows to identify the lateral area of safe dural incision below arachnoid adhesions and above the dural outlet; the cranial view revealed fibrotic midline adhesions -- possibly consolidated by the immobility of the tethered placode -- extending cranially beyond laminotomy in 16 cases; untethering the cranial adhesion in those cases was completed	26% of children in the intervention group showed improvement in bladder dysfunction. 26% of children in the intervention group showed significant improvement of spasticity, scoliosis, and bladder dysfunction. 3/13 children in the intervention reported low back pain improvement. Subgroup: NA

		endoscopically without enlarging the access; a dural graft must be inserted preserving enough space to maintain CSF circulation **Control:** Other Conventional dural midline approach **Comparator:** NA **Comparator 2:** NA	
Al-Holou, 2009[101] Trial ID NA Cohort study N = 84 US Sites: 1 Setting: N/A	**Study population:** Patients who underwent spinal cord untethering after at least 1 primary repair, who had undergone spinal cord untethering preceded by previous repair of an myelomeningocele or lipomyomeningocele **Comorbidity:** NA **Female:** 51.2% **Age mean:** 12.3 (5.9) Min age: 0 Max age: 25.9 **Age subgroup**: Mixed age sample **Ethnicity:** N/A	**Intervention:** Surgical detethering Incomplete untethering during tethered cord release **Control:** NA **Comparator:** Surgical detethering Complete untethering during tethered cord release	Stable and improved motor outcomes Improved outcomes in patients with complete untethering, patients who underwent incomplete untethering still had positive outcomes in many cases, with no statistically significant difference between groups. Subgroup: Age Younger age at untethering was significantly associated with worse long-term neurological outcomes.
Zhang, 2020[102] Trial ID NA Cohort study N = 16 US Sites: 1 Setting: N/A	**Study population:** Adults with recurrent TSC, MR images demonstrating a tethered cord, clinical symptoms related to the tethered cord, and a surgical procedure to treat the TCS, no active malignancy or infection, and no traumatic cause of symptoms **Comorbidity:** NA **Female:** 50% **Age mean:** Spinal column shortening mean: 47.5; Revision spinal cord detethering mean: 48 Min age: Max age: **Age subgroup**: Adults **Ethnicity:** N/A	**Intervention:** Vertebral column shortening The level of the osteotomy was usually at the thoracolumbar junction, away from the previous surgery, yet close enough to the tether that it could be effective; L1 or L2 was usually chosen as the distal level of fusion to avoid accelerating degeneration of the lumbar spine; in most cases, instrumentation at 2 levels above and below was performed; laminectomies at the osteotomy site and above and below were performed, pedicles were removed, and lateral walls dissected, a temporary rod was placed, vertebral body decancellated, lateral walls and posterior cortex were removed; anterior wall was shaved paper thin using a high-speed burr, but not penetrated	Spinal column shortening: 4 of 8 patients had improvement in their urinary function; Revision detethering: 3 patients had worsening of bowel and bladder function, and 1 patient had improvement of bladder function Spinal column shortening: none had worsening of neurological function; Revision detethering: 2/8 patients had worsening of lower-extremity strength Spinal column shortening: 6/8 patients had improvement in their preoperative pain; VAS leg 8.4 (preop) >4.3 (postop); VAS back: 6 (preop) > 2.2 (postop); Revision detethering: NR; VAS leg 5.8 (preop) >2.3 (postop); VAS back: 4.5 (preop) > 2 (postop) Complications Spinal column shortening: no complications; revision detethering: 3 wound-related

		with the burr, which was confirmed with fluoroscopy; after anterior cortex was thinned, the spinal column was shortened by closure of the osteotomy with gentle compression on the screws; neuromonitoring was used, and, if there were any changes, the compression was released; the other rod was placed, the screws were tightened, and arthrodesis was performed with local osteotomy and laminectomy bone **Control:** NA **Comparator:** Revision detethering Patients were placed prone for revision laminectomies; with the aid of the operating microscope, the dura was reopened, and the spinal cord was identified; the spinal cord was gently dissected and freed off the dura using micro instruments; cases were performed jointly by a pediatric neurosurgeon and an adult spinal neurosurgeon; neuromonitoring was always used, and, after adequate detethering was performed, the dura was closed; an expansion duraplasty was performed only if intraoperatively assessed that there was not enough room for the spinal cord and nerve roots with direct primary closure; if primary closure would not compress the neural elements, then a primary closure was performed; if the primary closure would result in constriction of the neural elements, then a duraplasty was also performed; each case was addressed individually; in complex wound revision cases, the plastic surgery team was also involved to close the wound; patients were kept flat in bed for approximately 2–3 days,depending on the quality of the dura and the quality of the closure	complications, with 2 CSF leaks and 1 wound infection Subgroup: NA

		Comparator 2: NA	

Appendix D. Critical Appraisal and Applicability Tables

Table D.1. Critical appraisal for included studies, KQ1

Author, Year	Patient Selection	Index Test	Reference Standard	Flow Timing
Arikan, 1999[38]	High risk	Low risk	Unclear risk	Unclear risk
Barutcuoglu, 2015[8]	Unclear risk	Unclear risk	Low risk	Unclear risk
Barutcuoglu, 2016[27]	Unclear risk	Unclear risk	High risk	High risk
Ben-Sira, 2009[39]	Low risk	Low risk	Low risk	Unclear risk
Bischoff, 2019[9]	Unclear risk	Unclear risk	Unclear risk	Unclear risk
Brezner, 1999[51]	Unclear risk	Unclear risk	Unclear risk	Unclear risk
Broderick, 2015[53]	Unclear risk	Unclear risk	Low risk	Unclear risk
Brophy, 1989[10]	Low risk	Low risk	Low risk	High risk
Cornips, 2010[11]	High risk	Low risk	Unclear risk	Unclear risk
Cowley, 2022[40]	High risk	Low risk	Low risk	Unclear risk
Filippi, 2010[12]	Unclear risk	Unclear risk	Unclear risk	Unclear risk
Gholampour, 2018[30]	Unclear risk	High risk	Low risk	Unclear risk
Hall, 1988[13]	Unclear risk	Unclear risk	Unclear risk	Unclear risk
He, 2016[41]	Low risk	Unclear risk	Unclear risk	Unclear risk
Heinz, 1979[29]	High risk	Unclear risk	Unclear risk	Unclear risk
Heji, 1996[34]	Unclear risk	High risk	Unclear risk	Unclear risk
Jehangir, 2020[42]	Unclear risk	High risk	Low risk	Unclear risk
Kamei, 2022[1]	High risk	Low risk	High risk	Unclear risk
Kaplan, 1980[58]	High risk	High risk	High risk	High risk
Karrer, 1988[43]	Unclear risk	Unclear risk	Unclear risk	Unclear risk
Kerensky, 2024[44]	High risk	Low risk	High risk	High risk
Keykhosravi, 2023[45]	Unclear risk	Unclear risk	Low risk	Low risk
Kucera, 2015[50]	Unclear risk	Unclear risk	High risk	Unclear risk
Lam, 2004[46]	Unclear risk	Unclear risk	Low risk	Unclear risk
Lavallee, 2013[28]	High risk	Low risk	High risk	Unclear risk
Leung, 2015[2]	High risk	Unclear risk	Unclear risk	Unclear risk
Levitt, 1997[35]	High risk	Unclear risk	High risk	High risk
Li, 1996[3]	Low risk	Unclear risk	High risk	High risk
Mahapatra, 2005[57]	Unclear risk	Unclear risk	Unclear risk	High risk
McCullough, 1990[14]	High risk	Unclear risk	Low risk	High risk
Merx, 1989[59]	High risk	Unclear risk	Unclear risk	Unclear risk
Meyrat, 2003[54]	High risk	Unclear risk	Unclear risk	Unclear risk
Milhorat, 2009[32]	Unclear risk	Low risk	Low risk	Low risk
Mottet, 2016[47]	High risk	Unclear risk	High risk	Unclear risk
Moufarrij, 1989[15]	Low risk	Unclear risk	Unclear risk	Unclear risk
O'Neil, 1990[16]	High risk	Unclear risk	Low risk	Unclear risk
Polo, 1994[4]	Unclear risk	Unclear risk	Unclear risk	Low risk
Rafiee, 2023[26]	High risk	Low risk	Unclear risk	Unclear risk
Raghavan, 1988[17]	Unclear risk	Unclear risk	Unclear risk	Unclear risk
Roy, 1986[5]	Unclear risk	Unclear risk	Unclear risk	Low risk
Sankhe, 2021[18]	Low risk	Low risk	High risk	Unclear risk
Sasani, 2008[52]	Low risk	Low risk	Low risk	Unclear risk
Scottoni, 2014[48]	Low risk	Low risk	High risk	Low risk
Shin, 2023[33]	Unclear risk	Unclear risk	Unclear risk	Unclear risk
Singh, 2011[19]	Unclear risk	Low risk	Low risk	Unclear risk
Singh, 2019[20]	Unclear risk	Unclear risk	High risk	Unclear risk
Stamates, 2018[21]	Unclear risk	Low risk	Unclear risk	High risk
Steinbrook, 1999[22]	High risk	Unclear risk	High risk	High risk
Tamura, 2017[55]	Unclear risk	Unclear risk	High risk	Unclear risk
Teo, 2012[49]	Low risk	Unclear risk	Unclear risk	Unclear risk

Author, Year	Patient Selection	Index Test	Reference Standard	Flow Timing
Thomas, 2017[6]	High risk	Unclear risk	Low risk	Unclear risk
Tubbs, 2002[31]	High risk	Unclear risk	Unclear risk	Unclear risk
Tubbs, 2006[36]	Low risk	Unclear risk	Unclear risk	Unclear risk
Tubbs, 2007[37]	Low risk	Unclear risk	High risk	High risk
Umur, 2007[7]	Unclear risk	Unclear risk	Unclear risk	Unclear risk
Vernet, 1996[25]	Low risk	High risk	Low risk	High risk
Warf, 1993[23]	Unclear risk	Unclear risk	High risk	High risk
Witkam, 2001[24]	Unclear risk	Low risk	Low risk	High risk
Yarandi , 2019[56]	Unclear risk	Low risk	Low risk	Unclear risk

Table D.2. Applicability ratings for included studies, KQ1

Author, Year	Population	Intervention	Comparator	Outcome	Setting
Arikan, 1999[38]	N/A	N/A	N/A	N/A	Level of care different from current U.S. standard
Barutcuoglu, 2015[8]	N/A	N/A	Inadequate comparison therapy or use of a substandard alternative therapy	Other issues	Level of care different from current U.S. standard
Barutcuoglu, 2016[27]	N/A	N/A	N/A	N/A	Level of care different from current U.S. standard
Ben-Sira, 2009[39]	N/A	N/A	N/A	N/A	N/A
Bischoff, 2019[9]	More complex patients than typical	Unclear	Unclear	N/A	N/A
Brezner, 1999[51]	N/A	N/A	N/A	N/A	N/A
Broderick, 2015[53]	Narrow eligibility criteria	N/A	Inadequate comparison therapy or use of a substandard alternative therapy	N/A	N/A
Brophy, 1989[10]	N/A	N/A	N/A	N/A	N/A
Cornips, 2010[11]	N/A	Approach not reflective of current practice	N/A	N/A	N/A
Cowley, 2022[40]	N/A	N/A	N/A	N/A	N/A
Filippi, 2010[12]	N/A	Unclear	N/A	Unclear	N/A
Gholampour, 2018[30]	N/A	N/A	N/A	N/A	Level of care different from current U.S. standard
Hall, 1988[13]	N/A	N/A	Comparator unclear	N/A	N/A
He, 2016[41]	N/A	N/A	N/A	N/A	Level of care different from current U.S. standard
Heinz, 1979[29]	N/A	N/A	N/A	N/A	N/A
Heji, 1996[34]	N/A	N/A	Comparator unclear	N/A	N/A

Author, Year	Population	Intervention	Comparator	Outcome	Setting
Jehangir, 2020[42]	More complex patients than typical	N/A	N/A	N/A	N/A
Kamei, 2022[1]	Narrow eligibility criteria	N/A	N/A	N/A	N/A
Kaplan, 1980[58]	N/A	N/A	N/A	N/A	N/A
Karrer, 1988[43]	More complex patients than typical	N/A	Comparator unclear	N/A	N/A
Kerensky, 2024[44]	N/A	N/A	N/A	N/A	N/A
Keykhosravi, 2023[45]	N/A	N/A	N/A	Follow-up too short to detect impact	Level of care different from current U.S. standard
Kucera, 2015[50]	N/A	N/A	Comparator unclear	N/A	N/A
Lam, 2004[46]	N/A	N/A	N/A	N/A	N/A
Lavallee, 2013[28]	N/A	N/A	Comparator unclear	N/A	N/A
Leung, 2015[2]	More complex patients than typical	N/A	N/A	N/A	N/A
Levitt, 1997[35]	N/A	N/A	N/A	Other issues	N/A
Li, 1996[3]	N/A	N/A	N/A	N/A	N/A
Mahapatra, 2005[57]	More complex patients than typical	N/A	N/A	N/A	Level of care different from current U.S. standard
McCullough, 1990[14]	N/A	N/A	N/A	Follow-up too short to detect impact	N/A
Merx, 1989[59]	N/A	N/A	N/A	N/A	N/A
Meyrat, 2003[54]	N/A	N/A	N/A	N/A	N/A
Milhorat, 2009[32]	N/A	N/A	Unclear	N/A	N/A
Mottet, 2016[47]	N/A	N/A	N/A	N/A	N/A
Moufarrij, 1989[15]	N/A	N/A	N/A	N/A	N/A
O'Neil, 1990[16]	N/A	N/A	N/A	N/A	N/A
Polo, 1994[4]	N/A	Approach not reflective of current practice	N/A	N/A	N/A
Rafiee, 2023[26]	N/A	N/A	Comparator unclear	N/A	N/A
Raghavan, 1988[17]	N/A	N/A	N/A	N/A	N/A
Roy, 1986[5]	N/A	N/A	N/A	N/A	N/A
Sankhe, 2021[18]	N/A	N/A	N/A	N/A	Level of care different from current U.S. standard
Sasani, 2008[52]	N/A	N/A	N/A	N/A	Level of care different from current U.S. standard
Scottoni, 2014[48]	N/A	N/A	N/A	N/A	N/A
Shin, 2023[33]	N/A	N/A	N/A	N/A	N/A
Singh, 2011[19]	N/A	N/A	N/A	Unclear	N/A
Singh, 2019[20]	N/A	N/A	Comparator unclear	Other issues	Level of care different from current U.S. standard

Author, Year	Population	Intervention	Comparator	Outcome	Setting
Stamates, 2018[21]	N/A	N/A	N/A	N/A	N/A
Steinbrook, 1999[22]	N/A	N/A	N/A	N/A	Level of care different from current U.S. standard
Tamura, 2017[55]	N/A	N/A	N/A	N/A	N/A
Teo, 2012[49]	N/A	N/A	N/A	N/A	N/A
Thomas, 2017[6]	More complex patients than typical	N/A	Comparator unclear	N/A	Level of care different from current U.S. standard
Tubbs, 2002[31]	Unclear	N/A	N/A	N/A	N/A
Tubbs, 2006[36]	More complex patients than typical	N/A	N/A	N/A	N/A
Tubbs, 2007[37]	N/A	N/A	N/A	N/A	N/A
Umur, 2007[7]	N/A	N/A	N/A	N/A	Level of care different from current U.S. standard
Vernet, 1996[25]	N/A	N/A	N/A	N/A	N/A
Warf, 1993[23]	More complex patients than typical	N/A	N/A	N/A	N/A
Witkam, 2001[24]	N/A	N/A	N/A	N/A	N/A
Yarandi , 2019[56]	N/A	N/A	N/A	N/A	Level of care different from current U.S. standard

Notes: N/A not applicable (no applicability flag was raised)

Table D.3. Critical appraisal for included studies, KQ2

Author, Year	Selection Bias	Performance Bias	Attrition Bias	Detection Bias	Reporting Bias	Other Source of Bias
Byrne, 1995[62]	High risk	High risk	Low risk	Moderate/Unclear risk	High risk	Moderate/Unclear risk
Goldstein, 2019[63]	High risk	Moderate/Unclear risk	Low risk	Low risk	Moderate/Unclear risk	High risk
Li, 2022[60]	Moderate/Unclear risk	Moderate/Unclear risk	Low risk	Moderate/Unclear risk	High risk	Low risk
Ogiwara, 2015[61]	High risk	Moderate/Unclear risk	Low risk	Moderate/Unclear risk	High risk	Moderate/Unclear risk
Oi, 2009[64]	High risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk	High risk	Moderate/Unclear risk
Tu, 2016[65]	High risk	Moderate/Unclear risk	Low risk	Moderate/Unclear risk	High risk	High risk
van der Meulen, 2002[66]	High risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk	High risk	Moderate/Unclear risk
Xenos, 2000[67]	High risk	Moderate/Unclear risk	Low risk	Moderate/Unclear risk	High risk	Moderate/Unclear risk

Table D.4. Applicability ratings for included studies, KQ2

Author, Year	Population	Intervention	Comparator	Outcome	Setting
Byrne, 1995[62]	N/A	N/A	N/A	N/A	N/A
Goldstein, 2019[63]	N/A	N/A	N/A	N/A	N/A
Li, 2022[60]	N/A	N/A	N/A	N/A	Level of care different from current U.S. standard

Author, Year	Population	Intervention	Comparator	Outcome	Setting
Ogiwara, 2015[61]	N/A	N/A	N/A	N/A	N/A
Oi, 2009[64]	N/A	N/A	N/A	N/A	Level of care different from current U.S. standard
Tu, 2016[65]	Narrow eligibility criteria	N/A	N/A	N/A	N/A
van der Meulen, 2002[66]	N/A	N/A	N/A	N/A	N/A
Xenos, 2000[67]	N/A	N/A	N/A	N/A	N/A

Notes: N/A not applicable (no applicability flag was raised)

Table D.5. Critical appraisal for included studies, KQ3

Author, Year	Selection Bias	Performance Bias	Attrition Bias	Detection Bias	Reporting Bias	Other Source of Bias
Abdallah, 2018[78]	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk	High risk	Moderate/Unclear risk
Baldia, 2020[68]	High risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk	High risk	Moderate/Unclear risk
Byrne, 1995[62]	High risk	High risk	Low risk	Moderate/Unclear risk	High risk	Moderate/Unclear risk
Caldarelli, 1995[79]	High risk	Moderate/Unclear risk	Low risk	Moderate/Unclear risk	High risk	Moderate/Unclear risk
Chern, 2011[69]	High risk	High risk	Low risk	High risk	High risk	Moderate/Unclear risk
Duz, 2008[91]	High risk	High risk	Moderate/Unclear risk	Moderate/Unclear risk	High risk	Moderate/Unclear risk
Erkan, 1999[80]	High risk	Moderate/Unclear risk	Low risk	Moderate/Unclear risk	High risk	Moderate/Unclear risk
Erkan, 2000[81]	Low risk	Low risk	Low risk	Moderate/Unclear risk	High risk	Low risk
Fekete, 2019[70]	High risk	Moderate/Unclear risk	High risk	Moderate/Unclear risk	High risk	Moderate/Unclear risk
Hayashi, 2018[71]	High risk	Moderate/Unclear risk	Low risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk
Hoffman, 1985[82]	High risk	High risk	Low risk	High risk	Moderate/Unclear risk	Moderate/Unclear risk
Jalai, 2017[92]	High risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk
Jiang, 2019[72]	Low risk	Moderate/Unclear risk	Low risk	High risk	Moderate/Unclear risk	Low risk
Jun , 2016[83]	High risk	Moderate/Unclear risk	Low risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk
Kanematsu, 2020[73]	High risk	Moderate/Unclear risk	Low risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk
Klekamp, 2011[93]	High risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk	High risk	High risk
Kunes, 2022[84]	High risk	Moderate/Unclear risk	Low risk	Moderate/Unclear risk	Low risk	High risk
Lagae, 1990[94]	High risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk	High risk	Moderate/Unclear risk
Lalgudi, 2021[74]	High risk	Moderate/Unclear risk	Low risk	Moderate/Unclear risk	Moderate/Unclear risk	Low risk
Liu, 2023[95]	High risk	Moderate/Unclear risk	Moderate/Unclear risk	High risk	High risk	Moderate/Unclear risk
Mehta, 2010[85]	High risk	Moderate/Unclear risk	Low risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk

Author, Year	Selection Bias	Performance Bias	Attrition Bias	Detection Bias	Reporting Bias	Other Source of Bias
Mehta, 2011[86]	High risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk
Nakashima, 2016[96]	High risk	Low risk	Low risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk
Oda, 2012[87]	High risk	Moderate/Unclear risk	High risk	Moderate/Unclear risk	Moderate/Unclear risk	High risk
Ogiwara, 2015[61]	High risk	Moderate/Unclear risk	Low risk	Moderate/Unclear risk	High risk	Moderate/Unclear risk
Oi, 2009[64]	High risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk	High risk	Moderate/Unclear risk
Pan, 2023[75]	High risk	Low risk	Low risk	High risk	High risk	Moderate/Unclear risk
Potts, 2010[97]	High risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk	High risk
Sadrameli, 2019[98]	High risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk
Samuels, 2009[88]	Moderate/Unclear risk	Moderate/Unclear risk	Low risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk
Shahjouei, 2016[76]	Low risk	Low risk	Low risk	Low risk	Moderate/Unclear risk	Moderate/Unclear risk
Steinbok, 2016[99]	Low risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk	High risk	Moderate/Unclear risk
Strong, 2015[89]	High risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk
Tao, 2019[90]	Moderate/Unclear risk	Low risk	Low risk	High risk	High risk	High risk
Udayakumaran, 2018[77]	High risk	Moderate/Unclear risk	Moderate/Unclear risk	High risk	Moderate/Unclear risk	Moderate/Unclear risk
van der Meulen, 2002[66]	High risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk	High risk	Moderate/Unclear risk
Xenos, 2000[67]	High risk	Moderate/Unclear risk	Low risk	Moderate/Unclear risk	High risk	Moderate/Unclear risk
Yoneyama, 1985[103]	High risk	High risk	High risk	Moderate/Unclear risk	Moderate/Unclear risk	Moderate/Unclear risk

Table D.6. Applicability ratings for included studies, KQ3

Author, Year	Population	Intervention	Comparator	Outcome	Setting
Abdallah, 2018[78]	N/A	N/A	N/A	N/A	Level of care different from current U.S. standard
Baldia, 2020[68]	N/A	N/A	N/A	N/A	Level of care different from current U.S. standard
Byrne, 1995[62]	N/A	N/A	N/A	N/A	N/A
Caldarelli, 1995[79]	N/A	N/A	N/A	Unclear	N/A
Chern, 2011[69]	Narrow eligibility criteria	N/A	Comparator unclear	Follow-up too short to detect impact	N/A
Duz, 2008[91]	N/A	N/A	Inadequate comparison therapy or use of a substandard alternative therapy	N/A	Level of care different from current U.S. standard

Author, Year	Population	Intervention	Comparator	Outcome	Setting
Erkan, 1999[80]	N/A	N/A	Comparator unclear	N/A	Level of care different from current U.S. standard
Erkan, 2000[81]	N/A	N/A	N/A	N/A	Level of care different from current U.S. standard
Fekete, 2019[70]	N/A	N/A	N/A	N/A	N/A
Hayashi, 2018[71]	N/A	N/A	N/A	N/A	N/A
Hoffman, 1985[82]	N/A	N/A	N/A	N/A	N/A
Jalai, 2017[92]	N/A	N/A	N/A	N/A	N/A
Jiang, 2019[72]	N/A	N/A	N/A	N/A	Level of care different from current U.S. standard
Jun , 2016[83]	N/A	N/A	N/A	N/A	Level of care different from current U.S. standard
Kanematsu, 2020[73]	N/A	N/A	N/A	N/A	N/A
Klekamp, 2011[93]	N/A	N/A	N/A	Other issues	N/A
Kunes, 2022[84]	N/A	Unclear	N/A	N/A	N/A
Lagae, 1990[94]	N/A	N/A	N/A	N/A	N/A
Lalgudi, 2021[74]	N/A	N/A	N/A	N/A	N/A
Liu, 2023[95]	N/A	N/A	Comparator unclear	Other issues	Level of care different from current U.S. standard
Mehta, 2010[85]	N/A	N/A	N/A	N/A	N/A
Mehta, 2011[86]	More complex patients than typical	Co-intervention that are likely to modify the effectiveness of therapy	N/A	N/A	N/A
Nakashima, 2016[96]	N/A	N/A	N/A	N/A	N/A
Oda, 2012[87]	Narrow eligibility criteria	N/A	Comparator unclear	Follow-up too short to detect impact	N/A
Ogiwara, 2015[61]	N/A	N/A	N/A	N/A	N/A
Oi, 2009[64]	N/A	N/A	N/A	N/A	Level of care different from current U.S. standard
Pan, 2023[75]	N/A	N/A	N/A	N/A	N/A
Potts, 2010[97]	N/A	N/A	N/A	N/A	N/A
Sadrameli, 2019[98]	N/A	N/A	N/A	Composite outcomes that mix outcomes of different significance	N/A
Samuels, 2009[88]	N/A	N/A	N/A	N/A	N/A
Shahjouei, 2016[76]	N/A	N/A	N/A	N/A	Level of care different from current U.S. standard
Steinbok, 2016[99]	N/A	Unclear	N/A	N/A	N/A

Author, Year	Population	Intervention	Comparator	Outcome	Setting
Strong, 2015[89]	Narrow eligibility criteria	N/A	N/A	N/A	N/A
Tao, 2019[90]	More complex patients than typical	N/A	N/A	N/A	Level of care different from current U.S. standard
Udayakumaran, 2018[77]	More complex patients than typical	Approach not reflective of current practice	Comparator unclear	N/A	Level of care different from current U.S. standard
van der Meulen, 2002[66]	N/A	N/A	N/A	N/A	N/A
Xenos, 2000[67]	N/A	N/A	N/A	N/A	N/A
Yoneyama, 1985[103]	N/A	N/A	N/A	Unclear	Level of care different from current U.S. standard

Notes: N/A not applicable (no applicability flag was raised)

Table D.7. Critical appraisal for included studies, KQ4

Author, Year	Selection Bias	Performance Bias	Attrition Bias	Detection Bias	Reporting Bias	Other Source of Bias
Al-Holou, 2009[101]	High risk	Low risk	Low risk	Moderate/Unclear risk	High risk	Moderate/Unclear risk
Haberl, 2004[100]	High risk	Moderate/Unclear risk	Low risk	High risk	High risk	Moderate/Unclear risk
Zhang, 2020[102]	High risk	Moderate/Unclear risk	Low risk	High risk	Moderate/Unclear risk	Moderate/Unclear risk

Table D.8. Applicability ratings for included studies, KQ4

Author, Year	Population	Intervention	Comparator	Outcome	Setting
Al-Holou, 2009[101]	N/A	N/A	N/A	N/A	N/A
Haberl, 2004[100]	More complex patients than typical	N/A	N/A	N/A	N/A
Zhang, 2020[102]	N/A	N/A	N/A	N/A	N/A

Notes: N/A not applicable (no applicability flag was raised)

Appendix E. List of Included Studies

1. Abdallah A, Emel E, Abdallah BG, et al. Factors affecting the surgical outcomes of tethered cord syndrome in adults: a retrospective study. Neurosurg Rev. 2018 Jan;41(1):229-39. doi: 10.1007/s10143-017-0842-z. PMID: 28293750. *IncludeDE_KQ3*

2. Al-Holou WN, Muraszko KM, Garton HJ, et al. The outcome of tethered cord release in secondary and multiple repeat tethered cord syndrome. J Neurosurg Pediatr. 2009 Jul;4(1):28-36. doi: 10.3171/2009.2.Peds08339. PMID: 19569907. *IncludeDE_KQ4*

3. Arikan N, Soygur T, Selcuki M, et al. Role of magnetic resonance imaging in children with voiding dysfunction: Retrospective analysis of 81 patients. Urology. 1999 Jul;54(1):157-60. doi: 10.1016/s0090-4295(99)00183-1. PMID: WOS:000081251100032. *IncludeDE_KQ1*

4. Baldia M, Rajshekhar V. Minimizing CSF Leak and Wound Complications in Tethered Cord Surgery with Prone Positioning: Outcomes in 350 Patients. World Neurosurg. 2020 May;137:e610-e7. doi: 10.1016/j.wneu.2020.02.073. PMID: 32088374. *IncludeDE_KQ3*

5. Barutcuoglu M, Selcuki M, Selcuki D, et al. Cutting filum terminale is very important in split cord malformation cases to achieve total release. Childs Nerv Syst. 2015 Mar;31(3):425-32. doi: 10.1007/s00381-014-2586-1. PMID: 25466279. *IncludeDE_KQ1*

6. Barutçuoğlu M, Selçuki M, Sukru Umur A, et al. Scoliosis may be the first symptom of the tethered spinal cord. Indian Journal of Orthopaedics. 2016;50(1):80-6. doi: 10.4103/0019-5413.173506. PMID: 112384793. Language: English. Entry Date: 20160205. Revision Date: 20190514. Publication Type: Article. *IncludeDE_KQ1*

7. Ben-Sira L, Ponger P, Miller E, et al. Low-risk lumbar skin stigmata in infants: the role of ultrasound screening. J Pediatr. 2009 Dec;155(6):864-9. doi: 10.1016/j.jpeds.2009.06.003. PMID: 19643444. *IncludeDE_KQ1*

8. Bischoff A, Peña A, Ketzer J, et al. The conus medullaris ratio: A new way to identify tethered cord on MRI. J Pediatr Surg. 2019 Feb;54(2):280-4. doi: 10.1016/j.jpedsurg.2018.10.081. PMID: 30518494. *IncludeDE_KQ1*

9. Brezner A, Kay B. Spinal cord ultrasonography in children with myelomeningocele. Dev Med Child Neurol. 1999 Jul;41(7):450-5. PMID: 10454228. *IncludeDE_KQ1*

10. Broderick KM, Munoz O, Herndon CD, et al. Utility of urodynamics in the management of asymptomatic tethered cord in children. World J Urol. 2015 Aug;33(8):1139-42. doi: 10.1007/s00345-014-1414-2. PMID: 25271106. *IncludeDE_KQ1_IncluеDE_KQ3*

11. Brophy JD, Sutton LN, Zimmerman RA, et al. Magnetic resonance imaging of lipomyelomeningocele and tethered cord. Neurosurgery. 1989 Sep;25(3):336-40. doi: 10.1097/00006123-198909000-00002. PMID: 2771003. *IncludeDE_KQ1*

12. Byrne RW, Hayes EA, George TM, et al. Operative resection of 100 spinal lipomas in infants less than 1 year of age. Pediatr Neurosurg. 1995;23(4):182-6; discussion 6-7. doi: 10.1159/000120956. PMID: 8835207. *IncludeDE_KQ2_IncludeDE_KQ3*

13. Caldarelli M, DiRocco C, Colosimo C, et al. Surgical treatment of late neurological deterioration in children with myelodysplasia. Acta Neurochirurgica. 1995;137(3-4):199-206. doi:

10.1007/bf02187194. PMID: WOS:A1995TL37000021. *IncludeDE_KQ3*

14. Chern JJ, Tubbs RS, Patel AJ, et al. Preventing cerebrospinal fluid leak following transection of a tight filum terminale. J Neurosurg Pediatr. 2011 Jul;8(1):35-8. doi: 10.3171/2011.4.Peds10502. PMID: 21721886. *IncludeDE_KQ3*

15. Cornips EM, Razenberg FG, van Rhijn LW, et al. The lumbosacral angle does not reflect progressive tethered cord syndrome in children with spinal dysraphism. Childs Nerv Syst. 2010 Dec;26(12):1757-64. doi: 10.1007/s00381-010-1281-0. PMID: 20857121. *IncludeDE_KQ1*

16. Cowley N, Maheshwari M, Lerner DG, et al. Assessment of MRI and Ultrasound Screening for Tethered Cord Syndrome in Patients Diagnosed With Esophageal Atresia/Tracheoesophageal Fistula. J Surg Res. 2022 Nov;279:193-9. doi: 10.1016/j.jss.2022.06.004. PMID: 35779449. *IncludeDE_KQ1*

17. Düz B, Gocmen S, Secer HI, et al. Tethered cord syndrome in adulthood. J Spinal Cord Med. 2008;31(3):272-8. doi: 10.1080/10790268.2008.11760722. PMID: 18795476. *IncludeDE_KQ3*

18. Erkan K, Unal F, Kiris T. Terminal syringomyelia in association with the tethered cord syndrome. Neurosurgery. 1999 Dec;45(6):1351-9; discussion 9-60. doi: 10.1097/00006123-199912000-00018. PMID: 10598703. *IncludeDE_KQ3*

19. Erkan K, Unal F, Kiris T, et al. Treatment of terminal syringomyelia in association with tethered cord syndrome: clinical outcomes with and without syrinx drainage. Neurosurg Focus. 2000 Mar 15;8(3):E9. doi: 10.3171/foc.2000.8.3.9. PMID: 16676932. *IncludeDE_KQ3*

20. Fekete G, Bognár L, Novák L. Surgical treatment of tethered cord syndrome-comparing the results of surgeries with and without electrophysiological monitoring. Childs Nerv Syst. 2019 Jun;35(6):979-84. doi: 10.1007/s00381-019-04129-9. PMID: 30963241. *IncludeDE_KQ3*

21. Filippi CG, Andrews T, Gonyea JV, et al. Magnetic resonance diffusion tensor imaging and tractography of the lower spinal cord: application to diastematomyelia and tethered cord. Eur Radiol. 2010 Sep;20(9):2194-9. doi: 10.1007/s00330-010-1797-4. PMID: 20432039. *IncludeDE_KQ1*

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Appendix F. Case Series

Table F.1. KQ1 case series

Index Test	**Study ID** Author, Year; Multiple Publications; Study Size; Location	**Results**	**Diagnostic Accuracy** **Adverse Events**	**Author Conclusions**
EP	Nair, 2021[104] N = 100 India	Intra-operative monitoring of motor evoked potentials in children undergoing tethered cord surgery	**Diagnostic accuracy:** Evoked potentials worsened in 3% of children during surgery, thought there was no clinical worsening in 2/3 children; in 55%, there was no change in the evoked potentials at the end of the surgery. **Adverse events:** No seizures, tongue bites, skin burns at stimulation sites or cardiac arrhythmia.	Motor evoked potentials have a high accuracy although, false positive and false negative results can occasionally be experienced.
EP	Oz, 2010[105] N = 30 Turkey	The tibial nerve posterior to the medial malleoli was stimulated, surface electrodes recorded somatosensory evoked potentials, latency for thoracal and cortical potentials as well as the thoraco-cortical tibial somatosensory evoked potentials conduction time for both left and right tibial nerves were measured, and to stimulate the tibial nerve for a cortical response, electrodes were placed on the vertex and midline frontal region, for peripheral response, electrodes were placed on the 12th thoracic vertebra and anterior superior iliac spine, with bilateral peroneal and tibial motor nerves and the sural sensory nerve studies conducted, along with late	**Diagnostic accuracy:** In patients with adult Tethered Cord Syndrome 60% had abnormal tibial somatosensory evoked potentials cortical response latency, 43.3% showed chronic neurogenic involvement in needle electromyography, 16.6% had reduced motor unit action potential amplitudes in nerve conduction studies, and 43.3% had abnormal H reflexes, these results suggest that tibial SEP abnormalities are the most sensitive electrophysiological finding in adult TCS patients, so electrophysiological examinations are recommended for TCS patients, regardless of whether they have subjective	The study recommends comprehensive electrophysiological examinations for patients with adult tethered cord syndrome to identify various abnormalities

		responses (F-wave and H-reflex), also needle electromyography was performed bilaterally in the L4, L5, and S1 myotomes using concentric needle electrodes	or objective complaints. **Adverse events:** N/A	
EP	Sendromlu, 2010[106] N = 30 Turkey	The protocol involved stimulating the tibial nerve behind the medial malleoli to record somatosensory evoked potentials, measuring both thoracal and cortical potential latencies and conduction times, with additional nerve conduction studies and (electromyography performed on various nerves and myotomes using standard techniques	**Diagnostic accuracy:** Tibial somatosensory evoked potentials are effective in detecting abnormalities, as evidenced by abnormal cortical response latency in 60% of patients, chronic neurogenic involvement in 43.3% via needle electromyography, reduced motor unit action potential amplitudes in 16.6%, and abnormal H reflexes in 43.3% of patients in nerve conduction studies **Adverse events:** N/A	It is recommended that patients with adult Tethered Cord Syndrome undergo comprehensive electrophysiological examinations, regardless of whether they present subjective or objective symptoms, as tibial somatosensory evoked potentials have shown to be particularly sensitive in detecting abnormalities
EP : Transcranial electrical motorevoked potentials (TeMEPs)	Pratheesh, 2014[107] N = 45 India	The multimodality intraoperative neuromonitoring included transcranial electrical stimulation, using a D185 stimulator, and recording of transcranial electrical motor evoked potentials with Viking IV or Endeavor machines, the stimulation was done with specific electrode placements, and stimuli consisted of five pulses with specific parameters, also muscle motor evoked potentials were recorded from various muscles, and compound muscle action potentials were recorded using subcutaneous needle electrodes, additionally, free-running	**Diagnostic accuracy:** Evoked EMG was an effective mapping technique for untethering with minimal damage to functional neural tissue, intraoperative MEPs improved in 51% of cases, remained the same in 46.7%, and worsened in 2%, also motor improvement was observed in 7 patients, and clinical improvement in 17 immediately after surgery, with postoperative neurological worsening occurred in 2.2% of cases, also late clinical improvement was seen in 73.5% of patients whose intraoperative MEPs	Intraoperative MEP improvement occurs in about 50 % of the patients following successful untethering

		electromyography recordings were obtained from the same muscle groups, and evoked compound muscle action potential were recorded with 4.1 Hz with a duration of 0.5 ms bipolar stimulation to differentiate neural tissue from scar tissue and identify the filum terminale from nerve roots with a range follow up of 5 to 24 months	remained the same or improved. **Adverse events:** One patient (2.2%) experienced postoperative neurological worsening	
IONM	Dulfer, 2017[108] N = 65 Netherlands	A mapping protocol was employed, which relied on the threshold of nerve root stimulation unique to each patient; nerve roots with stimulation values below three times the threshold were deemed functional and were preserved, while those with values above three times the threshold were considered nonfunctional tethering structures and were surgically cut, also motor evoked potentials were used also to monitor and confirm the surgical decisions regarding the removal of nonfunctional structures which served to strengthen the decision-making during surgical detethering based on the mapping protocol	**Diagnostic accuracy:** Pain domain displayed significant improvement postoperatively, and this improvement was sustained over time, providing enduring relief to patients, while the neurological and urological domains demonstrated stability with a slight decline in symptom severity during the extended follow-up period, indicating positive outcomes in these areas. **Adverse events:** Some patients experinced progressive scoliosis	Surgical detethering with intraoperative neuromonitoring in tethered spinal cord patients demonstrates lasting effects on neurological, urological, and pain domains
IONM	McGrath, 2024[109] N = 20 US	During retethering surgery, transcranial motor evoked potentials (tcMEP) were recorded from various muscles using the Cadwell Cascade system, with regular monitoring intervals and additional intrafield monopolar stimulation performed	**Diagnostic accuracy:** 100% of cases showed intraoperative tcMEPs at or below clinical function levels, with the majority revealing deeper neurological function than clinically observed **Adverse events:** N/A	The presence of positive stimulation potentials below the clinical function level in patients undergoing detethering reoperations for complex spinal dysraphism suggests preserved neuronal connectivity, recommending future

		to ensure nerve integrity and minimize patient movement		treatment strategies that could include devices designed to stimulate these neurological pathways.
IONM	Paradiso, 2006[110] N = 44 Canada	The procedures involved somatosensory evoked potentials testing with electrical stimulation of the posterior tibial nerve to assess both cortical and subcortical responses, along with continuous intraoperative electromyographic recording of lower limb and sphincter muscle activity using a combination of needle and surface electrodes	**Diagnostic accuracy:** Two patients experienced new neurologic deficits, one transient and one permanent, while one patient had persistent posterior tibial nerve somatosensory evoked potentials amplitude reduction following microsurgical manipulation; furthermore, in 36 patients (82%), electromyographic bursts were recorded, and the two patients with postoperative neurologic worsening had electromyographic activity in the affected myotomes, where their new deficits manifested, ultimately demonstrating a sensitivity of 100% for continuous electromyographic but with a specificity of 19%, while for somatosensory evoked potentials, the sensitivity was 50% and specificity 100%. **Adverse events:** One patient experienced a neurologic complication following surgery	The study proposes that combining posterior tibial nerve SSEPs with continuous and evoked EMGs in intraoperative neurophysiologic monitoring can be a valuable adjunct to microsurgery for adult tethered cord syndrome, offering high sensitivity and specificity for predicting neurologic deficits and accurately identifying functional neural tissue
IONM	Pouratian, 2010[111] N = 38 US	Both passive and active monitoring techniques were used, passive monitoring involved continuously monitoring electrical activity to detect nerve discharges caused by surgical manipulation or stretching of neural	**Diagnostic accuracy:** Intraoperative findings revealed that the most common causes of tethering were dense scar tissue and tethered placodes, while electrophysiological	The study supports the effectiveness of surgical untethering for spinal cord syndrome, emphasizing the benefits of electrophysiological monitoring as a reliable intraoperative

		elements, while active monitoring involved stimulating suspected functional tissue and recording compound muscle action potentials at various muscle sites	monitoring played a crucial role in identifying functional neural tissue near tethered elements, significantly influencing the surgical approach in 41% of cases, allowing for more aggressive dissection and untethering in areas without electrophysiological activity and leading to notable improvements in symptoms like low-back pain, lower-extremity paresthesia, and spasticity in a significant majority of patients following untethering surgery, with cutting above electrophysiologically defined autonomous placodes resulting in marked improvement in back pain and spasticity for the majority of patients, although there was one case of immediate postoperative neurological deterioration. **Adverse events:** Infections and cerebrospinal fluid leakage	guidance method to limit iatrogenic injury, identify and untether autonomous placodes, and potentially reduce retethering rates
IONM	Sala, 2013[112] N = 47 Italy	Neurophysiological mapping of the conus-cauda is performed through direct stimulation of these structures and bilateral recording from segmental target muscles	**Diagnostic accuracy:** While mapping identifies ambiguous neural structures, their functional integrity during surgery can be assessed by monitoring techniques only, such as somatosensory evoked potentials (SEPs), transcranial motor-evoked potentials (MEPs) from the limb muscles and anal sphincters, and the	The use of intraoperative neurophysiology, particularly mapping techniques and MEP/BCR monitoring, is recommended, in pediatric tethered cord surgery, as they help identify and spare functional neural tissue, potentially leading to modifications in surgical strategy and improved neurological outcomes

			bulbocavernosus reflex (BCR). **Adverse events:** Two out of 47 patients presented a transient neurological worsening; In six patients, an unexpected muscle response was evoked by stimulating tissue macroscopically considered as not functional	
IONM	Udayakumaran, 2021[113] N = 87 India	Corkscrew electrodes were placed on the scalp at Fc3 and Fc4 for transcranial motor evoked potentials, and they were recording from various muscles using monopolar needle electrodes; bulbocavernous reflex and sensory evoked potential were not considered, mapping of the cauda equina was performed by directly stimulating suspected functional tissue with a concentric bipolar electrode and assessing compound muscle action potentials, also threshold approach was used to distinguish functional from non-functional structures by identifying the lowest threshold current for a healthy nerve, with any structure requiring significantly higher stimulation current considered non-significant	**Diagnostic accuracy:** 32% had preoperative motor deficits, and 28% had abnormal bladder and bowel function; postoperatively, patients without deficits maintained motor function, but some experienced worsening bladder and bowel function, intraoperative neurophysiological monitoring demonstrated 100% high sensitivity and specificity for predicting new motor deficits, with 100% negative and positive predictive values and a 100% diagnostic accuracy. Anal motor evoked potentials had 100% specificity but were 97% sensitive in identifying new anal sphincter deficits. **Adverse events:** N/A	Lower extremity motor MEP monitoring is feasible with very high sensitivity and specificity in monitorable infants and predicts motor outcome
IONM	Wang, 2000[114] N = 1 Taiwan	Intraoperative F response and somatosensory evoked potential monitoring involved using a Cadwell Sierra EP EMG system, with bilateral posterior tibia nerves stimulation conducted at a specific site behind	**Diagnostic accuracy:** Baseline data collected after the muscle relaxant effect had dissipated, showed stable F wave latency with no waveform suppression or latency prolongation during stimulation,	The use of F wave monitoring alongside traditional SSEP monitoring is a potentially safer and more effective method for monitoring spinal cord function during surgical procedures

		and proximal to the medial malleolus, using supramaximal stimulation (34 mA) at a rate of 2 Hz, also a ground connection was established between the stimulation point and the recording electrode, while surface electrodes were positioned over the abductor hallucis, just slightly below and anterior to the navicular tuberosity, and the reference electrode was placed distally near the metatarsal head. SSEP was also performed using the same PTN stimulation and recorded from the Ez-Fpz channel	and throughout the surgical procedure to remove the lumbosacral lipoma, F wave latency and amplitude remained unchanged, indicating stable motor responses, while concomitant somatosensory evoked potential monitoring revealed no pathologic changes; a wake-up test was unnecessary due to the absence of deterioration in F wave and somatosensory evoked potential, the patient exhibited improved sensation and muscle power, with a graded improvement from 4+ to 5/5, which indicates that monitoring is significance in maintaining patient safety and assisting surgeons in making informed decisions during complex nerve-related surgeries **Adverse events:** N/A	
MRI	Aoun, 2019r[115] N = 1 US	A 3 Tesla magnetic resonance imaging of the lumbar spine was performed with the patient lying down; the magnetic resonance imaging included axial T1 and T2 scans, as well as T2 sagittal reconstructions; the T2 sagittal reconstructions were used to evaluat	**Diagnostic accuracy:** The patient's MRI revealed a low-lying conus medullaris at the L3-4 disc space level, and there was significant forward movement of the spinal cord, exceeding 10% of the central canal width when comparing prone to supine sagittal T2 images, so prone MRI is a valuable tool for assessing spinal cord tethering. **Adverse events:** N/A	Prone MRI is a valuable tool for neurosurgeons assessing adult patients with ambiguous clinical and imaging findings of spinal cord tethering

MRI	Davidoff, 1991[116] N = 87 US	Barson's study of normal vertebral levels for termination of the spinal cord' was the reference used in the evaluation of spinal anatomy; magnetic resonance imaging evidence of caudal displacement of the conus medullaris of the spinal cord to the level of	**Diagnostic accuracy:** Of the 87 patients who have undergone treatment for anorectal malformations, thus far 8 have had spinal cord abnormalities detected that required an operation, while 6 had minor abnormalities that are being followed-up. Two patients with intermediate level imperforate anus showed physical findings suggesting the presence of a dysraphic lesion of the spinal cord. Two others had spinal cord malformations detected due to neurological deficits, specifically lower extremity dysfunction. Additionally, 4 patients had occult spinal dysraphism identified through screening MRI. Three of them underwent routine MRI as part of their evaluation for anorectal malformation, while the fourth patient had a tethered spinal cord and syrinx detected at 13 months of age. One more patient with significant difficulties in maintaining bowel continence had a lipoma in the thecal sac detected through MRI, leading to the release of the tethered cord with subsequent improvement in bladder control. One false-positive MRI interpretation occurred, leading to spinal exploration, but no abnormal neuroanatomy was found during the operation. Four	All patients with anorectal anomalies should undergo MRI imaging of their spines during initial evaluation to screen for occult spinal dysraphism, and consideration should be given to recalling older patients for MRI evaluation

			patients with fat in the filum terminale of the spinal cord were asymptomatic and had appropriately positioned conus, so surgical intervention was not pursued. Two patients with small syrinxes on MRI are being closely monitored. **Adverse events:** N/A	
MRI	Howells, 2022[117] N = 273 US	Magnetic resonance imaging disclosed a fatty or thickened filum, and a conus medullaris located caudal to L2, which are signals for the possibility of tethering; no other magnetic resonance imaging information provided	**Diagnostic accuracy:** 233 patients (85%) had a fatty filum, 179 (66%) had a thickened filum (greater than 2 mm in diameter, regardless of fat infiltration), and 106 (39%) had a low-lying conus, children under 5 years of age were less likely to exhibit urological, gastrointestinal, neurological, or orthopedic symptoms, and patients with thickened filum were less likely to have urological symptoms, and those with low-lying coni were less likely to have gastrointestinal symptoms, as well as patients who presented with symptoms initially showed reduced symptom rates during follow-up, but the reduction in symptoms over time did not correlate with demographic or diagnostic factors **Adverse events:** Constipation	The study notes constipation as a common symptom and observes that children under 5 years old were less likely to show evident symptoms across various domains
MRI	Just, 1988[118] N = 56 Germany	MRI examinations were performed with a 0.28 Tesla resistive magnet system, T1- and T2- weighted spin echo sequences with a slice thickness of 8-10ram were applied routinely; strongly T2-	**Diagnostic accuracy:** In 47 of 56 cases the diagnosis of tethered cord could be proposed. **Adverse events:** N/A	MRI is highly efficient in the diagnostic evaluation of dysraphic myelodysplasia

		weighted fast-imaging procedures in axial or sagittal orientation to		
MRI	Nakanishi, 2013[119] N = 26 Japan	T2- weighted magnetic resonance imaging examinations in sagittal and axial views were performed using a Signa 1.5-T device or a Signa HDxt 3.0-T device with all patients in a prone position on a flat table; on each axial view, the distance between various	**Diagnostic accuracy:** On prone-position axial MRI, the terminal filum was separated from the cauda equina and was shifted caudally to posterior in the subarachnoid space in all patients with OTCS. The locations of the caudal cauda equina shifted to ventral in the subarachnoid space. The TF values in the OTCS group were significantly lower than those in the control group at the L3–4 ($p = 0.023$), L-4 ($p = 0.030$), L4–5 ($p = 0.002$), and L-5 ($p < 0.001$) levels. In contrast, the DN values in the OTCS group were significantly higher than those of the control group at the L-2 ($p = 0.003$), L2–3 ($p = 0.002$), L-3 ($p < 0.001$), L3–4 ($p < 0.001$), L-4 ($p = 0.007$), L4–5 ($p = 0.003$), and S-1 ($p = 0.014$) levels, and the VN values in the OTCS group were also significantly higher than those of the control group at the L2–3 ($p = 0.022$), L-3 ($p = 0.027$), L3–4 ($p = 0.002$), L-4 ($p = 0.011$), L4–5 ($p = 0.019$), and L5–S1 ($p = 0.040$) levels. Sections were collected during surgery for histological evaluation, and a decreased elasticity	Patients with occult tethered cord syndrome exhibit significant posterior positioning of the terminal filum and anterior positioning of the cauda equina on prone MRI, indicating a potential difference in elasticity between the two structures

			within the terminal filum was suggested. **Adverse events:** N/A	
MRI	Niggemann, 2011[120] N = 4 Germany	MRI scans were taken in different positions (neutral sitting, flexion sitting, extension standing, and supine); various magnetic resonance imaging sequences were used, including T1 and T2-weighted sequences and short tau inversion recovery sequences, then	**Diagnostic accuracy:** Three patients had a low conus medullaris located at L4 or L5, continuing into a thickened filum terminale, two of them had their thickened filum terminale tethered to sacral cysts, and one was tethered to a sacral lipoma, also had sacral dysraphism, and one had a conus medullaris at L1 with a slightly thickened filum terminale tethered to a small lipoma at L5; in flexion, the filum terminale was clearly distinguishable from nerve roots, tethering sites were identifiable in flexion due to lumbar spine straightening and partial kyphosis, while in the neutral sitting position, there was an increasing lordosis, and contact with the myelon or cauda equina and dorsal elements of the lumbar spinal canal was observed in all patients **Adverse events:** As the lordosis of the lumbar spine increases, the degree of contact between neural structures and dorsal elements of the lumbar spinal canal also increases, making it more challenging to detect Tethered Cord Syndrome	Positional MRI can be useful to confirm or rule out TCS and helpful to identify the site of tethering

MRI	Sun, 2022[121] N = 46 China	Fetal spinal MRI was performed on 1.5 T (Achieva Nova dual, Philips Medical Systems) or 3.0 T (Magneton Skyra, Siemens-Healthcare) MRI devices. A single-shot turbo spin echo (SSTSE) sequence, a balanced turbo-field echo (BTFE) sequence, and a diffusion-we	**Diagnostic accuracy:** Significant differences were found between the 13 fetal patients and the 20 children with TCS (U, 26.50; Z, -3.87; p < 0.001) and between the normal fetal and child groups (U, 23.50; Z, -4.13; p < 0.001). The CMs in fetuses with tethered cords were marked lower than those in normal fetuses (U, 0.00; Z, -5.43; p < 0.001), with a similar relationship for the CM level between children with TCS and normal counterparts (U, 3.50; Z, -5.43; p < 0.001) **Adverse events:** N/A	The current study's results indicate that tethered spinal cord syndrome can be diagnosed in utero with MRI combined with several characteristics, particularly the position of the conus medullaris. Special attention should be paid to the gestational age of the fetus because normal changes in spinal cord position occur with gestational development
MRI	Sutterlin, 1987[122] N = 22 US	Performed with a Siemens Magnetome of 1.0 T maximal capacity, operating at 0.35 T; spin-echo techniques were used to obtain both T1-weighted and T2-weighted images in most cases	**Diagnostic accuracy:** 10/22 patients examined during this 12-month period proved to have significant intraspinal pathology diagnosed by MRI. Just as important was that intraspinal pathology was ruled out in the other 12 patients. Diastomatomyelia was diagnosed in 4 patients, syringomyelia in 4 patients, tethered spinal cord in 3 patients, intraspinal lipomas in 2 patients, and a spinal cord tumor in one patient. **Adverse events:** N/A	MRI is efficacious in diagnosing developmental conditions of the neuroaxis and recommend MRI as an early diagnostic study in the appropriate clinical situations
MRI,Physical exam,Urodynamic	Zhang, 2020[123] N = 1 China	Magnetic resonance imaging of the lumbosacral region showed an increased curvature of lumbar vertebrae, and lower conus medullaris Revealed the lumbar lordosis angle increased, with tenderness at the spinous process level	**Diagnostic accuracy:** **Adverse events:** Lower back pain complicated by increased lumbosacral angle for more than 20 days	Surgery is recommended when children present with low back pain and an increased lumbosacral angle

		of approximately L1, L2, and L4-S4 with no evident tenderness or percussion pain in the paravertebral muscle; the lumbar forward flexion activity was significantly Measured the fatigable detrusor contraction and the maximum detrusor contractile pressure		
MRI,Ultrasound	Duczkowska, 2011[124] N = 252 Other	1.5T magnets; Single-shot fast spin-echo (ssFSE) or half-Fourier acquisition single-shot turbo spin-echo (HASTE) sequences were performed; T-2 weighted images in 3 planes (Axial, coronal, and sagittal) acquired through the brain followed by images in 3 pl	**Diagnostic accuracy:** Ultrasonography remains the first method in the evaluation of fetal central nervous system (CNS) abnormalities but in case of the spinal canal and cord it is often insufficient since the bony structures may obscure these structures; Prenatal magnetic resonance imaging (MRI) is therefore the final noninvasive tool for the assessment of these malformations allowing for correction of sonographic findings, revealing the full extent of complex lesions and choosing the candidates for in utero treatment **Adverse events:** N/A	Magnetic resonance imaging is highly valuable and suitable for recognizing fetal spinal canal and spinal cord pathologies
MRI,Urodynamic,EP	Suppiej, 2009[125] N = 74 Italy	Seventy-four anorectal malformation (ARM) patients underwent spinal magnetic resonance imaging (MRI) performed with 1.0-T magnet (Marconi Picker Polaris) to assess the condition of their spinal cord and identify any abnormalities; all studies were Axial a The ARM patients dually diagnosed with tethered cord patients underwent a series of	**Diagnostic accuracy:** Twenty-five out of 74 ARM patients had evidence of tethered cord at MRI (33.7%): 18/25 high lesions (72%) and 7/25 (28%) low lesions. The combined use of SEPs and UDs allowed to classify these 20 patients within three main categories: group S (‘‘stable’’, 9 patients), group C (possible ‘‘candidates’’ for	The study recommends routine MRI and multidisciplinary follow-up for tethered cord in children with anorectal malformations while suggesting the combined use of somatosensory-evoked potentials (SEPs) and urodynamic studies as a potentially helpful adjunct for cases opting for a 'wait and see' approach rather

		assessments, including videourodynamic (UD) studies (SEPs), and neurological examinations; baseline assessments were conducted for all these patients; follow-up assessment The ARM patients dually diagnosed with tethered cord patients underwent a series of assessments, including videourodynamic (UD) studies, somatosensory-evoked potentials (SEPs), and neurological examinations; baseline assessments were conducted for all these patients; follow-up assessments for these patients occurred at 5 and 10 years of age, but the schedule was adjusted based on initial findings; somatosensory-evoked potentials methodology adopted in our laboratory and normal values have been previously described; a dedicated channel montage was used, with recording electrodes placed: over the tibial nerve at the popliteal fossa referred to contralateral popliteal fossa, over the spinous process of the twelfth thoracic vertebra referred to supra-umbilical region, over the spinous process of L5 vertebra referred to supra-umbilical region and on the scalp 2 cm behind the vertex referred to mid-frontal region	unthetering, 8 patients), and group O (‘‘operated’’, 3 patients). Patients of group S, although affected from various urinary, fecal, and orthopedic signs and symptoms, remained stable at MRI, neurological examinations, SEP, and UD repeated over time. They have been scheduled for repeating instrumental and clinical examinations at the time points defined as ‘‘high risk’’, that is, during periods of accelerated growth. Patients of group C, despite the fact they persist clinically unchanged, show alterations at either UD or SEP, and are scheduled for repeating all examinations at an individually tailored short-term follow-up. If signs and symptoms of worsening would occur at instrumental or clinical check ups, respectively, the child would be promptly referred to the neurosurgeon. Patients of group O (15%) were untethered based on the results of UD, SEP, and neurological status. Patient 1: This patient underwent surgery at 6 years and 6 months due to the onset of urine leakage without urinary infections. UD Findings: Urodynamic (UD) evaluation showed reduced bladder capacity for their age, reduced compliance, detrusor	than prophylactic surgery.

			overactivity, a flattened uroflow pattern, and postvoiding residue of more than 20%. Somatosensory-evoked potentials (SEPs) were normal before the surgery. Postoperatively, this patient showed clinical improvement over time and is currently continent. They are awaiting further UD and MRI assessments. Patient 2: This patient underwent surgery at 6 years and 10 months due to initial gait disturbance, asthenia, and worsening fecal incontinence. Abnormal findings had been reported previously. SEPs from the posterior tibial nerve showed delayed central conduction and abnormal cortical activation, while SEPs from median nerve stimulation and UD were normal. Postoperatively, the lower limb motor deficit rapidly normalized, and SEPs improved. At 18 months postoperatively, the neurological examination remained normal. Patient 3: This patient had cloacal exstrophy and performed intermittent catheterization. They were untethered at 6 years and 4 months. SEPs from the posterior tibial nerve showed delayed central conduction, while SEPs from median nerve stimulation were normal.	

			Postoperatively, the neurological examination remained normal, despite some shortening of the right leg. SEPs normalized. **Adverse events:** N/A	
Myelogram	Chaseling, 1985[126] N = 23 Australia		**Diagnostic accuracy:** There was no morbidity directly associated with myelography. **Adverse events:** There was no morbidity directly associated with surgery.	The tethered cord group presented with progressive neurological deterioration and changing patterns of somatosensory-evoked potentials; surgery was likely to be beneficial to such patients, although the clinical details of outcome are scanty.
Myelogram	Fitz, 1975[127] N = 24 Canada		**Diagnostic accuracy:** Properly performed oil or air myelography is the only method of preoperative confirmation of a tethered conus and should be done in all cases where it is suspected. **Adverse events:** N/A	Operative results are difficult to evaluate in a growing child whose neurological status is normally changing. Over-all there is a definite improvement of at least some symptoms in our series. At worst there is a halting of symptom progression. Even children with bladder difficulties have improved. There seems to be a better improvement in those with only a tethering without associated intradural masses, possibly reflecting a lesser degree of abnormality.
other : Anorectal manometry and defecography	Becker, 1994[128] N = 1 Germany	Anorectal manometry was performed using a multilumen continuous-perfusion catheter in a stationary pull-through technique	**Diagnostic accuracy:** The observation revealed a decrease in resting pressure and a reduced increment in squeeze pressure, while changes in pressure during coughing and straining fell within the normal range, with an elevated rectal perception threshold;This elevated threshold	Specific diagnostic procedures directed to intestinal motility and perception were of decisive importance in enabling us to apply the appropriate treatment to our patient

			holds particular significance as it guides in the selection of the most appropriate treatment for patient **Adverse events:** N/A	
other : Intrathecal endoscopy	Woods, 2010[129] N = 68 Japan	The patients underwent endoscopic examination of the filum and cauda equina; this involved a lumbar or sacral laminectomy, followed by the insertion of a flexible endoscope through a small dural and arachnoid incision into the subarachnoid space; the filu	**Diagnostic accuracy:** Endoscopic observation revealed that the filum terminale was located behind the cauda equina and in contact with the posterior arachnoid membrane, and the filum elongation was consistently less than 10% on the stretch test, while in healthy individuals, it is typically greater than 50% on the same test. **Adverse events:** Cerebrospinal fluid leakage	Endoscopic identification of the posteriorly displaced filum, confirmed by open surgery, along with the stretch test and subsequent filum sectioning, led to metabolic and neurological improvements
Ultrasound	Huynh, 2003[130] N = 1 US	An AcusonSequoia 6.01 with a linear array transducer at 8, 10, 11, and 13 MHz was used for the sonographic evaluation; sonography was performed with the infant in a prone position	**Diagnostic accuracy:** Sonography revealed that the spinal cord extended inferiorly to the L4-L5 disc space in the sagittal view. On MRI, On the T1-weighted and T2-weighted scans, sagittal views showed a very thin and elongated spinal cord extending down to L5. A conus medullaris was noted at the L5-S1 disc space. **Adverse events:** NR	Sonography performed by experienced sonographers plays a very important role in the early detection of a tethered cord in infants carrying clinical suspicion
Ultrasound	Raghavendra, 1983[131] N = 16 US	All examinations were performed with a mechanical-sector, meal-time ultrasound unit (Advanced Technology Laboratories, Bellevue, WA) with the transducer operating at a frequency of 7.5 MHz, after applying the ultrasonic gel, the	**Diagnostic accuracy:** Using sonography, it is difficult to determine the exact level of termination of the conus with respect to the vertebral bodies, two criteria are used to diagnose cord tethering: inability to visualize the normally	High-resolution, real-time ultrasonography is a safe and rapid technique for evaluating the spinal cord in infants

		transducer probe was place	tapered conus medullaris and visualization of the spinal cord in the lumbosacral spinal canal. Overall, the spinal cord is readily visualized by sonography in infants less than 5 months of age, presumably because of lack of ossification of the posterior elements of the spine. It is imperative that higher frequency transducers (5 MHz or higher) be employed to adequately visualize the spinal cord. Additionally, real-time capability allows for screening of the entire spinal canal, including the intracranial contents, in less than 15 minutes. Although axial views of the spinal cord can be obtained, sagittal sections provide better spatial omientation for interpretation. **Adverse events:** N/A	
Ultrasound : linear transducer	Lode, 2008[132] N = 6 Germany	The spinal cords of all infants were investigated with a high-resolution linear transducer with a frequency of > 7.5 MHz (Sequoia, Acuson); Sagittal sections through the midline and additional transverse sections through the thoracic and lumbar spine were	**Diagnostic accuracy:** The sonographic diagnosis was confirmed by MR-imaging before neurosurgical intervention in all patients **Adverse events:** N/A	The study emphasizes the use of spinal sonography for early diagnosis of spinal dysraphism in infants with cutaneous markers or back masses
Urodynamic	Alatas, 2015[133] N = 41 Turkey	A Dyno® device was utilized to measure various urodynamic parameters, involving the introduction of a urethral cystometry catheter into the bladder to measure vesical pressures, a rectal balloon catheter	**Diagnostic accuracy:** In patients who underwent tethered cord surgery, preoperative urodynamic findings showed various issues, including extremely active detrusor, detrusor	Urodynamic improvement in three out of four patients undergoing surgery for tethered spinal cord syndrome during second control urodynamics emphasizes the importance of ongoing

		into the rectum to measure intraabdominal pressures	sphincter dyssynergy, and normal urodynamic results, after surgery, some patients experienced improvements, such as transitioning from extremely active detrusor to detrusor sphincter dyssynergy or normal urodynamic patterns, one patient with both extremely active detrusor and detrusor sphincter dyssynergy also showed reduced intra-bladder pressure postoperatively, while one patient with normal urodynamic results had no change, urodynamic findings are important in assessing the development of neuropathic bladder, tethered cord, and/or retethering **Adverse events:** N/A	urodynamic studies for assessing the development of neuropathic bladder, tethered cord, and/or retethering
Urodynamic	Dushi, 2011[134] N = 29 Switzerland	A 4-parameter Urinary Dysfunction (UD) score was used to evaluate bladder function, grading volume, compliance, detrusor activity, and bladder sphincter synergy based on their deviation from normal values, with bladder volume assessments made when a child	**Diagnostic accuracy:** There was an improvement in urodynamic scores post-surgery in some patients **Adverse events:** There was no improvement in urodynamic scores in some patients, and they experienced worsening neurological conditions.	The urodynamic score is a useful tool for monitoring children with lipomyelomeningocele as it correlates well with the presence of symptoms.
Urodynamic	Fukui, 1980[135] N = 46 Japan	A voiding urodynamic examination was performed, measuring intra-abdominal, vesical, and urethral pressures, anal sphincter tone, electromyography of the anal sphincter, and flow rate simultaneously using a 6-channel polygraph; two 4F open-tip catheters we	**Diagnostic accuracy:** Postoperative voiding parameters improved immediately and six months after the operation, likely due to the normalization of detrusor contraction and reduced tonus at the vesical neck and external urethral sphincter, as evidenced by	As a result, urodynamic and electrophysiologic examinations are considered as excellent methods, which are safe and give objective findings, for diagnosis and prolonged observation of not only tethered cord syndrome but also congenital neurogenic bladder

			decreases in maximal vesical voiding pressure, demonstrating the satisfactory results of intraspinal surgery for tethered cord syndrome, with urodynamic and electrophysiologic examinations being considered safe and effective methods for diagnosis and long-term observation. **Adverse events:** N/A	
Urodynamic	Giddens, 1999[136] N = 21 Canada	A 5F pressure catheter and a Foley catheter are inserted into the bladder, a 14F rectal balloon catheter is also placed; electromyography is recorded from the pelvic floor muscles with urodynamics monitor bladder, intra-abdominal, and rectal pressures	**Diagnostic accuracy:** Urodynamic improvements were observed in 4 out of 14 patients (29%), while no changes were noted in 10 patients (71%), among the 4 patients with preoperative external detrusor-sphincter dyssynergia, 3 experienced resolution of this condition postoperatively, and 1 remained unchanged. Regarding urinary symptoms, 19% of patients (4) saw improvement, 76% (16) remained unchanged, and 5% (1) experienced worsening **Adverse events:** Some patients did not experience any change in their conditions, and patients with external detrusor-sphincter dyssynergia did not demonstrate any improvement	Urodynamic evaluation is recommended for adults with tethered cord syndrome before neurosurgical procedures, and surgical untethering for those with neurological and orthopedic symptoms

Urodynamic	Hellstrom, 1986[137] N = 18 US	The urodynamic study involved a simultaneous cystometrogram, perineal electromyogram, and voiding cystourethrogram; a room-temperature cystographic contrast medium was introduced through a urethral catheter without sedation or anesthesia, at a rate of app	**Diagnostic accuracy:** Improvements in bladder function for some, while others remained the same **Adverse events:** Some patients did not experience any improvement in bladder function	Urological evaluation in patients with tethered spinal cord syndrome is valuable for diagnosis and effective preoperative and postoperative management, and the observed improvement in lower urinary tract function in some patients advocates for early and proactive neurosurgical intervention in individuals with this syndrome
Urodynamic	Palmer, 1998[138] N = 20 US	Urodynamic evaluation both before and after surgery; an urethral catheter was used for dynamic studies, the bladder was filled with sterile water at a controlled rate, and the expected bladder capacity was determined based on the child's age; medications,	**Diagnostic accuracy:** 15 (75%) showed improvement in their urodynamic parameters, these improvements varied, with 10 children showing improvement in one parameter, 3 children in two parameters, 1 child in three parameters, and 1 child in four parameters; the urodynamic studies identified only 2 children had decreased pressures below 40 cm of water after the surgery, as well as two children experienced postoperative deterioration of bladder compliance **Adverse events:** 1 child demonstrated a loss of bladder sensation, also bladder compliance remained unchanged in 14 of the children	The study recommends routine preoperative and postoperative urodynamic evaluations in children with tethered cord syndrome, as these assessments reveal improvements in urodynamic findings after spinal cord untethering and can identify asymptomatic cases with urinary tract changes requiring early management
Urodynamic	Proctor, 2001[139] N = 16 US	Urologic assessment was performed by a pediatric urologist who also performed the urodynamic studies; urodynamic evaluation was performed using cystometrogram and electromyography of the external urethral sphincter	**Diagnostic accuracy:** Although none of the group 1 children presented with urological symptoms, 72% of them had abnormalities on urodynamic testing. In group 2, 1 patient had any voiding	Patients with spinal cord meningeal cysts typically tolerate surgery well with few complications, experiencing rare neurological deterioration, but in cases of retethering, intervention is needed. Although

			difficulty, even though 3 of the 4 patients had a urodynamic abnormality. Two of 4 patients had UMN disease, 1 had LMN dysfunction, and 1 patient had a normal examination. **Adverse events:** There was only one early surgery-related complication: one patient developed a cerebrospinal fluid leak that required wound reexploration on postoperative Day 10. No source for the leak was found, and the patient recovered uneventfully with bedrest. This	surgery stabilizes or improves bowel and bladder function and relieves pain, preexisting vertebral column deformities often progress, necessitating spinal fusion in most cases. Urodynamic studies is effective in patients to assess spinal cord dysfunction, guide surgical decisions, aid in perioperative management.
Urodynamic	Satar, 1995[140] N = 21 US	A 7F triple lumen urodynamic catheter was inserted into the bladder transurethrally allowed continuous measurement of intravesical pressure as the bladder was filled to capacity; saline warmed to 37C was infused at a rate equal to 10% of predicted capacit	**Diagnostic accuracy:** **Adverse events:** N/A	Older children and adults with occult spinal dysraphism are at a higher risk of presenting with irreversible urological and neurological issues
Urodynamic	Zoller, 1991[141] N = 14 Germany	In a standardized manner with the patient in a supine position, urodynamic examinations were performed, during which the residual volume was estimated prior to the initiation of the study, utilizing an urodynamic device to record intravesical and rectal p	**Diagnostic accuracy:** Urodynamic evaluations detected diverse bladder dysfunctions, showing some improvement after neurosurgical interventions but also complications, highlighting the need for pre- and postoperative urodynamic assessments as a crucial component of care for children with tethered spinal cord syndrome. **Adverse events:** Few patients developed urodynamic	Urodynamic evaluation should be repeated postoperatively for patients with tethered spinal cord syndrome due to the potential deterioration of bladder function following neurosurgical untethering

			dysfunction after surgery	
Urodynamic,EP	Selçuki, 1998[142] N = 13 Turkey	Urodynamic studies Somatosensory-evoked potentials	**Diagnostic accuracy:** Urodynamic studies appear to be more predictive of a tight filum terminale than SSEPs. However, pathological SSEP results seem to correlate with poor surgical outcomes. Ninety-three percent of operated patients were continent by the first post-surgical day. However, disappointingly, almost half lost continence within the first month after surgery. **Adverse events:** N/A	In cases of incontinence with a normal level conus medullaris, but urodynamic studies showing a hyperreflexic neurogenic bladder, sectioning of the filum terminale often improves continence.
X ray	Merx, 1983[143] N = 16 Netherlands	Myelography under general anesthesia or Valium; paramedian lumbar punctures in lateral decubitus with a short bevel lumbar puncture needle	**Diagnostic accuracy:** 9/16 patients showed a combination of tethering causes and all patients who underwent meingomyelocele repair in the past showed an additional filum terminale **Adverse events:** N/A	Lumbar myelography can diagnose low positioned conus and its tethering causes

Table F.2. KQ2 case series

Study: Author, Year; Study Size; Location	**KQ2 Interventions**	**Outcome and Results** **Adverse Events**	**Author Conclusions**
Inoue, 1994[144] N = 12 Japan	Other After microsurgical untethering of the spinal cord, efforts were made to remove as much lipomatous and/or scar tissue as possible; all spinal roots in the affected area were carefully exposed and identified, extending from the rostral normal roots to the caudal filum terminale, following spinal reconvolution or conus reconstruction, a surgical membrane made of expanded polytetrafluoroethylene (Gore-Tex) was placed over the reconstructed spinal cord and attached to the lateral dural surface with stay sutures to prevent slipping, in cases where the dura mater was insufficient for primary closure, paravertebral fascia was used for dural plasty, the laminar defects were covered and reinforced with paravertebral muscle, and the patients were followed up for a period ranging from 23 months to 7 years	**Bladder:** N/A **Neurological:** Among the patients in the treatment surgery group, four showed either improvement or had unchanged conditions, whereas in the prevention surgery group, patients did not experience any changes in their conditions, and there were no adhesions or neurological deterioration observed in either group **Adverse events**: N/A	It is concluded that this simple new method is effective for the treatment and prevention of tethering and/or retethering of the spinal cord, although a longer follow-up study is required.
Tubbs, 2004[145] N = 11 US	Other Surgical sectioning of the tight filum terminale	**Bladder:** Case 11: After surgery the patient demonstrated voluntary control in the quadriceps and hamstring muscle groups, along with bladder and bowel control **Neurological:** The evidence presented in these 11 cases is insufficient to conclude that either neurological deficit or scoliosis resulted from spinal cord tension **Adverse events**: N/A	When scoliosis is accompanied by neurological deficits, surgery to section the tight terminal filum is recommended, as it often leads to improvement in neurological symptoms
Vassilyadi, 2012[146]	Other A low lumbar single or partial laminectomy	**Bladder:** At primary presentation, 51.4% had bladder/bowel dysfunction. Patients with bladder/bowel dysfunction improved by 84%.	A more conservative approach is needed for initially asymptomatic

N = 146 Canada	was performed, followed by a linear durotomy to expose the cauda equina, the filum terminale was identified based on its thickness and pale color, approximately 1 cm of the filum terminale was exposed, coagulated at a low frequency with the bipolar instrument at either end, and sectioned after 0.5–2 mA stimulation with a hand-held battery-operated stimulator; in the majority of cases a specimen was submitted to Pathology; intraoperative neurophysiology monitoring was not used	**Neurological:** At primary presentation, 26.7% had neuroorthopedic symptoms. Patients with neuroorthopedic symptoms improved by 92%. **Adverse events**: Of the 146 patients at CHEO who underwent surgery, 7.5% retethered, with 36% being initially asymptomatic.	children without tethered cord symptoms to avoid unnecessary surgery and the potential risk of symptomatic retethering in the future
Galhom, 2013[147] N = 10 Egypt	Other surgery Laminectomy performed on asymptomatic and symptomatic patients: untethering procedures consist of dissecting and debulking the lipoma upon the lumbodorsal fascia, laminectomy on the lower lumbar spine according to the level involved and opening the dura for exposing the intradural portion of the lipoma; the junction between the lipoma and the neural placode is dissected and divided for untethering; the lipoma was subtotally excised to allow the neural placode to move freely within the spinal canal, and any tethering arachnoidal adhesions were divided; after the subtotal resection of the lipoma, the pia was closed if possible and the filum terminale	**Bladder:** There was statistically significant improvement in the bladder function capacity, compliance and post voiding residual (p=0.023, p=0.005, p=0.004, respectively). Only two patients still had hyperreflexic bladder **Neurological:** During the follow-up, all the patients had either symptoms unchanged (3 patients, 30%) or improved (7 patients, 70%); in 7 patients symptoms totally resolved; one patient didn't improve from leg weakness after surgery and had equinovarus deformity; no specific outcomes partitioned out for prophylactic treatment **Adverse events**: Five children had (50%) with CSF leakage; two patients (20%) had persistent leakage that mandate subcutaneous catheter drainage above the incision line and improved after two weeks; one patient (10%) had skin infection due to primary skin sinus and improved with time, one patient with transient foot drop for two months, and lastly one patient (10%) had transient urine retention due to conus manipulation in case with caudal conus lipoma; no specific outcomes partitioned out for prophylactic treatment	Early recognition of symptoms and signs of tethering of the spinal cord is crucial in diagnosis and prognosis of spinal dysraphism. Early surgical release of the tethering elements is important for recovery and avoidance of retethering.

	was divided to release any potential tethering		
Arts, 2006[148] N = 2 Netherlands	Surgical detethering Surgical detethering technique consisting of wrapping a dura graft around the myelum to prevent recurrent transdural herniation to treat Idiopathic transdural spinal cord herniation	**Bladder:** N/A **Neurological:** Case 1: The initial post-operative neurological deficit was unchanged and there was no sign of cerebrospinal fluid leakage; Case 2: Postoperative MRI showed untethering of the spinal cord with a normal position in the spinal canal and the wrapped sheet of durapatch visible, the patient's neurological deficit was improved. **Adverse events**: N/A	A novel technique of using a dural graft around the spinal cord is effective in preventing excessive manipulation during surgery
Babic, 2003[149] N = 47 Other	Surgical detethering N/A	**Bladder:** Few patients had improvement in sphincter function **Neurological:** Pain, motor, and scoliosis improvement in some patients **Adverse events**: Worsen or no changes in motor, scoliosis, and sphincter functions	Early prophylactic surgery is recommended
Bulsara , 2001[150] N = 42 US	Surgical detethering All patients received lumbar laminectomies with microsurgical lipoma resection and neural placode reconstitution, followed by clinical examinations at 1 week, 3 months, and annually post-surgery	**Bladder:** improvement in bladder and bowel functions **Neurological:** Improvement in pain, motor and sensor functions **Adverse events**: Superficial wound infection occurred in one patient, while others experienced no significant changes in bowel function, scoliosis, or pain	It is recommended to provide specific counseling based on different types of spinal lipomas, investigate their unique tethering properties
Dushi, 2011[134] N = 29 Switzerland	Surgical detethering Spinal untethering was performed with at least 2 years of urodynamic follow-up	**Bladder:** Some patients experienced an improvement in urological function. **Neurological:** Some patients experienced improvement in neurological function. **Adverse events**: There was no improvement in urodynamic scores in some patients, and they experienced worsening neurological conditions.	The urodynamic score is a useful tool for monitoring children with lipomyelomeningocele as it correlates well with the presence of symptoms.
Farrokhi, 2006[151] N = 36 Iran	Surgical detethering Complete untethering of the spinal cord, removal of the tethering processes such as the osseous septum in split cord malformations, and the removal of a intramedullary lipoma if present; after closure of the fascia and skin, reconstructive surgery was performed if necessary	**Bladder:** Bladder dysfunction observed in 7 before surgery vs in 4 after surgery. **Neurological:** The differences between preoperative and postoperative examinations were statistically significant (p 0.05) in relation to reflex anomalies, hyposhesia, limb paresis, foot deformity, and soliosis. **Adverse events**: CSF leakage, wound infection, meningitis	Prophylactic surgical intervention in cases of occult spinal dysraphism is a safe and recommended procedure prior to the onset of neurologic deterioration.
Foo, 2022[152] N = 16 Singapore	Surgical detethering Surgery for detethering is performed under intraoperative neuromonitoring;	**Bladder:** patients who experienced bladder dysfunction preoperatively (n=3), remained unchanged after surgery. **Neurological:** All patients who underwent prophylactic intent surgery (n¼13, 81.2%)	Early recognition and timely intervention are crucial for managing focal nondisjunction of primary neuralisation and a multidisciplinary

	briefly, an elliptical incision around the cutaneous lesion of interest is opened and traced inwards to its entry into the spinal canal; next, laminectomy is performed after widening the interlaminar space to expose the tract's attachment to the dura; under microscope visualization, the dura is opened; after ensuring hemostasis, the dura is closed primarily with continuous monofilament sutures	remained neurologically intact during the entire duration of follow up. Amongst patients who underwent therapeutic intent surgery (n=3, 18.8%), their pre-existing neurological deficits remained unchanged after surgery. **Adverse events**: Wound-related issues were encountered in four patients (25%). Three of them had superficial wound infections that were treated conservatively with systemic antibiotics. The remaining patient had a deep surgical wound infection associated with CSF leak, requiring surgical repair and prolonged antibiotics.	approach to achieve favorable outcomes is recommended
Hayoshi, 2019[153] N = 53 Japan	Surgical detethering Prophylactic tethered cord release: subject did not reveal details of tethered cord release	**Bladder:** Overall, 43 (81%) voided volitionally, and 41 (77%) were continent without clean intermittent catheterization at the latest follow-up. Six patients (11%) were incontinent with or without clean intermittent catheterization. two patients (4%) had renal dete **Neurological:** NR **Adverse events**: NR	Even after prophylactic tethered cord release in infancy in children with spinal lipoma, 19% of patients needed clean intermittent catheterization and 11% of patients had urinary incontinence in the long-term follow-up of children with spinal lipoma in lo
Huang, 2010[154] N = 25 China	Surgical detethering Under general anesthesia, patients underwent surgery for lipomyomatous mass removal involving incision, dissecting the mass, and resecting adjacent laminae, partial lipoma excision, spinal covering suturing, and dural closure, with no need for additional plastic surgery, and follow-up from 1-4years	**Bladder:** Improvement in bowel and bladder functions by one Hoffman's grade **Neurological:** Improvement in neurological functions **Adverse events**: Only two patients experienced temporary neurological deterioration following surgery, including one who had a temporary worsening of bladder control	Early surgical intervention for lipomyomatous mass patients, including asymptomatic ones, is recommended to prevent neurological deficits, involving partial lipoma excision, suturing of the spinal pia mater, and a longitudinal cut of the filum terminale t
Indriyani, 2022[155] N = 1 Other	Surgical detethering lipomyelomeningocele resection using intraoperative neurophysiological monitoring with three weeks of following-up	**Bladder:** Urinary incontinence improved, and the sensation of urination was restored, but fecal incontinence persisted **Neurological:** There was an improvement post-operative in neurological deficits **Adverse events**: No complications post surgery	lipomyelomeningocele resection with intraoperative neuromonitoring guidance is advised, as it helps reduce postoperative neurological complications by enabling the identification and preservation of

			entrapped neural networks.
Kanev, 1990[156] N = 108 US	Surgical detethering	**Bladder:** Patients with bladder paralysis experienced pyelonephritis. **Neurological:** Motor and sensory function improvement **Adverse events**: Cerebrospinal fluid leakage and meningitis	Lipomyelomeningocele with tethered cord is a severe condition that necessitates surgical intervention to prevent bladder or neurological deterioration, preferably at an early age.
Lim, 2023[157] N = 164 Singapore	Surgical detethering The surgical procedure for detethering fatty filum terminale involves making a partial laminotomy, opening the midline of the dura, performing direct stimulation to confirm the location resecting while minimizing residual tissue, primarily closing the dura with sutures, applying TachoSil to aid in sealing, and closing the remaining layers of the wound; surgery for prophylactic intent Detethering surgery for therapeutic intent	**Bladder:** N/A **Neurological:** Although there was improvement in the various neurological deficits, the improvements were not complete (47.6% motor deficits...) **Adverse events**: There were 11 cases with surgical complications: 9 (5.5%) were wound related and 2 (1.2%) were pseudomeningoceles; 3 patients (1.8%) required surgical treatment (1 wound infection, 1 wound dehiscence, and 1 pseudomeningocele). There were no cases of overt CSF leakage. Separately, 11 patients (6.7%) required postoperative clean intermittent catheterization.	Detethering surgery for fibrofatty filum terminale is a relatively safe procedure and can be performed prophylactically. Nonetheless, the risks of postoperative clean intermittent catheterization should be emphasized during the preoperative counseling pro
Ogiwara, 2012[158] N = 161 Japan	Surgical detethering Untethering was performed for symptoms in 126 patients (78.3%), and for prophylaxis in 35 patients (21.7%); included one level laminotomy at L4 or partial laminectomy of lower L3 and upper L4 in older patients; dura was incised and a filum terminale was identified by its pale color and midline location, surgical untethering was performed using a microscope; neurophysiologic intraoperative monitoring was used; filum was coagulated by bipolar and sectioned; dura was closed primarily using	**Bladder:** N/A **Neurological:** The untethering of a tethered spinal cord by transecting a fatty filum terminale is a relatively straightforward procedure that can prevent or ameliorate neurological symptoms **Adverse events**: No intra-operative complications were observed. None of the patients experienced a CSF leak postoperatively; postoperative MRI demonstrated pseudomeningocele, a fluid collection outside the limits of the dura and within the soft tissues, in 0.6% of patient; no patients developed wound infection; one patient (0.6%) experienced retethering of the filum; the overall complication rate was 1.2%; no specific outcomes partitioned out for prophylaxis vs symptoms group	Maintaining patients in a flat position for an extended duration following the transection of a tight filum terminale appears to reduce the incidence of cerebrospinal fluid leakage and pseudomeningocele formation; no specific author conclusions about prop

	4-0 Neurolon with interlocking; laminoplasty was performed using sutures after laminotomy or small bone particles were put back after laminectomy; the paraspinal muscles and the fascia were closed using 2-0 Surgilon, in addition, the fascia was sutured using 3-0 Surgilon, and 3-0 Prolene with "Figure of Eight" technique; the dermal layer was approximated using 4-0 or 3-0 PDS suture; the epidermal layer was sutured using 5-0 Ethilon; they all were kept lying flat for 8 days		
Pastuka, 2022[159] N = 1 Other	Surgical detethering Fetoscopic repair: laparotomy with lower-segment transverse incision was performed and the uterus was exteriorized, ultrasound was used to determine the exact position of the placenta on the anterior wall; the 3.5 mm ports were inserted into the uterus using the Belfort technique, with our own modifications; the optical port was inserted through all layers of the uterine wall, including the amniotic membrane, and secured with two opposing sutures; the same technique was used for the two surgical ports; adiode laser beam was used to separate the muscle (2 mm length), up to the level of the amniotic membrane; humidified CO2 heated to 37.7 C was infused into the	**Bladder:** At 12 month post-delivery, micturition diary revealed signs of urinary retention (10–40 mL of residual urine). To date, the child has made no attempts at controlled micturition. A urodynamic test revealed a neurogenic bladder of normal volume, and unstabl **Neurological:** Neurological examination at 11 months postdelivery revealed: head circumference of 43.5 cm, closing frontal fontanelle, cranial nerves without any signs of damage, axial hypotonia, decreased muscle tone in the lower extremities, tendon reflexes present apart from ankle reflexes, absent pathological reflexes. Psychomotor development of the child is slightly retarded. Ultrasound test of the bifid spine revealed a mobile medullary cone, positioned at L3. No clinical signs of tethering were observed. **Adverse events**: N/A	Prenatal open spina bifida repair using the fetoscopic approach to insert the ports into the exteriorized maternal uterus may be an effective method of treating myelomeningocele

	amniotic cavity while the amniotic fluid was gradually removed; adequate pressure inside the amniotic cavity was maintained using carbon dioxide insufflation (0.6 L/min; range: 12–15 mm Hg) to prevent uterine contractility		
Sade, 2003[160] N = 62 Israel	Surgical detethering Release of the primary tethering without draining the syrinx	**Bladder:** N/A **Neurological:** N/A **Adverse events**: 4 patients developed significant increases in their terminal syrinx (4/62 in the general group and 4/23 in the group of patients who had a syrinx before the primary untethering). One of the patients who had surgery for the syrinx had new orthopedic symptomatology with the progression of syrinx. Despite the collapse of the syrinx, the clinical status did not improve, and a new untethering procedure was done. The other patient had no neurological deficit in the pre- and postoperative periods relating to her primary untethering operation and was operated on to preserve the neurological status when the syrinx progression was detected. Another patient had spontaneous regression of the previously enlarged syrinx and was clinically stable throughout follow-up. The last patient had a stable neurological deficit before the primary untethering procedure and throughout follow-up despite progression of the syrinx and was therefore not operated on.	When tethering and an associated terminal syrinx are diagnosed, most surgeons would favor a releasing procedure without a direct approach to the syrinx, some, however, would prefer a simultaneous approach to both pathologies
Sathi, 1993[161] N = 18 US	Surgical detethering The surgical procedure involved untethering the spinal cord, laser debulking of the lipoma, and placement of a dural graft	**Bladder:** Urological function improvement **Neurological:** Improvement in neurological functions **Adverse events**: N/A	Early prophylactic surgery may reverse abnormal urinary tract function in infants with lipomeningocele
Seki, 2016[162] N = 31 Japan	Surgical detethering Surgical untethering with a period of 116 months of median follow-up	**Bladder:** In the univariate analysis, the presence/absence of preoperative bowel bladder dysfunction, and symptoms were strongly associated with the risk of children and adolescents with TCS ($p<0.05$) **Neurological:** Among the symptomatic patients, 10.5% experienced improvement in preoperative deficits after surgery, and 89.5% remained stable, and in the group of asymptomatic patients, 8.3% experienced worsened symptoms after surgery, while 11.7% remained stable, there was also a significant difference between the two groups at the final follow-up ($p<0.01$) **Adverse events**: Some patients experienced sensory disturbances	Prophylactic surgery is recommended for asymptomatic tethered cord syndrome in patients aged <34 months or as soon as possible, based on the findings, which showed a significant improvement in neurological prognosis with this approach and emphasized the i

Totonelli, 2019[163] N = 33 Italy	Surgical detethering The two groups were compared for age at neurosurgery, post-operative complications, mean post-operative follow-up, pre- and post-operative functional outcome, and presence of cutaneous stigmata (i.e. dermal sinus, localized hypertrichosis, hyperpigmented lesion); bowel evaluation was performed by neonatal/pediatric surgeons in terms of fecal incontinence and constipation and bowel management was indicated in patients with soiling grade 2 or 3 and/or constipation grade 2 or 3, according to Krickenbeck score; urological evaluation was performed by pediatric neuro-urologists in terms of bladder urodynamic studies (calyceal ectasia, bladder wall thickening, post-void residual) pad test and diary, and urodynamic evaluation in selected cases after 2 years of age; neuro-motor function was assessed by neurosurgeons with physical examinations; intraoperative neurophysiological monitoring was performed using somatosensory evoked potentials, motor evoked potentials and bulbocavernosus reflex; neuro-motor deficits include back pain worsened by activity and relieved with rest, leg pain, leg numbness or tingling, changes in leg strength, leg and/or	**Bladder:** A significantly higher number of patients in group A needed bowel management compared to group B (p=0.0035) **Neurological:** In particular, group A was associated with a less severe type of lipoma, the filum lipoma (p=0.057), with spinal lipoma only presenting in group B; most of the patients with isolated spinal dysraphism (87%) presented with cutaneous stigmata, compared to a minority (20%) in anorectal malformation-associated spinal dysraphism group (p=0.0004)l a significantly higher number of patients in group A needed bowel management and presented with neuro-motor deficits, compared to group B (p=0.0035 and p=0.04 respectively); group A showed a significant postoperative neuro-motor improvement as compared to group B (p=0.002); three patients in group B (2 lipomyelocele, 1 lipomyelomeningocele) and no patient in group A underwent redo-detethering surgery for residual lipoma (p=ns). **Adverse events**: Three patients in group A developed post-operative minor complications: one localized epidural subcutaneous infection treated with wound toilet and local disinfection, and two intermittent leg pain and leg tiredness resolved spontaneously within 12 months from the untethering surgery (p=ns).	Untethering surgery can help with neuromotor symptoms in some anorectal malformation patients but doesn't improve intestinal and urinary symptoms

	foot deformities, gait disorders, and scoliosis; in patients with tests both before and after neurosurgery, the evolution of bowel function, urinary function and neuromotor function was also studied		
Tuuha, 2004[164] N = 223 Canada	Surgical detethering NR	**Bladder:** Urinary and bowel incontinence present preoperatively did not improve with the mean follow-up of approximately 5 years. Similarly, 3 patients underwent prophylactic untethering of the cord. The decision to have prophylactic surgery was because of patient/ **Neurological:** Symptoms improved significantly in all patients who had surgery for neuro/motor deterioration. Specifically, the surgery was beneficial in reversing the damage that caused gait disturbances, muscle tone (weakness or rigidity), and delayed developmental milestones. Similarly, 3 patients underwent prophylactic untethering of the cord. The decision to have prophylactic surgery was because of patient/surgeon preference. All 3 patients had urinary and bowel symptoms, and these did not improve after the surgery with mean follow-up of 8.4 years. These patients, however, did not have neuro/motor symptoms. There were no complications. **Adverse events**: Urinary and bowel incontinence present preoperatively did not improve with the mean follow-up of approximately 5 years. There was no death associated with surgery; however, one patient's recovery was prolonged by a cerebrospinal-fluid (CSF) leak postoperatively	Surgery can lead to improvements in neuro/motor functions for symptomatic patients with tethered cord, but it may not significantly impact bowel and urinary functions; furthermore, prophylactic surgery appears to offer minimal benefit, while an expectant
Valentini, 2020[165] N = 40 Germany	Surgical detethering Patients were all treated prophylactically and underwent complete perioperative and postoperative neurological and urological assessment, including urodynamic study (UDS); surgical detethering with radical resection of the conus lipoma when present; all infants received inhalatory anesthesia (sevoflurane 1 MAC) with fentanyl boluses when needed; after	**Bladder:** All patients treated prophylactically: at 1-month follow-up, preoperative motor disturbances were stable, 7/11 UDS alterations normalized, and the remaining 4 were stable; at 6-month follow-up, 8/11 preoperative UDS alterations had improved; 7 children wi **Neurological:** All patients treated prophylactically: at preoperative evaluation, 2 children had motor disturbances before neurosurgery; at 1-month follow-up, preoperative motor disturbances were stable; at 6-month follow-up, all motor deficits had improved. **Adverse events**: NR	This small highly selected series confirms that early de-tethering may stop or revert the spontaneous neurourological deterioration

	resection of the subcutaneous mass and of the dermal sinus, if present, the laminar exposure was targeted one level cranially to the site of tethering; then a laminotomy was performed		
Van Calenbergh, 1999[166] N = 32 Belgium	Surgical detethering Surgical untethering was performed, and the mean follow-up period for the patients was 3.4 years	**Bladder:** Some patients experienced improvement in bladder functions, while others remained unchanged or saw a worsening of their condition **Neurological:** Some patients experienced improvement in sensory and motor functions, and pain, while others remained unchanged or saw a worsening of their condition **Adverse events**: A superficial infection involving the subcutaneous tissue, with cerebrospinal fluid leakage, urinary tract infection, and herpes zoster affecting the L2-L3 region, aseptic meningitis and a neurological deficits	Surgical intervention for tethered cord syndrome did not prevent the later development of new deficits, leading to the argument against prophylactic surgery in asymptomatic patients
Vora, 2021[167] N = 109 India	Surgical detethering Surgery included radically excise lipomas in children, involving detaching the lipoma from the dura, denuding the neural placode, and performing neurulation and dural closure using autologous or synthetic materials, with a mean follow-up of 62.5 months	**Bladder:** Most of patients experienced urological function improvement **Neurological:** Most of patients experienced neurological function improvement **Adverse events**: A few patients experienced a CSF leak, and some had unchanged conditions or neurological deterioration	Radical resection of lipomyelomeningocele appears to preserve neurological function in over 90% of children at long-term follow-up.
Yerkes, 2017[168] N = 56 US	Surgical detethering The surgery involved a neurosurgeon determining the type of spinal lipoma, the level of the conus, and whether the resection was complete or partial, based on operative reports and preoperative MRI scans	**Bladder:** Improvement in bladder function **Neurological:** N/A **Adverse events**: N/A	It is essential for long-term urologic follow-up after tethered cord release.

Table F.3. KQ3 case series

Study: Author, Year; Study Size; Location	KQ3 Interventions	Outcome and Results Adverse Events	Author Conclusions
Almotairi, 2023[169] N = 1 Other	Other Spinal cord tethering confirmed with magnetic resonance imaging. The surgical intervention included lumbar laminectomy (L 3–5), excision of a dermal sinus tract, and untethering of the spinal cord with the aid of neurophysiology monitoring. Following bone removal and before untethering the spinal cord, intraoperative ultrasound was performed. We used both B-mode and shear wave lastography provided by the SuperSonic Aixplorer system with a linear transducer array (2–15 MHz, SuperLinear 15–4) and an intraoperative ultrasonography frequency of 2 MHz .	**Bladder:** N/A **Neurological:** Intraoperative neurophysiology assessment showed no changes in somatosensory evoked potentials, electromyography, or motor evoked potentials compared to baseline except for moderate transient tibialis anterior improvement. **Adverse events**: N/A	Other findings: Before untethering, the mean elasticity of the distal end of the spinal cord was 20–24 kPa. Following anatomic confirmation of the detethering process, this evaluation was repeated and it showed a significant drop in the mean elasticity of the distal end of the spinal cord (<11 kPa at L4 level), indicating a softer spinal cord and, possibly, lower tension following untethering. Conclusion : The elasticity of the tethered spinal cord was never clearly demonstrated. To our knowledge, this is the first demonstration of reduced stiffness (elasticity value) of the lower end of the spinal cord before and following untethering using intraoperative ultrasound shear wave elastography. Intraoperative use of ultrasound shear wave elastography for tethered spinal cord cases has academic value and encouraging practical implications. Further research is needed to evaluate the elasticity of the spinal cord in tethered spinal cord cases and correlate it with clinical findings.

Aprecio, 2009[170] N = 1 US	Other Midazolam 5 mg orally; standard monitors were applied and general anesthesia was induced by facemask with 4 L/min oxygen, 7L/min nitrous oxide, and sevoflurane titrated to 8%; after an intravenous (IV) line was secured, propofol 20 mg and fentanyl 10 mcg were given; no neuromuscular blockade was administered; using a Wisconsin #1 laryngoscope blade, the trachea was intubated with a 3.5 cuffed endotracheal tube (ETT); an orogastric tube was then placed and a second IV line secured; nitrous oxide and sevoflurane were discontinued and propofol 200 mcg/kg/min and remifentanil 0.05 mcg/kg/min infusions were initiated for maintenance; a bispectral index (BIS) monitor was placed, with readings maintained between 40 and 60; the patient was then positioned prone with no pressure on the eyes, ears, nose, or genitalia; endotracheal tube placement was again confirmed with bilateral breath sounds and positive end-tidal carbon dioxide (EtCO2); the remifentanil infusion was then increased to 0.1 mcg/kg/min for the remainder of the case; gentamycin 25 mg, ampicillin 250 mg and dexamethasone 5 mg were administered prior to incision	**Bladder:** N/A **Neurological:** N/A **Adverse events**: There were no surgical complications.	Open communication between the anesthesia team, nursing and surgical team, the surgeons, and the neurophysiology technicians will ensure patient safety during any type of surgery.

Balkan, 2001[171] N = 20 Turkey	Other Computerized urodynamic testing assessed lower urinary tract function before and after surgery; two distinct sets of clinical criteria were employed for interventions; in the case of clean intermittent catheterization, the criteria encompassed the presence of residual urine, hyperreflexia, poor compliance, high leak point pressure, detrusor-sphincter dyssynergia, and vesicoureteric reflux; additionally, the use of anticholinergic drugs was recommended for cases characterized by hyperreflexia, poor compliance, and Vesicoureteral Reflux	**Bladder:** Enhancements were observed in detrusor functions (35%), electromyography recordings (45%), high leak point pressures (55%), as well as anal and urinary continence (70%) **Neurological:** Enhancement in detrusor function following untethering **Adverse events**: Some patients showed signs of retethering, and (10%) exhibited a decline in both anal and urinary continence	Achieving improvements in cases of lower urinary tract dysfunctions secondary to tethered cord syndrome can be accomplished through a carefully timed division of the spinal tethered cord
Bamba, 2011[172] N = 19 Japan	Other Laminectomy or laminotomy	**Bladder:** NR **Neurological:** NR **Adverse events**: CSF leakage	Utilizing a three-dimensional reconstruction method combined with image Overlay in the treatment of patients has resulted in a lack of neurological complications, improving the visual understanding of complex surgical situations and potentially enhancing surgical efficiency and outcomes

Barley, 2010[173] N = 1 US	Other Combined scoliosis and tethered cord release surgery with neurophysiologic intraoperative monitoring, continuous electroencephalogram and electromyography monitoring were performed along with somatosensory-evoked potentials intermittent and transcranial motor-evoked potentials; cortical electrodes were placed in accordance with the international 10 to 20 system for electroencephalogram, somatosensory-evoked potentials, and transcranial motor-evoked potentials; subdermal recording electrodes were placed bilaterally to the quadriceps femoris, tibialis anterior, gastrocnemius, sphincter, abductor pollicis brevis, and abductor hallucis muscles; stimulating electrodes for transcranial motor-evoked potentials were placed at C1, C2 and for somatosensory-evoked potentials' electrodes were placed on the posterior tibia and ulnar nerves; transcranial motor stimuli for the left extremities were between 145 and 187 mA and the right extremities were stimulated between 175 and 200 mA	**Bladder:** N/A **Neurological:** Postoperatively, the family and physicians noticed an immediate change in the patient's left upper extremity function versus preoperative status; the patient began to actively flexing the elbow, which had been held flaccidly in extension before the procedures. In addition, the patient had active finger and wrist function that was not present before the surgical procedure. At 2 months follow-up, this new functional status had been maintained. The patient's spinal deformity was corrected significantly and he was able to sit unassisted for the first time on the third postoperative day. No improvement in lower extremity function was noted and he subsequently underwent comprehensive clubfoot releases. **Adverse events**: N/A	The neurophysiologic monitoring and clinical findings in this case provide the first reported instance of immediate improvement of motor monitoring and function after tethered cord syndrome. In addition, the appearance of new, functional motor activity in the immediate postoperative period in a patient undergoing untethering has not been previously reported in the literature. The main goal and value of neurophysiologic intraoperative monitoring is to detect neurologic changes owing to surgical manipulation and avert potential complication or injury, which is well documented in the literature. However, our case report demonstrates not only a lack of neurologic complications, but a remarkably positive patient outcome (eg, development of new function) as the direct result of surgical manipulation, documented during neurophysiologic intraoperative monitoring.

Behaine, 2015[174] N = 1 US	Other First two detetherings: NR; Final detethering: At surgery, the laminectomy was extended rostrally to involve T-12 and L-1 with the intention of achieving radical resection of the filum lipoma, particularly where it emerged from the conus at L-1. Dural opening revealed several nerve roots tethered to the filar stump and wrapped around the lipoma at awkward angles traveling rostral and then caudal, making an S-shaped turn. We directly stimulated these nerve roots using the microstimulator at 0.2 and 0.3 mA, obtaining robust signals from electrodes placed in the left and right anal sphincters, as well as the right extensor hallucis longus muscle. The nerve roots were completely microsurgically disentangled from the filum, and the remainder of the lipoma was resected up to the conus	**Bladder:** He regained complete sphincter control within days of the surgery, and at 9 months postoperatively, the symptoms had not returned **Neurological:** NR **Adverse events**: NR	Following the surgical procedure, the patient observed a degree of improvement in bladder and bowel function
Beyazova, 2010[175] N = 10 Turkey	Other A comprehensive monitoring strategy encompassed the recording of various neurophysiological signals, including motor evoked potentials, somatosensory evoked potentials, free-run electromyography, direct nerve root/rootlet stimulation, and F-waves, with recordings taken from different parts of the body	**Bladder:** few cases with neurological bladder successfully improved after untethered surgery **Neurological:** Patients with mild paraparesis and neurological bladder improved after untethered cord surgery **Adverse events**: There were no adverse neurological events after untethering by using intraoperative neurophysiological monitoring	It is recommended to include direct nerve root/rootlet stimulation as a component of intraoperative neuromonitoring during surgery for tethered cord syndrome to help prevent postoperative neurological deficits

Borgstedt-Bakke, 2020[176] N = 45 Denmark	Other N/A	**Bladder:** N/A **Neurological:** Short-term follow-up was on average 4.7 months (range 1.2–10.5 months) and long-term follow-up was on average 72.6 months (range 22.8–153.5 months). The number of patients who improved was halved between short- and long-term follow-up, whereas the number of patients who deteriorated increased more than 4 times. The percentage of patients who stabilized is approximately the same at short- and long-term follow-up. **Adverse events**: Perioperative complications occurred in 1 of 47 operations (2%); this was a neurotmesis. Due to the poor preoperative neurological status of the patient, no major neurological worsening was observed. Postoperative complications occurred in 7 procedures (15%). Of these, 2 were CSF leakage, 2 were suspected meningitis (both treated before CSF was cultured), 1 was a wound infection, 1 was a fistula, and 1 was fecal incontinence. This results in a total complication rate of 17%. One procedure (2%) was discontinued prematurely due to high risk of neurological deterioration in a complete TCR procedure.	Tethered cord release in myelomeningocele patients initially provides a short-term benefit, but this effect diminishes over time, leading to uncertainty about long-term effectiveness and potential complications

Bowman, 2009[177] N = 163 US	Other After adequate shunt function is confirmed, the child is positioned prone on chest gel rolls to avoid pressure sores. Prior to positioning, a urinary catheter is placed. A prophylactic antibiotic is administered. Preoperative MR images assist in determining the location and extent of the surgical incision (Fig. 3). Most of the time, the entire previous myelomeningocele scar will need to be reopened. If the child originally underwent closure with a transverse incision, we create a longitudinal incision dorsal to the placode. The incision is started superiorly, dorsal to the last intact lamina, and carried deep to the fascial layer. The paraspinal musculature is dissected laterally, exposing the last intact lamina. The ligamentum flavum is released from the undersurface of the intact lamina utilizing periosteal elevators, thereby exposing the superior epidural plane. If adequate normal dura mater is not present, then a small inferior laminectomy is completed with bone rongeurs. If there is significant fibrofatty tissue in the epidural plane, the CO2 laser is useful in identifying the dura distally. Prior to dural opening, the child is tipped gently into the Trendelenburg position to limit the amount of spinal fluid loss. The dura is subsequently opened superiorly and retracted laterally. At the time of the original closure, the placode is imbricated, and hence, the tether is usually along the dorsal, pial suture line. During the dissection, we continually	**Bladder:** In 30 children (26%), worsened urological functioning was a clinical sign of tethering, as determined by our urologist based on cystometrography, voiding cystoureterography, and/or renal ultrasonography. Thirty-seven procedures (23%) were performed for de **Neurological:** Forty-seven children (41%) received diagnoses of symptomatic tethered cords after their LE strength declined. Fifty-four TCRs (33%) were performed in these 47 children. In 6 procedures (11%), a change in the MMT was the only indication of neurological worsening. In these 54 release surgeries, 70% resulted in improvement in motor functioning as assessed by physical therapists on the postoperative MMT, and in 28% the patients remained in stable condition. One surgery (2%) led to further decline in the child's LE motor strength postoperatively. Thirty-seven TCRs (23%) were performed in 34 patients (30%) due to the development of LE contractures. In 1 patient, the development of contractures was the only symptom of tethering. As expected, 22% of the contractures were improved postoperatively as assessed clinically by an orthopedic surgeon, with 78% remaining in stable condition. Spasticity was the indicator of tethering that led to 75 TCR procedures (46%) completed in 54 patients (47%) and was the only indication in 11 cases. Evaluation by orthopedic and rehabilitation medicine specialists 3 months postoperatively in these patients revealed that spasticity was improved in 63% and remained stable in 37% of the cohort. A worsening in the child's gait was a clinical sign of symptomatic tethering in 29 patients (25%) who underwent 32 procedures (20%). Two release surgeries were performed in a patient with gait changes as the only indicator of tethered cord. At the 3-month postoperative visit, 79% of patients showed improvement	Tethered cord release is beneficial in preserving neurological, urological, and orthopedic functioning in children born with a myelomeningocele

	work distally on either side of the cord, taking care to preserve all dorsal nerve roots. All intradural dissection is completed with operating loupes and a headlight. If the spinal cord is densely adherent to the dorsal dura, dissection is carried out laterally on either side of the adherent zone, eventually circumferentially untethering the cord, except for the dorsally adherent dura. At this point, usually by working gently in all directions, the small, adherent dorsal dura is able to be removed. At the conclusion of the untethering, the spinal cord relaxes into the anterior spinal canal. Our senior author (D.G.M.) has noted no difference in outcome when intraoperative neurophysiological monitoring is used. Consequently, these surgical procedures are completed without the use of monitoring, but with diligent preservation of all nervous tissue during the release, even if the spinal cord cannot be untethered completely. Once the spinal cord is completely untethered, the spinal column should be inspected for other pathological entities including dermoid tumors in the distal spinal cord, a fatty or thickened filum, or split cord malformation. If other pathologies are confirmed, they are resected or released. After confirming that no other lesion is present, the dura is closed in a watertight fashion. Synthetic and cadaveric dural substitutes were used in 9 patient (AlloDerm in 4; cadaver dural graft in 4; GoreTex in 1) to create a capacious, watertight dural closure.	in this symptom, and 19% remained stable, as determined by orthopedic surgery and rehabilitation medicine specialists. One child (3%), the same child who had a worsened MMT postoperatively, had a worse gait because of increased weakness in her quadriceps. **Adverse events**: 3.5% of patients were neurologically worse after untethering. All 4 patients declined by at least 1 motor level on the MMT. In 3 patients, this weakness arose after the first untethering, and in another patient after the second surgery. In 2 patients, there was an associated lesion consisting of a large, distal dermoid tumor in 1 child, and a diastematomyelia with a thickened, fatty filum in another. Other complications have consisted of CSF leak (4%) and wound dehiscence/infection (7%). No patient who required a dural patch developed a postoperative CSF leak. Of the patients with a postoperative CSF leakage, 4 required temporary CSF diversions and another underwent ventriculoperitoneal shunt revision. One patient required a wound revision and another improved after an extended period of flat bed rest. In the 2 children with wound dehiscence, intravenous antibiotic agents were used with dressing changes; a sample in 1 patient cultured positive for meningitis. All cases of superficial wound dehiscence healed with local wound care (wet to dry dressing changes).	

	The deep layers are closed and the skin is secured with nonabsorbable suture. Postoperatively, the child is maintained on flat bed rest for 4 days and then slowly mobilized		
Carpineta, 2017[178] N = 1 Italy	Other In flexed lateral position, under continuous two-projections-X-rays control, an extreme lateral interbody approach for discectomy and arthrodesis (XLIF) at L3-L4 was performed. A stand-alone PEEK trapezoidal cage (Nuvasive, San Diego, CA) filled with gel of hydroxylapatite was inserted in the space, obtaining indirect spinal cord decompression and anterior stability by arthrodesis	**Bladder:** Six months after surgery, the preoperative paraparesis and bladder dysfunction were markedly improved (confirmed by urodynamic studies and the subjective impression of the patient) and patient returned to his previous activity of daily living function **Neurological:** Six months after surgery, the preoperative paraparesis and bladder dysfunction were markedly improved (confirmed by urodynamic studies and the subjective impression of the patient) and patient returned to his previous activity of daily living function **Adverse events**: NR	Early surgical decompression is crucial for neurological recovery, and the XLIF approach is safe, fast, and an excellent option for achieving spinal cord indirect decompression and lumbar interbody fusion
DeAngelis, 1986[179] N = 1 Italy	Other Benzidamine, Netaprina, oxybutynin; no duration of follow-up reported	**Bladder:** Disappearance of uninhibited detrustor contractions; urethral pressure profile and flowmetry otherwise unchanged **Neurological:** NR **Adverse events**: NR	The anti-inflammatory drug (benzidamine) and urinary disinfectant improved the symptoms of sensitive urge, without modifying the incontinence. A subsequent cycle with flavoxate and emepronium bromide, later associated with alpha stimulants at low doses did not bring any results. A further treatment first with oxybutynin and Netaprina and later oxybutynin alone, resolved the symptomatology, with remarkable psychological relief in one patient. The urodynamic survey confirmed the delay of the proprioceptive stimulus after administration of anti-inflammatory drugs, and the disappearance of the uninhibited detrusor contractions only after the use of oxybutynin. The urethral pressure profile and flowmetry were not modified during any of the cycles.

Destro, 2018[180] N = 33 Italy	Other Two experienced pediatric surgeons, who are the medical referrers of the outpatient clinic for follow-up, performed all operations for ARM corrections by Peña operation	**Bladder:** In a scale from 1 to 5 (1 = poor and 5 = excellent), the majority of patients defined as 3 for their physical and mental state but two were considered as 2 (patient no. 3 and 7). An impairment in the following functions/structures was reported: intestinal **Neurological:** Six patients in Group A improved after surgery: UDS normalization and resolution of symptoms (n = 4), normalization of the neuromotor aspects (n = 2). One patient had retethering requiring redo surgery and four remained stable (three of them used clean intermittent catheterization [CIC] and Peristeen). In a scale from 1 to 5 (1 = poor and 5 = excellent), the majority of patients defined as 3 for their physical and mental state but two were considered as 2 (patient no. 3 and 7). An impairment in the following functions/structures was reported: intestinal (n = 5), urinary (n = 4), motor (n = 2), spine (n = 5), kidneys (n = 3), eyesight (n = 1), attention (n = 1), and feeling perception (n = 1) **Adverse events**: NR	Both clean intermittent catheterization and the Peristeen transanal irrigation can be viable interventions for managing urinary and bowel issues in the studied patients

Etus, 2006[181] N = 6 Turkey	Other NR	**Bladder:** NR **Neurological:** Follow up examination of the five patients in whom intradural exploration and microsurgical untethering of the spinal cord were performed showed that they were neurologically stable. The patient treated with a simple subcutaneous resection of the sac without releasing the intradural tethering bands was admitted to our clinic with progressive scoliosis, spasticity of the lower extremities and worsening of hand function 16 months following the initial operation. MRI of the spine revealed traction of the spinal cord dorsally at the level of C7, and a prominent syrinx at C4–C7. The patient was re-operated. Using the operating microscope, a careful intradural exploration was carried out, and microsurgical release of the spinal cord was performed by meticulous resection of all tethering bands and fibrosis. Postoperatively, the neurological deficits gradually improved in this patient. Postoperative follow up MRI studies of the spine showed that the spinal cord was untethered and that the width of the syrinx cavity had diminished, which were consistent with the neurological improvement of the patient **Adverse events**: NR	We suggest that the surgical technique in these lesions should include careful intradural exploration and microsurgical release of the spinal cord by meticulous resection of all tethering bands. This enables postoperative neurological improvement and possible prevention of future neurological deficits due to cord tethering

Falci, 1999[182] N = 70 US	Other Surgery, including spinal cord untethering and cyst shunting if a cyst was present, was performed on all 70 patients. Laminectomies were performed to expose the dura in the region of tethering as determined by preoperative MRI. Intraoperative ultrasonography was used to demonstrate adequate exposure of normal subarachnoid space cephalad and caudal to the region of cord tethering. The operative microscope was used to dissect arachnoidal scar from spinal cord and rootlets and their attachments to the dura, thereby untethering the spinal cord and rootlets. Scarring was often fine and web-like but could be dense and vascular. Untethering was performed dorsally, laterally, anterio-laterally, and widely to the level of the nerve root foramen. Attention was given to the reestablishment of cord and rootlet motion and release of tension off of these elements. Anterior and posterior subarachnoid spaces were entered cephalad and caudal to the region of tethering as well as along the region of tethering to improve spinal fluid flow. If tethering existed anteriorly, untethering was performed to the limits of a posterior exposure and with gentle rotation of the cord after section of selected dentate ligaments. With severe anterior tethering, this was often believed to be too risky. Additionally, it was not attempted if anterior retethering seemed inevitable because of the inability to place an anterior duraplasty from a	**Bladder:** NR **Neurological:** At 1 year follow-up after surgery, there was a small increase in light touch scores (0.67 points), pinprick scores (1.3 points), and motor scores (0.41 points). Although not statistically significant, these increases did demonstrate that progressive sensory and motor deterioration were arrested. Of 24 who responded to a questionnaire, 64.3% believed they regained a functional activity lost prior to surgery (e.g., feeding, dressing, assisting with transfers). Of the 64.3%, 21.4% believed their ability to perform the activity fully returned, and 14.3% believed their ability to perform the activity improved to better than baseline. There were 62.5% who reported significant improvement in spasticity, 25% no change, and 12.5% a continued worsening trend; and 55.6% saw substantial improvement in central deafferentation pain while 44.4% r port d persistence of the pain. All patients who experienced hyperhidrosis (n = 4) reported r resolution or improvement. 95.8% felt that surgery prevented further neurologic deterioration. None felt a loss of function due to surgery. **Adverse events**: Superficial postoperative wound infection; CSF leak; Pseudomeningocele; Meningitis; Cyst recurrence	The one-year follow-up suggests favorable outcomes for first-time surgery in terms of improved sensory and motor scores, functional recovery, reduced spasticity, diminished neurogenic pain, and perceived prevention of further neurological deterioration

	posterior approach. If a spinal cord cyst was present and did not collapse after spinal cord untethering, a myelotomy was performed in the midline at the most caudal end of the cyst, or over the thinnest portion of the cyst if it was avascular, for placement of a shunt tube. The dorsal root entry zone was never used as a site for myelotomy for fear of triggering or exacerbating central deafferentation pain. A portion of lumbo-peritoneal shunt tube was then threaded cephalad the entire length of the cyst. Multiple perforations were placed along the length of the shunt tube. The distal end of the shunt tube was placed in normal subarachnoid space caudal to the region of tethering or in the peritoneal space for larger cysts. The shunt tube was always valveless. An expansion duraplasty was performed using a graft of cadaver dura, cadaver freeze-dried fascia lata, or bovine pericardium, depending on availability of graft material. Duraplasty was performed to minimize the chance of retethering. All surgeries were performed with somatosensory evoked potential (SSEP) monitoring if a baseline signal could be achieved		
Glenn, 2015[183] N = 17 US	Other N/A	**Bladder:** Two children who presented with constipation and urinary incontinence, and one who presented with urinary incontinence, were unchanged after surgery **Neurological:** Two children with scoliosis demonstrated benefits from SFT, with curve improvement noted in one, and halted curve progression noted in another **Adverse events**: N/A	The author suggests that patients with both Chiari malformation type 1 (CM1) and tethered cord syndrome, even if they do not exhibit classic Chiari-related symptoms, may potentially benefit from surgical intervention with sectioning of the filum terminale to achieve symptomatic improvement, but further follow-up is required to confirm these findings

Hashiguchi, 2005[184] N = 13 Japan	Other 3D constructive interference in steady-state imaging sequences for the preoperative anatomical evaluation of lumbosacral lipomas, for establishing precise neuroanatomical information around lumbosacral lipomas and for predicting the level of surgical difficulty; constructive interference in steady-state magnetic resonance images were analyzed in terms of three findings: 1) direction of nerve roots in the subarachnoid space; 2) involvement of nerve roots in the lipoma; and 3) obliteration of the subarachnoid space by the lipoma	**Bladder:** N/A **Neurological:** In six of nine transitional type cases, satisfactory untethering of the cord was achieved without postoperative neurological deterioration. In three of nine cases, satisfactory untethering could not be accomplished, because preoperative CISS images and intraoperative findings confirmed spinal roots involvement in lipomas. These three patients had no subarachnoid spaces at both sides of the lipomas, and it was difficult to dissect the roots from the lipomatous tissue. No neurological worsening was caused by the operative procedures in all cases. **Adverse events**: N/A	CISS imaging provides precise neuroanatomical information for lumbosacral lipomas, demonstrating the complicated relationship of the spinal cord and roots and supporting its use as a valuable tool in surgical interventions

Herta, 2022[185] N = 22 Other	Other Patients underwent tethered cord surgery with motor evoked potentials monitoring with a intraoperative neuromapping protocol for tethered cord surgery which also involved somatosensory evoked potentials monitoring of the median and tibial nerve, bulbocavernosus reflex monitoring, and lumbar and sacral nerve root mapping	**Bladder:** N/A **Neurological:** SSEP monitoring of the median and tibial nerve was feasible in 19 out of 22 patients (86.36%) and 17 out of 22 patients (77.27%), respectively. Monitoring of BCR was available in 21 patients and feasible in 13 patients (61.90%). Lumbar and sacral nerve root mapping was successfully used in 18 patients (94.74%) and was not feasible in only one patient. MEP signals in the upper extremities were successfully elicited in all patients (100% success rate), and in the lower extremities, MEPs were present in 21 out of 22 patients (95.45% success rate). Of these, 17 patients (80.95%) showed a robust signal throughout the surgery. In total, MEP monitoring was considered feasible in 21 patients (95.45%). No new postoperative muscle weakness occurred in patients where MEPs were present until the end of surgery. In three patients, at least one MEP under the neurosurgical site was rated as unsteady, but this did not result in postoperative clinical deterioration in motor function. Linear regression analysis showed no significant correlation between the minimal stimulation intensity needed for MEP and various factors, except for patient age, which showed a significant association in univariate analysis but not in multivariate analysis. No complications were caused by intraoperative monitoring of MEPs. **Adverse events**: N/A	Motor-evoked potentials monitoring is safe and feasible in children under 12 months during untethering procedures

Hou, 2018[186] N = 15 China	Other Patients were placed in a prone position, exposing and fixing the L2-L5 levels with pedicle screws, resecting specific spinal structures, performing discectomy and fusion, and confirming screw placement using fluoroscopy; patients were immobilized with waist support for 8-12 weeks post-surgery	**Bladder:** The urinary dynamics results revealed enhanced bladder compliance and increased safety capacity in 14 out of 15 cases (93.3%) **Neurological:** Motor dysfunction improved in all 11 cases (100%), and low back pain showed improvement in 8 out of 9 cases (88.89%). Manual muscle tests indicated a significant enhancement in the strength of the tibialis anterior muscle among patients with preoperative motor dysfunction **Adverse events**: No complications, including infection, pulmonary embolism, nerve injury, or broken rod, were reported during the follow-up period	Homogeneous spinal-shortening axial decompression is an effective and safe surgical method for tethered cord syndrome, allowing for direct decompression of the tethered spinal cord
Husain, 2009[187] N = 40 US	Other During untethering surgery, the Neurophysiological Intraoperative Monitoring technique entailed continuous monitoring of free-running electromyography in specific lower limb muscles and the external anal sphincter, alongside continuous stimulation and monitoring; the surgeon, while using bipolar probe stimulation to identify neural tissues, employed constant current stimulation, and the surgical procedure consistently began with the induction of anesthesia using isoflurane and succinylcholine	**Bladder:** N/A **Neurological:** Patients who exhibited higher stimulation thresholds after the untethering procedure also experienced a significant deterioration in motor function ($p < 0.0001$) **Adverse events**: All individuals who experienced neurologic deterioration had undergone at least one prior untethering surgery	Neurophysiologic intraoperative monitoring during tethered cord syndrome surgery can serve both to reduce operative morbidity and to help predict postoperative outcomes

Inoue, 1994[144] N = 12 Japan	Other After microsurgical untethering of the spinal cord, efforts were made to remove as much lipomatous and/or scar tissue as possible; all spinal roots in the affected area were carefully exposed and identified, extending from the rostral normal roots to the caudal filum terminale, following spinal reconvolution or conus reconstruction, a surgical membrane made of expanded polytetrafluoroethylene (Gore-Tex) was placed over the reconstructed spinal cord and attached to the lateral dural surface with stay sutures to prevent slipping, in cases where the dura mater was insufficient for primary closure, paravertebral fascia was used for dural plasty, the laminar defects were covered and reinforced with paravertebral muscle, and the patients were followed up for a period ranging from 23 months to 7 years	**Bladder:** N/A **Neurological:** Among the patients in the treatment surgery group, four showed either improvement or had unchanged conditions, whereas in the prevention surgery group, patients did not experience any changes in their conditions, and there were no adhesions or neurological deterioration observed in either group **Adverse events**: N/A	It is concluded that this simple new method is effective for the treatment and prevention of tethering and/or retethering of the spinal cord, although a longer follow-up study is required.

Kabayel, 2007[188] N = 1 Turkey	Other In the treatment plan, Gabapentin was administered at an initial dose of 300 mg per day, gradually increasing to a maximum of 1800 mg per day, and tizanidine (2 mg/day) to address neuropathic pain and flexor reflex responses, also therapeutic modalities were employed, including 20 minutes of infrared radiation daily in the lumbar region and 20 minutes of transcutaneous electrical nerve stimulation along the bilateral sciatic nerve line; additionally, a comprehensive five-week regimen was implemented, encompassing isometric exercises, range of motion exercises, motor control exercises, and stretching routines, targeting chronic non-specific lower back pain	**Bladder:** N/A **Neurological:** Notable improvements were observed in muscle recovery, a reduction in the rate of flexor reflex responses, and alleviation of lower back pain with a return to sleep regularity and normal walking posture, contributing to an overall enhancement in the individual's quality of life **Adverse events**: N/A	A rehabilitative approach, including medical treatment, physical therapy, and exercises, yielded positive results for a patient with tethered cord syndrome
Kawamura, 2010[189] N = 2 Japan	Other Pedicle subtraction osteotomy was conducted at the L4 level, along with the removal of the yellow ligament at L3/4 and L4/5 with the CD Horizon Legacy 5.5 spinal system; during the operation, the posterior height of the vertebra was reduced by 14 mm	**Bladder:** Bladder dysfunction showed significant improvement, and both incontinence and encopresis also saw noticeable enhancements within four weeks after the surgery **Neurological:** Improvement in low-back pain, as well as a reduction in pain and numbness in the legs, and an improvement in gait disturbances **Adverse events**: N/A	Pedicle subtraction osteotomy is an alternative surgical technique for senior patients with tethered cord syndrome caused by lumbosacral spinal lipoma, when the syndrome occurs along with lumbar canal stenosis
Khoshhal, 2012[190] N = 35 Other	Other No treatment	**Bladder:** Six of the eight (75%) patients with TCS secondary to myelomeningocele presented with neurogenic bladder **Neurological:** 68.4% presented with progressive neurological deficits in a 2-year period. **Adverse events**: N/A	Early intervention is important to prevent the development of progressive neurological deficits

Kobets, 2021[191] N = 9 US	Other Nine patients in the series underwent 12 surgeries total, with two having symptoms mild enough to not warrant surgery, five undergoing a single detethering procedure, one undergoing three surgeries, and one undergoing four successive surgeries due to a recurrent symptoms and supporting radiographic findings; all initial surgeries addressed the split cord and remote low-lying conus, when identified at that time, and subsequent surgeries addressed the tethered low-lying conus; of the seven patients who underwent detethering procedures, two underwent duroplasty with an artificial graft as stated, all but one had intraoperative monitoring utilized, and all remained prone for 48 hours after surgery, followed by a day lying flat, after which the activity was liberated	**Bladder:** N/A **Neurological:** Motor recovery was delayed in patients with preoperative deficits but was back to baseline by 3-month follow-up. **Adverse events**: Two patients experienced wound dehiscences which were oversewn and corrected, and two patient experienced motor deterioration postoperatively that significantly improved back to baseline upon follow-up at 3 months. Of the two patients who had multiple detethering operations, both experienced a return of their leg pain and clinical symptomatology consistent with tethered cord syndrome with a follow-up MRI consistent with a low-lying conus, fatty filum, or a dural adhesion band prior to the decision to reoperate. One had transient motor decline after her second surgery, which was resolved by the first follow-up, and both experienced years of improvement of their leg pain after each subsequent surgery after the first.	Surgery is recommended for patients with concurrent split cord and tethered cord syndrome, as the majority of patients in the study improved with operative intervention; however, it is noted that conservative management may be successful for up to 25% of patients, and even after multiple operative interventions, some patients may experience symptom recurrence decades later, but reoperation can still provide years of relief and should be considered.
Lad, 2007[192] N = 9733 US	Other Spinal laminectomies (ICD-9 primary procedure codes 0359, 0309, and 034)	**Bladder:** N/A **Neurological:** 1.6% had postoperative neurological complications **Adverse events**: The complication rate after surgery was 9.5%, including postop hemorrhage/hematoma (2.3%), renal (2.2%), pulmonary (1.9%), neurological (1.6%), infectious (1.1%), thromboembolic (0.003%), cardiac (0.0001%).	The primary complications noted were postoperative hematoma (2.3%) and renal complications (2.2%), with neurological and infectious complications being less common (1.6 and 1.1%).

LaMarca, 1997[193] N = 270 US	Other NR	**Bladder:** FFT patients: urinary symptoms improved in 3 of 8 cases after first operation; LCM patients: urinary symptoms improved in 6 after first operation, 4 of 18 cases of urinary symptoms improved after second operation **Neurological:** FFT patients: motor symptoms improved in all cases after first operation; LCM patients: muscle weakness in 26 cases after first operation, muscle symptoms in 19 of 26 cases after second operation **Adverse events**: NR	Spinal lipomas should be operated on as soon as possible on a prophylactic basis, and careful and constant follow-up should be carried out to permit prompt reintervention in cases with deterioration
Liu, 2016[194] N = 4 China	Other During anesthesia, all the patients felt radiating pain in the lower extremities or perineal region when a spinal needle was attempted to insert into the subarachnoid space. The pain disappeared immediately when the spinal needle was withdrawn. The anesthetic effects were satisfactory, and the operations were completed successfully. All the patients were given postoperative analgesia	**Bladder:** NR **Neurological:** The follow-up period ranged from 3 weeks to 4 months. The dysfunction of nervous system in Cases 1, 2, and 4 disappeared within 3 weeks. But in Case 3, the paraesthesia and weakness of lower extremities were persistent, and there was not any improvement until 4 months after surgery **Adverse events**: NR	These cases suggest anesthesiologists and surgeons alert to the association of adult TCS and spinal anesthesia. Spinal anesthesia should be prohibited in patients with adult TCS to prevent neurological damages

Metcalfe, 2006[195] N = 36 US	Other No surgical details rather than sectioning of filum terminale was performed; ll patients were referred for neurosurgical evaluation by the referring urologist only after a prolonged attempt at medical management had failed; voiding symptoms and the degree of improvement were assessed by the urologist, as reported by the patient and family, while neurological symptoms and physical examination findings were determined by the neurosurgeon; bowel symptoms were categorized only by the subjective presence of constipation and encopresis. Any improvement in symptoms was only considered a result of surgery if present at the 3-month followup clinic appointment and they were excluded if improvements were first documented greater than 1 year after surgery	**Bladder:** Among the patients, 16 (57%) demonstrated improved urodynamic parameters, while 8 out of 25 patients (32%) experienced the resolution of unstable contractions; In contrast, 6 patients showed a reduced bladder capacity ranging from 7 to 88 cc, and 5 out of **Neurological:** 55% had non-urological neurological symptoms indicative of a tethered spinal cord, patients with both voiding dysfunction and additional neurological symptoms showed an 80% clinical improvement rate, while those without additional symptoms had a 62.5% improvement rate p = 0.24 **Adverse events**: There were no post-operative neurological complications, but there were two cases of superficial wound infections which responded well to bedside débridement and antibiotics	Sectioning a normal-appearing filum terminale can lead to significant improvement in severe urinary and fecal dysfunction in a highly select population
Muller, 2014[196] N = 25 France	Other NR	**Bladder:** Twenty-three out of 25 patients had reached the age of urinary continence. Twelve out of these 23 patients (52%) were continent, dry with no leakage, and able to void spontaneously at last clinical examination (normal bladder function group). Eleven patie **Neurological:** NR **Adverse events**: NR	This is the first study, which highlights the impact of different types of spinal dysraphism on functional outcome in patients with cloaca. Short spinal cord seemed to carry the worst prognosis. A prospective study with a larger series is mandatory to confirm these preliminary results

Murata, 2014[197] N = 1 Japan	Other Opening the lamina and dural sac and shifting the tethered cord to the dorsal side by utilizing lumbar through a dorsal incision spanning from the L3 to S2 vertebrae, which exposed the lamina and lipoma by retracting the muscles of the back; Subsequently, the L3, L4, and L5 laminae were resected to gain access to the dural sac, and the dural sac was then cut longitudinally, extending from the L3-L4 disc height to the margin of the protruding lipoma, the remaining lipoma the dural sac, was extruded due to its internal pressure	**Bladder:** N/A **Neurological:** Surgery provided immediate relief from pain and numbness **Adverse events**: Despite some relief from frequent urination, urodynamic assessments did not show a clear improvement following surgery	Shifting the tethered cord and lipoma to the dorsal side by harnessing lumbar lordosis, rather than traditional detethering, is a viable treatment option for tethered cord syndrome
Music, 2021[198] N = 1 US	Other The stimulator paddle was places at T11-T12 due to the patient's conus medullaris terminating at L5	**Bladder:** NR **Neurological:** The stimulator trial ameliorated his pain by 80%, allowing unassisted walking for the first time in a year. At his first follow-up appointment, the patient endorsed 80% to 90% relief of his lower-back and leg pain, which improved to 100% improvement at last follow-up at 12 mo. **Adverse events**: NR	Spinal cord stimulation can be highly efficacious for pain relief in patients with a combination of long-standing tethered cord syndrome and degenerative spine disease
Novik, 2019[199] N = 1 US	Other Implantation of paddle lead spinal cord stimulation (SCS) was performed. The placement of SCS was performed with the patient under general anesthesia and with neurophysiological somatosensory-evoked potential guidance for optimal placement of lead. The 5-column paddle lead SCS was placed at the L1 level.	**Bladder:** N/A **Neurological:** Improved ambulation **Adverse events**: N/A	The author recommends considering spinal cord stimulation as a potential intervention for patients with recurrent tethered cord syndrome who primarily experience pain and are not interested in more invasive surgeries, but highlights the need for further studies to determine the long-term effectiveness of spinal cord stimulation in treating chronic pain in spinal dysraphism.

Okay, 2021[200] N = 5 Turkey	Other Minimally invasive endoscopic untethering of tight filum terminale was performed under general anesthesia with the patient in the prone position, tethering level was determined by fluoroscopy, a small skin incision was made, and the vertebral lamina was exposed, 0-degree neuroendoscope was used to inspect the area, followed by laminotomy with a high-speed drill, with neuromonitoring and neurostimulation were used to confirm the filum terminale, the dura mater was cut to expose the caudal fibers, and nerve root stimulation was performed, the filum was cut once stimulation failed, ensuring the identification of L5 and S1 nerve roots, and the dura was sutured tightly	**Bladder:** N/A **Neurological:** All patients experienced improvement after surgery **Adverse events**: A case involving a split cord malformation experienced neurological deterioration due to the removal of a fibrous septum at the thoracic level, this deterioration was not related to an endoscopic procedure performed at the L5-S1 level	Endoscopic release of the filum terminale is a safe technique, mainly when performed with neuromonitoring, and may offer benefits like shorter hospital stays and reduced blood loss

Quin˜ones-Hinojosa, 2004[201] N = 67 US	Other During the surgical procedure, electromyogram recordings were used to assess nerve health during tether release; a laminectomy was typically performed, and real-time electromyography feedback helped identify nerve irritation, also bipolar stimulation and compound muscle action potentials recording distinguished nerve roots from fibrous tissue, and the filum terminale was dissected with specific criteria. and in the presence of low threshold responses, attached nerve roots were dissected., a more extensive laminectomy was done for patients with lipomas, with electrical stimulation assisting in nerve root identification; the dura was closed securely, and the fascia and skin were closed in the standard manner	**Bladder:** In 46% of patients, there was an improvement in bowel and bladder function **Neurological:** Some patients experienced improvements in lower extremity sensory symptoms and motor function (31%), alongside noticeable relief in their back pain (39%) **Adverse events**: There were no new neurological symptoms or signs developing in any of the patients following the surgery	Tethered cord release is a safe procedure that generally results in the improvement or stabilization of neurological function while also preventing intraoperative nerve root injury and associated new neurologic deficits
Rensing, 2021[202] N = 23 US	Other Implantation of an InterStim II device manufactured by Medtronic, Inc, the patient was placed under general anesthesia, and they were positioned in a prone (face-down) orientation, and a tined lead was positioned near the S3 nerve root to ensure the lead was appropriately placed, a combination of fluoroscopic guidance and assessments, such as monitoring the patient's bellows response and observing plantar flexion on the same side, were employed to evaluate the proximity of the lead to the S3 nerve root	**Bladder:** There was a significant improvement in urinary symptoms, with over 50% of patients experiencing this improvement, the median PedsQL score showed an enhancement, increasing from 61.7 to 86.7 ($p < 0.0001$) **Neurological:** N/A **Adverse events**: N/A	Sacral neuromodulation implantation is an effective treatment option for pediatric patients with refractory urinary incontinence following functional sacralization, highlighting its safety and potential for improving quality of life

Rochkind, 1991[203] N = 4 Israel	Other Laser treatment was given to patients according to the protocol A 35 mW continuous wave- CW He-Ne laser intraoperatively to the conus medullaris using fiberoptic instruments with spot size 3 cm in diameter and energy density 7 J/cm^2	**Bladder:** NR **Neurological:** Intraoperative application of laser irradiation to the surgically treated spinal cord increased evoked responses from 15 to 52% (mean 26.7%) of the post-surgery value before the laser treatment. **Adverse events**: NR	Using low-level laser therapy (LLLT) may improve neuronal metabolism, prevent neuronal degeneration and promote improved spinal cord function and repair
Sala, 2014[204] N = 64 Italy	Other Patients underwent surgery for tethered cord under intraoperative neurophysiological monitoring surveillance; the study outlines a intraoperative neurophysiological monitoring protocol used in tethered cord surgeries and emphasizes the surgical perspective on this complex intraoperative neurophysiological monitoring approach; in 44 of these 64 patients, both neurophysiological monitoring and mapping techniques were used, while in 20 patients, only mapping was used	**Bladder:** N/A **Neurological:** Monitorability rates were 84% for somatosensory evoked potentials (SSEPs), 97% for limb muscle motor evoked potentials (mMEPs), 74% for anal sphincter mMEPs, and 59% for the bulbocavernosus reflex (BCR). In almost all patients (47 out of 48), neurophysiological monitoring responses remained stable during surgery. At the end of the procedure, no loss in motor evoked potentials (mMEPs) or significant drops in SSEPs and BCR amplitudes were observed. In the 20 patients where only mapping techniques were used, neurophysiological mapping was successful in all cases. **Adverse events**: Two patients (4.1%) showed transient new or worsened neurological deficits postoperatively. One patient showed postoperative worsened urinary incontinence and perineal sensory impairment, which gradually subsided over a few weeks. The second patient, a 10-year-old boy who underwent surgery for cord retethering, had intraoperative loss of mMEPs and BCR responses, but these deficits also recovered within weeks.	The use of a combination of monitoring and mapping techniques in tethered cord surgery is advised, with a preference for mapping techniques due to their ability to spare functional neural tissue while also highlighting the value of monitoring techniques like MEP and BCR in improving surgical reliability and potentially impacting neurological outcomes

Satar, 1997[205] N = 28 US	Other NR	**Bladder:** Early postoperative evaluation revealed that 8 patients (29%) had improvement after surgery, including 2 of the 15 who had an abnormal neurological examination and 6 of the 10 who had an abnormal urodynamic assessment. Conversely the condition of 9 patien **Neurological:** Early postoperative evaluation revealed that 8 patients (29%) had improvement after surgery, including 2 of the 15 who had an abnormal neurological examination and 6 of the 10 who had an abnormal urodynamic assessment. Conversely the condition of 9 patients (32%) worsened after surgery, including 4 of the 13 who were neurologically and 6 of the 18 who were urodynamically normal (including 1 with deterioration in both categories) Because these children were followed periodically after surgery with careful neurological and urodynamic examinations, several had changes with time. The condition of 7 patients (25%) continued to deteriorate, including 6 urodynamically and 5 neurologically with 4 in both categories. Two children had improvement (7%), 1 each neurologically and urodynamically. The remaining 19 cases (68%) maintained a stable neurological and urodynamic condition. Six of the 7 patients (21% of the total) with progressive deterioration underwent secondary spinal surgery for tethering at a mean age of 8.5 years (range 4 to 15). At the latest followup neurological and urodynamic states stabilized after this secondary spinal surgery in all children. **Adverse events**: NR	Early surgical repair seems to provide a degree of protection against later spinal cord tethering, and subsequent neurological and/or urodynamic deterioration (25% of our patients versus a reported 80% of those followed expectantly)

Schneider, 1993[206] N = 10 US	Other With the patients lying prone and involved in a narrow laminectomy or osteoplastic laminectomy of the last intact neural arch, intraoperative monitoring included electromyography of the external anal sphincter and selected lower extremity muscles, as well as cortical somatosensory evoked potentials; the dural tube and arachnoid were carefully identified and opened, and a laser flow blood perfusion monitor device, equipped with a laser-doppler flowmetry disc probe, was positioned approximately 1 cm above the tether site, and the probe was secured with dural sutures and covered by a collagen sponge, and the follow-up interval ranged from 9 to 30 months	**Bladder:** N/A **Neurological:** All patients experienced improvement in their neurological conditions **Adverse events**: All patients experienced a smooth postoperative recovery with no complications, morbidity, or mortality	Tethered cord release results in significant improvement in distal spinal cord blood flow

Schoenmakers, 2003[207] N = 73 Netherlands	Other Surgical techniques for release of the tethered cord were: (1) removal of excessive lipomatous tissue, (2) resection of the midline bony or cartilaginous spur in cases of split cord malformation, (3) transection of the filum, and (4) a duroplasty. All untethering procedures were performed using standard microsurgical techniques. Intrinsic lipomas were debulked using a microscope-mounted CO2-laser. All initial surgical releases were performed by the same, experienced pediatric neurosurgeon	**Bladder:** NR **Neurological:** In all patients, 6 weeks to 6 months after surgery, ambulation level remained stable compared with the preoperative situation. Late deterioration of the ambulatory status was seen in five patients; three of them had lipomyelomeningocele and two myelomeningocele with intradural lipomas. In 26 of the 44 patients ambulation remained stable during the entire follow-up period. Thirteen children were too young to ambulate at time of operation (<2 years 6 months). In the long-term, four of the patients became community ambulant: they all had lipomyelomeningocele. In two of these children, ambulation level was normal half a year after operation (at the age of 2 years 6 months), but it deteriorated in the long term and they became community ambulators. All other children younger than 2 years 6 months of age (n=9) at time of operation, developed normal walking abilities that remained stable during the entire follow-up. During long-term follow-up (ranging from 4 to 9 years) 44 children underwent a total of 57 untethering operations. Thirty-five children had a single untethering procedure. Revision of the initial tethered cord release was seen in nine of the 44 children. Five patients had lipomyelomeningocele, three had myelomeningocele, and one had filum terminale lipoma. In the patients with lipomyelomeningocele, two patients required three releases, and one patient underwent four releases. All these patients presented with recurrent acute back pain, combined with progressive foot deformities due to progressive neurological loss. The other six patients had two releases. The second release was carried out 1 year 6 months to 6 years to after the initial untethering. The presence of lipomas (17 of 44), and age at operation were not significantly associated with the occurrence of retethering	After neurosurgical untethering, long-term stability in neurosegmental motor level and ambulatory status is observed in most patients

		Adverse events: NR	

Shang, 2019[208] N = 326 China	Other Patients received general anesthesia in the prone position. Longitudinal incisions were usually preferred to fully expose the operational field. The bony exposure had to be wide enough to expose the normal dura. Excess fat, fibrous tissue, and scarring were removed, which caused spinal cord and nerve compression. The dural sac was usually opened along the midline under a microscope. As much as possible, all factors that may stretch and compress the spinal cord (such as lipoma and bony spur) were removed. Finally, the filum terminale was cut to relieve tension in the lower spine and cauda equina. Different operational points were used for TCS. (1) Tight filum terminale: the boundary between the spinal cord and filum terminale was identified and the lower end of the filum terminale was cut. (2) Lipomyelomeningocele: after separately expanding the upper and lower lamina of the bulging part, the boundary of normal dura was identified to free the bulging sac and protect the spinal cord (which may potentially bulge out). After freeing the adhesion nerves, the excess dura sac was removed to ensure the bulging cord and nerve roots sank into the dura sac. Lastly, 5-0 absorbable suture was used to remodel the lumbosacral epidural shape. The most important objective was to build an adequate barrier above the spinal defect to preserve remnant neural function and prevent infection (Dias, 1999; McLone, 2005; Mattogno et al., 2017). (3) Cicatricial adhesion-type: surgical	**Bladder:** N/A **Neurological:** N/A **Adverse events**: Cerebrospinal fluid leakage was observed in seven cases, six of which belonged to lipomatous malformation-type and one belonged to postoperative adhesion-type. They were all cured after conservative treatment. Urinary retention occurred in six patients (lipoma) during the early post operation period. Nine cases experienced lower extremity numbness, and three cases had decreased distal limb muscle strength. Delayed wound healing occurred in two cases	Early diagnosis and microsurgical operation are crucial for treating tethered cord syndrome, with various factors influencing the outcome and prognosis, and clinical classification can aid in predicting prognosis and guiding treatment.

	removal of the scar and adhesion(s) were performed under a microscope with electrophysiological monitoring. (4) Lipoma type: there were several forms of this type, with the surgery being relatively complicated. Based on the relationship between lipoma and conus medullaris according to the study of Pang et al. (2013), lipomas could be divided into dorsal, transitional, terminal, and chaotic types. For the terminal type, the boundary between the spinal cord and filum terminale lipoma was intraoperatively identified and the lipoma resected. For dorsal and transitional types, it was necessary to identify the neural placode. Dissection began from the rostral end of the lipoma and was cut all the way along the neural placode using a Cavitron Ultrasonic Surgical Aspirator and neurophysiological monitoring. Total or near-total resection was achieved in most cases. For some chaotic types, only near-total excision was possible as it was difficult to identify the complete neural placode and the nerve root always traversed through the lipoma. After removal of the lipoma, and ensuring that nerve adhesions were completely released, the pia from both sides was sutured together with 6-0 absorbable thread to reconstruct the neural placode and reduce the risk of local adhesions. Finally, the dural sac was repaired using artificial dura mater. (5) Split cord malformation: the surgical approaches were different for types I and II of diastematomyelia deformities (Pang sub-		

	types: type I reflects bone separation and type II reflects fiber or membrane separation) (Shang et al., 2010). For type I, after removing the bone spur, part of the dura mater was resected to turn two dural sacs into a single one. This achieved complete decompression of the spinal cord and cut the end of the filum terminale. For type II, the cause for the tethered cord was specially analyzed, and the adhesive spinal nerves loosened or the filum terminale resected		
Smith, 1994[209] N = 5 US	Other Surgical detethering and duraplasty: each case had different methods of the procedure	**Bladder:** NR **Neurological:** All five of our patients are doing well without signs of recurrence of pain and neurological complaints with a mean follow-up period of 22 months. **Adverse events**: NR	Microsurgical sharp detethering of the cervical spinal cord appears to be safe and allows for resolution of symptoms and return of normal neurological function. To avoid retethering, wide Tutoplast duraplasty is recommended
Steinbok, 2007[210] N = 15 Canada	Other Filum terminale section was carried out on eight patients, the operative report was carefully examined to establish the surgical level, amount of bone removed, filum size during the surgery, the presence of fat in the filum during the procedure, and whether the filum retracted upon sectioning, while seven patients opted for continued medical treatment and were followed up for a mean period of 3.3 years	**Bladder:** In the filum section group, seven children experienced urological improvement over an average follow-up period of 3.1 years, with four of them showing better urodynamic results postoperatively. Among these patients, five out of six with non-urological bac **Neurological:** N/A **Adverse events**: Five patients had non-urological abnormalities in their back and/or lower limbs, and these conditions did not show any improvement in the non-surgical group	Section of the filum may lead to better urological outcomes in children with refractory urinary incontinence consistent with occult tethered cord syndrome compared to continued medical management

Sun, 2021[211] N = 28 China	Other Patients were placed under general anesthesia in a prone position, and an incision was made in the lower back near the sacral vertebrae, exposing the spinal cord's filum terminale, using electrophysiological monitoring, the surgeon identified the last pair of sacral nerves and cauterized the vessels on the filum terminale, the filum terminale was then cut and a fistula created to prevent closure, also the surgical site was closed layer by layer, and patients needed to remain in the prone position for 3-7 days post-surgery to prevent complications with 36 months of following up period	**Bladder:** Around 30% of patients with preoperative symptoms of paruria (uroschesis or uracratia) experienced an improvement, and among those, only one case had improved constipation **Neurological:** Limb impediment, including lower extremity amyotrophy and foot deformities, did not show any improvement or change following the surgery **Adverse events**: None of the patients experienced a relapse for up to 36 months after the surgery	Terminal ventriculostomy is effective in treating tethered cord syndrome with syringomyelia, significantly when the syrinx cavity extends to the filum terminale
Takagi, 2021[212] N = 1 Japan	Other A programmable pump was surgically implanted to provide continuous intrathecal delivery of baclofen; the catheter was carefully inserted into the intrathecal space, with its tip precisely placed at the T9–T10 interspace, using fluoroscopy to guide the paramedian puncture for catheter insertion at the T12–L1 level; this allowed for the consistent administration of baclofen; a pump for continuous delivery of baclofen was implanted in the right abdomen and maintained for 24 months, with a daily dosage ranging from 38.5 µg to 41.0 µg	**Bladder:** N/A **Neurological:** The treatment resulted in complete relief of both spasticity and pain **Adverse events**: N/A	Intrathecal baclofen therapy was very effective in improving spasticity in an adult with severe spasticity from tethered cord syndrome

Tredway, 2007[213] N = 3 US	Other All patients underwent a minimally invasive lumbar laminotomy and filum terminale sectioning procedure under general anesthesia, with patients in the prone position and guided by fluoroscopy for level localization through creating a midline dural exposure and carefully dissecting the sacral nerve roots from the thickened filum, and a nerve root stimulator was used for monitoring during the procedure	**Bladder:** One patient experienced a doubling of bladder capacity, leading to the resolution of incontinence **Neurological:** The patients experienced notable improvements, including complete resolution of back and leg pain, resolution of hypertonicity, doubling of bladder capacity with incontinence resolution in one case, and decreased allodynia in another, resulting in significantly improved postoperative outcomes with minimal hospitalization **Adverse events**: N/A	Tethered spinal cords can be safely and effectively untethered using minimally invasive surgery
Tuite, 2016[214] N = 20 US	Other Surgical detethering along + intradural somatic to autonomic nerve transfer: each patient underwent a lumbosacral spinal cord detethering performed by at least 2 neurosurgeons. the control group underwent only the DT procedure (DT group) and the experimental group underwent the Xiao procedure in addition to a standard DT procedure (DT+X group); for somatic-to-autonomic intradural anastomosis, the same protocols for electromyography (EMG) stimulation, donor and recipient root selection, nerve sectioning, and anastomosis as Xiao had used in China	**Bladder:** Patients in both treatment arms could intermittently void or dribble small amounts of urine (< 20% total bladder capacity) in response to scratching in dermatomes T-9 through S-2 using a standardized protocol, but the voiding was not reproducible and the **Neurological:** NR **Adverse events**: The addition of the Xiao procedure to spinal cord DT resulted in longer operative times ($p = 0.024$) and a greater chance of wound infection ($p = 0.03$).	Children with MMC and LMM undergoing spinal cord detethering with the Xiao procedure did not demonstrate improved bladder function compared to those undergoing only detethering
Tyagi, 2016[215] N = 1 US	Other Percutaneous spinal cord stimulation trial leads placed at the T-8 level; this involved sending mild electrical signals through thin wires (leads) into the epidural space just behind the spinal cord	**Bladder:** No improvement in bowel and bladder function **Neurological:** Allodynia, hyperpathia, and leg pain improved **Adverse events**: Recurrence pain	The implantation of a spinal cord stimulator in a young patient with tethered cord syndrome was effective in treating refractory chronic neuropathic pain

Vassilyadi, 2012[146] N = 146 Canada	Other A low lumbar single or partial laminectomy was performed, followed by a linear durotomy to expose the cauda equina, the filum terminale was identified based on its thickness and pale color, approximately 1 cm of the filum terminale was exposed, coagulated at a low frequency with the bipolar instrument at either end, and sectioned after 0.5–2 mA stimulation with a hand-held battery-operated stimulator; in the majority of cases a specimen was submitted to Pathology; intraoperative neurophysiology monitoring was not used	**Bladder:** At primary presentation, 51.4% had bladder/bowel dysfunction. Patients with bladder/bowel dysfunction improved by 84%. **Neurological:** At primary presentation, 26.7% had neuroorthopedic symptoms. Patients with neuroorthopedic symptoms improved by 92%. **Adverse events**: Of the 146 patients at CHEO who underwent surgery, 7.5% retethered, with 36% being initially asymptomatic.	A more conservative approach is needed for initially asymptomatic children without tethered cord symptoms to avoid unnecessary surgery and the potential risk of symptomatic retethering in the future

Wang, 2019[216] N = 64 China	Other Homogeneous spinal-shortening axial decompression: after anesthesia patients were placed in a prone position, all patients had neurophysiologic monitoring (somatosensory evoked potentials), spontaneous electromyogram, or motor evoked potential monitoring intraoperatively; the L1-S1 spinous process, lamina, and facet joint were exposed; the pedicle screws were implanted bilaterally in L1-S1; next, the interspinous ligament of L1-L2 was removed, then the inferior articular process of L1 and the superior edge of the L2 lamina were resected; subsequently, the L1-L2 intervertebral foramen was expanded, and the disc tissue was resected; an autograft was implanted into the L1-L2 intervertebral space, then L2-3 to L5-S1 were managed in the same way; slow, homogeneous compression was applied in each operated level; the surgeon ensured the spinous process gap and intervertebral space were significantly reduced, and the nerve root and dural sac were loosened; a C-arm x-ray was obtained to confirm good positioning of the screws; the range of operation should include the upper and lower 2 intervertebral spaces adjacent to the level where the conus medullaris was located	**Bladder:** Significant urinary function improvement occurred in 90.4% (47 of 52) of patients. Bladder capacity increased from 162.34 +/- 70.45 mL preoperatively to 263.29 +/- 65.85 mL post- operatively, which was statistically significant (P < 0.01). Detrusor leak p **Neurological:** N/A **Adverse events**: Neurologic deterioration and decline in lower extremity motor function occurred in 3.1% (2 of 64) of patients postoperatively, which could be associated with the stimulation of the tethered spinal cord during operation. 2 (3.1%) patients developed postoperative wound infection and recovered after 3 weeks of anti-infection treatment without other complications.	Homogeneous Spinal-Shortening Axial Decompression is recommended as a safe and effective alternative surgical procedure for tethered cord syndrome, offering good clinical results and avoiding potential complications associated with filum terminale release.

Yong, 2011[217] N = 152 Canada	Other All patients underwent similar initial procedures to divide the filum terminale. After a single-level or partial laminectomy, a linear durotomy was performed to expose the cauda equina below the conus medullaris. The filum terminale was identified macroscopically and isolated. If there was any uncertainty, electrical stimulation of the suspected filum and obvious nerve roots was used to confirm what was the filum on the basis of the amplitude of the stimulation required to cause a muscle contraction. In the majority of cases, the filum was released by excising a section for histopathology. The dura was closed in a primary fashion with a braided polyglactin (Vicryl) suture in all cases. Repeat procedures for untethering varied depending on the pathology observed but in general included extension of the laminectomy, repeat division of the filum terminale, and a dorsolateral lysis of adhesions when necessary. Electrophysiological monitoring was used, and duraplasties were again avoided	**Bladder:** Patients with pain had improvement in their symptoms after surgery in 87% of cases. Neuro-orthopedic abnormalities improved in 73% of cases, bowel or bladder complaints in 72%, and scoliosis in 44%. Among retethers, all patients in both groups underwent a **Neurological:** Patients with pain had improvement in their symptoms after surgery in 87% of cases. Neuro-orthopedic abnormalities improved in 73% of cases, bowel or bladder complaints in 72%, and scoliosis in 44%. Among retethers, all patients in both groups underwent a microsurgical lysis of adhesions with immediate improvement in symptoms. No further procedures were required for late retethers, whereas 4 of 8 early retethers went on to have 1 to 4 additional procedures for recurrent scarring of neural elements to dura. Despite repeat surgery, 6 of the 8 early retethers developed recurrent symptoms **Adverse events**: There were no deaths in the cohort related to surgery. Eighteen patients experienced 20 postoperative complications, yielding an overall complication rate of 12%. Major complications included bacterial meningitis in 1 patient and cerebrospinal fluid (CSF) leaks in 3. With regard to minor complications, pseudomeningoceles (8 patients) and superficial wound infections (7 patients) were the most common. One patient developed aseptic meningitis. Among the initial procedures performed on those who went on to be late retethers, only 1 of 5 had a complication (pseudomeningocele). In contrast, 3 of 8 patients in the early retethering group had complications after the initial procedure: 2 CSF leaks and 1 case of aseptic meningitis. Two patients who retethered late were initially operated on in the first year of life for prophylactic reasons, and all 5 patients with late retethering re-presented	The study highlights the risk of symptomatic retethering after a simple filum snip, recommending cautious long-term follow-up

		with urological dysfunction. In contrast, all patients who retethered early were initially symptomatic and re-presented with back and leg pain in addition to other symptoms.	

Acaroglu, 2017[218] N = 6 Turkey	Other surgery Patients underwent corrective surgery with instrumentation for congenital scoliosis associated with tethered cord (n=6), with five patients underwent corrective surgery following a detethering operation, one patient with diastematomyelia did not have surgery for excision for the bony spur, and two of the patients had only posterior surgeries, while four had both anterior and posterior; one Harrington and one Texas Scottish Rite Hospital (TSRH) instrumentation was used for the cases with only posterior surgeries with extension of the instrumentation down to the pelvis in the latter patient; ISOLA brand instrumentation was used for the other four cases with anterior and posterior multiple osteotomies, and none had to be extended down to the pelvis; the osteotomies were performed as closing wedges of the convex side of the deformity so as not to elongate the spinal column and stretch the spinal cord, and did not coincide with the level of the diastematomyelia in any of the cases; use of sublaminar wires was avoided in most cases unless the spinal canal could be demonstrated to be normal in diameter during surgery; the follow-up period ranges from 1 to 10 years for the five patients with corrective surgery, and the sixth patient was not followed for the same follow-up time because they died in the third postoperative month because of respiratory problems (see adverse events)	**Bladder:** N/A **Neurological:** One patient's neurologic status gradually deteriorated to complete paraplegia in one week, this complication could not be attributed to specific pathology except very poor oxygenation of the cord because of respiratory problems following surgery that necessitated continuous mechanical ventilation via a tracheostomy for one week **Adverse events**: Complications were seen in two patients. One patient had late deep infection of the instrumentation that necessitated hardware removal with mild loss of correction (from 45 degrees to 57 degrees). Another patient who had the most severe deformity in this group presented with a curve of 100 degrees and a forced vital lung capacity of 850 ccs. She had undergone sequential anterior-posterior surgery and demonstrated monoparesis of the left lower extremity after this intervention. Despite prompt removal of the instrumentation allowing collapse of the spinal column, her neurologic status gradually deteriorated to complete paraplegia in one week. This complication could not be attributed to specific pathology except very poor oxygenation of the cord because of respiratory problems following surgery that necessitated continuous mechanical ventilation via a tracheostomy for one week; she was weaned of the respirator in six weeks. This patient died three months after her discharge because of an acute upper respiratory tract infection.	Corrective surgery for severe congenital spinal deformities with a tethered cord can be challenging with a high complication rate, and in select cases, a staged anterior and posterior approach may be needed

Agawa, 2023[219] N = 342 Japan	Other surgery Sectioning of filum terminale- the filum terminale was sectioned at the rostral level to the dural incision to maintain the distance between the cut end of the sectioned filum and the dural incision; investigated whether this procedure decreased the occurrence of retethering	**Bladder:** In all 4 cases of retethering, symptoms of bladder/rectal disturbances function improved post detethering. **Neurological:** NR **Adverse events**: New bladder and/or bowel symptoms occurred in 4 patients with retethering (1.2%, 4/342).	Sectioning the filum terminale at the rostral level to the dural incision was considered an effective way to prevent retethering

Atala, 1992[220] N = 35 US	Other surgery Lipomyelomeningocele removal.	**Bladder:** Preoperative urodynamic studies were abnormal in 11 children. Of these patients 6 had an upper motor neuron lesion consisting of detrusor-sphincter dyssynergia in 4 and detrusor hyperreflexia in 2. Five children had a mixed upper and lower motor neuron le **Neurological:** Of the 29 infants 14 (48%) had an abnormal neurological examination involving the lower extremities, consisting of decreased deep tendon reflexes in 7, increased deep tendon reflexes in 6 and decreased motor strength in 1. Of these 14 patients 4 had decreased sacral sensation, 3 had an abnormal sacral reflex, and 2 had an abnormal sacral reflex and decreased sacral sensation. No child had an abnormal sacral examination with normal lower extremity innervation. Postoperatively, 10 of 14 patients (71%) with an abnormal neurological examination improved . All 6 older children had abnormal neurological examinations involving the lower extremities, consisting of increased deep tendon reflexes in 3, decreased deep tendon reflexes in 2 and decreased motor strength in 1. Of these patients 1 had absent sacral reflexes, 1 had decreased sacral sensation, and 1 had abnormal sacral reflexes and decreased sacral sensation. All 6 children had abnormal preoperative urodynamic studies. One child had a complete lower motor neuron lesion, consisting of bladder areflexia and absent motor unit potentials, and 5 had a mixed upper and lower motor neuron lesion, consisting of abnormal motor unit potentials and detrusor hyperreflexia in 3, and abnormal motor unit potentials, detrusor hyperreflexia and detrusor-sphincter dyssynergia in 2. Postoperatively the neurological examination improved in only 1 patient (17%). **Adverse events**: In 1/18 of patients with (6%) with normal	We conclude that lipomyelomeningocele has a progressive effect on lower spinal cord function because infants tend to present with fewer urinary manifestations and physical findings than older children. Individuals who escape early detection tend to have a more subtle cutaneous abnormality. As a result, older children are more apt to present with urological and neurological complaints. In some instances urodynamic studies are able to detect neurourological deficits not seen on neurological examinations. Surgical correction in infants provides a degree of reversibility not seen in older children. It is imperative that early identification, evaluation and treatment be undertaken to prevent this progression and the irreversibility of neurological changes and urinary dysfunction that invariably occur as the child grows.

		preoperative urodynamic studies, detrusor-shpincter dyssynergia developed postoperatively.	
Cochrane, 1998[221] N = 24 Canada	Other surgery Placode untethering: placode untethering was performed at British Columbia's Children's Hospital by one of two pediatric neurosurgeons; microsurgial techniques were used; no physiological monitoring was used except in 2 patients undergoing concomitant selective posterior rhizotomy	**Bladder:** Improvement in urinary control was seen postoperatively in 2/7 patients who experienced these symptoms preoperatively. Two of 3 patients who were unchanged by the procedure retained stable urological functioning over 2 years. One patient, stable at 3 mont **Neurological:** At 3 months, 8/15 patients who experienced motor dysfunction preoperatively showed improvement in motor function, 6 were unchanged and 1 had deteriorated. At 24 months, 83% of patients remained stable or had retained their improvement in respect of motor function. All patients who had pain as an indication for the untethering were improved initially. One patient relapsed within 3 months with recurrent pain and new urinary dysfunction **Adverse events**: 2 patients experienced nerve root injury, immediate postoperative complications included urinary tract infection in 2 patients, pneumonia in 1 and spinal wound infection in 1 patient, urinary retention in 2 patients who had had reflex bladder emptying prior to untethering and 1 patient was incontinent postoperatively.	The surgical procedure results in improvement in a large proportion of patients, but does not address all etiological factors, with the result that subsequent symptomatic tethering is to be anticipated in a significant proportion of patients
Edwards, 1987[222] N = 75 US	Other surgery Resection and surgical detethering- all procedures were performed with microsurgical techniques and the use of the argon or carbon dioxide laser coupled to a micromanipulator; intraoperative electrophysiologic monitoring (evoked potentials) was used in the early phases of this series and was found to be of no assistance or predictive value	**Bladder:** 19 patients have been followed by serial urologic evaluation for more than 3 years. 5 patients improved their urologic status following surgery. **Neurological:** Improvement in pre-operative motor status was observed in 20 (26%) patients and no patient was made worse by surgery. **Adverse events**: The morbidity of surgery was 8% and constituted 6 patients that developed a postoperative subcutaneous cerebral spinal fluid (CSF) collection (pseudomeningocele).	The current standard advocates for early, prophylactic care, even in asymptomatic children, as treating after the onset of a neurological deficit improves outcomes in approximately 25% of patients

Elmesallamy, 2019[223] N = 43 Egypt	Other surgery Microscopic surgery- all patients were subjected to microscopic surgeries for untethering under general anesthesia for releasing tethering elements and repair of the thecal sac	**Bladder:** Urodynamic studies improved in 73% of patients after surgery and children showed significant improvement in all symptoms except back pain than adult patients. **Neurological:** At the one-year follow-up, paresthesia improved in 60% of children and 30% of adults, weakness improved in 40% of children and 17% of adults. **Adverse events**: Postoperative complications were cerebrospinal fluid (CSF) leak in seven patients, of them, two patients needed secondary sutures and two patients suffered wound infection and treated conservatively	Microscopic surgery is of value for patients suffering tethered cord syndrome with low risk of complications
Galhom, 2013[147] N = 10 Egypt	Other surgery Laminectomy performed on asymptomatic and symptomatic patients: untethering procedures consist of dissecting and debulking the lipoma upon the lumbodorsal fascia, laminectomy on the lower lumbar spine according to the level involved and opening the dura for exposing the intradural portion of the lipoma; the junction between the lipoma and the neural placode is dissected and divided for untethering; the lipoma was subtotally excised to allow the neural placode to move freely within the spinal canal, and any tethering arachnoidal adhesions were divided; after the subtotal resection of the lipoma, the pia was closed if possible and the filum terminale was divided to release any potential tethering	**Bladder:** There was statistically significant improvement in the bladder function capacity, compliance and post voiding residual (p=0.023, p=0.005, p=0.004, respectively). Only two patients still had hyperreflexic bladder **Neurological:** During the follow-up, all the patients had either symptoms unchanged (3 patients, 30%) or improved (7 patients, 70%); in 7 patients symptoms totally resolved; one patient didn't improve from leg weakness after surgery and had equinovarus deformity; no specific outcomes partitioned out for prophylactic treatment **Adverse events**: Five children had (50%) with CSF leakage; two patients (20%) had persistent leakage that mandate subcutaneous catheter drainage above the incision line and improved after two weeks; one patient (10%) had skin infection due to primary skin sinus and improved with time, one patient with transient foot drop for two months, and lastly one patient (10%) had transient urine retention due to conus manipulation in case with caudal conus lipoma; no specific outcomes partitioned out for prophylactic treatment	Early recognition of symptoms and signs of tethering of the spinal cord is crucial in diagnosis and prognosis of spinal dysraphism. Early surgical release of the tethering elements is important for recovery and avoidance of retethering.

Guven, 2014[224] N = 2 Turkey	Other surgery Surgical detethering with intraoperative neuromonitorization	**Bladder:** N/A **Neurological:** At the 1-, 3-, 6-, and 12-months postoperative follow ups, both patients no symptoms and an MRI showed the surgical site to be normal. **Adverse events**: NR	This study recommends using free-run EMG, evoked EMG, MUP, and detrusor muscle function monitoring to reduce operative morbidity and improve patient prognosis
Habibi, 2016[225] N = 7 Iran	Other surgery Simultaneous surgery for split cord malformation and sacral extradural arachnoid cyst in patients with tethering of the cord	**Bladder:** Decrease in urodynamic disorders in 5 patients, no new overt urinary tract problems was detected. **Neurological:** No patient developed new neurologic symptoms during a mean of 23 months of follow up. **Adverse events**: Post operative period was uneventful in all cases.	The conditions are better to be managed surgically in one session under a single anesthesia to prevent duplicate complications of further anesthesia and interventions in scar tissue
Hamzaoglu, 2007[226] N = 21 Turkey	Other surgery After the exposure of the determined levels, placement of all pedicle screws was performed as the initial part of surgical procedure; then surgical treatment for intraspinal pathology (release of tethered cord and/or excision of diastematomyelic bone spur) was performed by the neurosurgical team, then followed completion of instrumentation and correction of the deformity (posterior shortening wedge osteotomy or subtotal vertebrectomy if needed); posterior instrumentation for correction of the deformity was short segment in 7 patients and long segment in the remaining 14 patients; also, vertebrectomy via posterior approach was performed in 5 patients and 3 patients had additional anterior surgery later to prevent pseudarthrosis and crankshaft phenomenon.; a combination of autograft and allograft was used for achieving fusion in all patients	**Bladder:** NR **Neurological:** Four patients had neurologic deficits at the time of presentation, and all 4 had associated kyphosis. None of the patients experienced deterioration in their neurologic status after surgery. None of the patients had infection, pseudarthrosis, or loss of correction during the follow-up visit. **Adverse events**: NR	The simultaneous surgical treatment for congenital deformity and intraspinal abnormality does not involve significant complications and seems to be an alternative and safe treatment option

Jiao, 2023[227] N = 1 China	Other surgery A computerized tomography (CT) scan revealed thoracic disc herniation and spinal stenosis at the T11/T12 level. Magnetic resonance imaging further identified an abnormal herniated disc at the T11/12 level and a bony type 1 split cord malformation with the conus ending at approximately the L4 level. A posterior operation was performed, involving laminectomy decompression from T9 to L2, discectomy of T11 to 12, and autogenous bone grafting into the intervertebral space for interbody fusion. Prior to fusion, limited osteotomy was performed in the facet joint on both sides. This approach corrected the patient's kyphosis and released tension on the spinal cord. Finally, fixation from T8 to L2 was achieved using a pedicle screw-rod system.	**Bladder:** N/A **Neurological:** Patient with no previous tethered cord syndrome diagnosis presented with severe numbness and pain in both lower extremities accompanied by difficulty in walking. Surgical exploration showed that tension of the dural sac decreased, and fluoroscopy confirmed that the degree of kyphosis was significantly improved after surgery. There were also no complications during or after surgery. Good lower limb activity and muscle strength were observed, and the patient's subjective symptoms were significantly relieved. The patient's spinal deformity was also improved according to imaging. After 4 months, the patient returned to the outpatient clinic of our hospital for reexamination. Both digital radiography and magnetic resonance imaging results showed that the internal fixation was in a good position, and the patient's self-reported symptoms were significantly improved. **Adverse events**: N/A	There are multiple surgical options for treating symptomatic adult patients with tethered cord syndrome. The treatment of these patients with a bony mediastinum and split cord could be more complicated with greater challenges. Therefore, limited procedures may be more successful in the absence of detethering or vertebral column shortening surgeries. Use of dekyphosis operation combined with limited osteotomy in the present case demonstrates the advantages and success of this type of approach. However, additional studies are needed to determine the durability of dekyphosis operation combined with limited osteotomy for the treatment of adult tethered spinal cord when additional conditions such as bony mediastinum, dichotomous spinal cord, thoracic disc herniation with kyphosis, and split spinal cord are present. The present case report demonstrates that limited operations can potentially achieve good results if they are carefully designed and individualized to the patient.
Kang, 2007[228] N = 75 Korea	Other surgery Mega-dural sac repair: the lipoma was debulked microsurgically to permit the conus to move more freely within the spinal canal, and any tethering bands suturing with 8-0 prolene over the residual lipoma on the site of placode; finally, a mega-dural sac was constructed with lyophilized dura or Gore-Tex, with the purpose of maintaining the CSF circulation and preventing retethering of the cord (this procedure was performed in 15 of the patients referred most recently)	**Bladder:** 3/15 patients who underwent urodynamic studies showed an improvement in bladder functions (2 in group A, 1 in group B), 9/15 patients showed no change in bladder dysfunction (4 in group A, 5 in group B), and 1/15 patient in group B had aggravated bladder **Neurological:** preoperative neurological deficits improved after surgery in 29 patients (39%), remained stable in 28 (37%), changed slightly in 13 (17%), and worsened in 5 (7%). Patients in group A obtained better outcomes than those in group B **Adverse events**: Complications related to operations were postoperative CSF leakage (5 cases, 6.7%) and newly developed neurological deficits (6 cases, 8%).	Based on our surgical experience of untethering and decompression of lipomas, a mega-dural sac repair is useful to prevent retethering of the cord

Khoury, 1990[229] N = 31 Canada	Other surgery Division of the filum terminale: patients were placed into a prone position, a limited laminectomy of the fifth lumbar neural arch was performed, the dura was opened and the filum terminale was identified anatomically and by electrical stimulation, the filum was cut between 2 metal clips and a small specimen from the caudal end was sent for pathological confirmation	**Bladder:** At the first follow up, 22 patients (71%) demonstrated early and significant improvement in incontinence, and relief of back and leg pain. At the last evaluation, daytime incontinence, which had been present in 29/31 patients, resolved in 21 patients (72% **Neurological:** NR **Adverse events**: N/A	Division of the filum terminale resulted in the resolution of daytime incontinence and urodynamic detrusor hyperreflexia in a significant proportion of the group without causing neurological sequela

Leary, 2023[230] N = 49 US	Other surgery Single level interlaminar lumbar laminectomy was performed, with the specific level determined as needed for a high fatty filum terminale approach with respect to the level of the conus medullaris observed on preoperative magnetic resonance imaging. Retrospective review of electronic health records for preoperative data (demographics, history of precipitating traumatic event, comorbidities of interest, symptomatic presentation), diagnostic data (pre- and postoperative radiologic evidence of tethered cord syndrome, preoperative urodynamic testing results when available), and postoperative symptomatic and complication data 12 months following surgery.	**Bladder:** Most patients reported urinary (79.6 %) and/or bowel (34.7 %) symptoms preoperatively. 44.9% of patients said they experienced urinary leaking. Among 24 patients (49.0 %) who underwent pre-operative urodynamic testing, nine had neurogenic bladder, three h **Neurological:** All patients (100 %) presented with neurological signs and symptoms. The most common individual signs and symptoms were back pain (87.8 %), fatigue (83.7 %), lower extremity pain (83.7 %), lower extremity paresthesia (69.4 %), hyperreflexia on exam (59.2 %), lower extremity motor weakness on exam (57.1 %), and sensory deficit to light touch on exam (49.0 %). Eighteen patients (36.7 %) reported headaches at baseline, and nine (18.4 %) had lumbar neurocutaneous signs such as sacral dimpling. Tethered cord syndrome associated signs & symptoms were categorized into four sets (neurologic, musculoskeletal, urinary, and bowel -related signs and symptoms), the proportion of patients experiencing each, of those who returned for follow-up, decreased significantly by the one-month post-operative visit (p < 0.001 for all). These improvements remained statistically significantly across the three- and 12-month follow-up compared to baseline. Symptom resolution appears to be generally maintained one year after surgery across all common symptom categories, with the caveat that approximately half of our retrospective study cohort did not return for 12-month follow-up. **Adverse events**: Overall, 10 patients (20.4 %) had a complication of any kind. Five (10.2 %) experienced a wound complication, one of which required re-operation. One patient developed a pseudomeningocele, two (4.1 %) developed arachnoid cysts, and two (4.1 %) developed recurrence of symptoms	In this single-institutional case series, we describe the preoperative and postoperative symptomatic characteristics and progression of 49 patients with adult-onset tethered cord syndrome . We demonstrate that surgical detethering is a viable option for many adult-onset tethered cord syndrome patients with moderate-to-severe presenting symptomatology and radiologic evidence of tethered cord syndrome, including in the presence of concomitant degenerative spinal disease. Our findings support the notion that altered spinal dynamics in the setting of age-related degenerative changes, anatomical changes within the spinal canal, and traumatic impacts to the spine of variable nature may contribute to the symptomatic decompensation of a congenitally "tethered" spinal cord in the setting of low-lying conus and a fatty or thickened filum terminale. The possibility of adult-onset tethered cord syndrome should be considered if such radiographic evidence exists in adult patients presenting with back pain, neurological decline and/or bladder dysfunction and not considered "incidental" findings. Management of this patient cohort should optimally include an interdisciplinary workup to weight potential benefit of tethered cord release.

		indicative of retethering within 12 months after surgery.	
Lee, 1997[231] N = 40 US	Other surgery surgical untethering combined with expansive duraplasty: the surgical procedure started with laminectomies and a midline dural opening; meticulous dissections of the lateral and dural adhesions and maintenance of hemostasis were performed; intraoperative ultrasonography was performed in all procedures using a 7.5-MHz transducer; a piece of cadaveric dura was used to expand the subdural space and a watertight closure was accomplished	**Bladder:** Sphincter dysfunction improved in 50% of the patients having this symptom preoperatively (6/12). **Neurological:** Untethering improved the motor symptoms in 79% of the patients. Radicular pain was relieved in 62% of the patients and sensory level loss improved in 43% of the patients having these symptoms preoperatively. **Adverse events**: N/A	Surgical untethering and expansive duraplasty, followed by postoperative position rotation to avoid retethering, provide symptomatic relief for patients with PPMM.
Menezes, 2020[232] N = 2 US	Other surgery Patient 1: Laminectomy; Patient 2: No surgery; Patient 3: Myelotomy	**Bladder:** Patient 1: Urodynamic studies showed that he emptied his bladder well. He was able to get back to work as a contractor. Patient 3: NR **Neurological:** Patient 1: Postoperatively, the patient was able to extend his fingers. The sensation to touch, pinprick and vibration, improved. Patient 3: The patient had marked improvement of sensation and hand function **Adverse events**: NR	Magnetic resonance imaging can aid in identifying such abnormalities to prevent spinal cord injury during surgical release

Morota, 2023[233] N = 15 Japan	Other surgery Surgical detethering of the spinal cord followed by ventral anchoring. Surgical procedures performed with intraoperative neurophysiological monitoring of the bulbocavernosus reflex and pudendal mapping.	**Bladder:** Complete untethering was achieved in all the patients. The bulbocavernosus refex was monitorable in nine patients, was stable in six patients, and was worse but preserved in three patients. None of the patients, including those whose bulbocavernosus refex **Neurological:** Symptoms before untethering were worsening of neurogenic bladder in six patients, deterioration of the motorsensory function of the lower extremities in fve patients, and progression of orthopedic symptoms (scoliosis and the ankle joint deformities) in four patients. **Adverse events**: All but one patient reported improvement or stabilization of the preoperative symptoms during the follow-up period. In this patient, postoperative magnetic resonance imaging demonstrated that the untethered conus medullaris had again come into contact with the dorsal dura mater. However, no complication directly related to the ventral anchoring was observed, and there was no tethered cord syndrome recurrence during the follow-up period (range: 12 to 104 months, average: 48.6 months, median: 45 months).	Ventral anchoring is a simple and safe surgical procedure when performed by an experienced surgeon and can prevent radiographic tethered spinal cord recurrence. It restores the dorsal subarachnoid space and keeps the conus medullaris away from the dorsal surface of the dura mater. The present preliminary study found that ventral anchoring has the potential to prevent recurrent tethering after corrective surgery for tethered spinal cord in patients with a congenital lumbosacral dysraphic spinal lesion. It should be reminded that ventral anchoring reduces the incidence of radiographic retethering but it is not clear enough whether this technique prevents clinical tethered spinal cord in the long-term. Further study with long-term follow-up is necessary to conclude its final efect.
Nakamura, 1995[234] N = 77 Japan	Other surgery The operative procedure is a laminectomy (two or three lamina above the lipoma), careful dissection of intrathecal adhesion, resection of the lipoma and severance of the filum terminale; a release operation was performed in 58 cases (28 LPCM cases and 30 TFT cases); forty-nine cases were examined 2 months or more after the surgery (27 LPCM cases and 22 TFT cases); twenty-one cases (78%) in the LPCM group and 15 cases (68%) in the TFT group showed improvement of various degrees	**Bladder:** NR **Neurological:** A release operation was performed in 58 cases (28 LPCM cases and 30 TFT cases). Forty-nine cases were examined 2 months or more after the surgery (27 LPCM cases and 22 TFT cases). Twenty-one cases (78%) in the LPCM group and 15 cases (68%) in the TFT group showed improvement of various degrees. **Adverse events**: NR	Surgical release operations is effective for improvement, with 73% showing positive outcomes in 49 cases two months or more after surgery

Natt, 2020[235] N = 50 Other	Other surgery Laminectomy and detethering of spinal cord under operative microscope was done by supervisor, assisted by researcher; patients were followed for 6 month postoperatively for outcome variables i.e. improvement in back pain, motor function, urinary incontinence	**Bladder:** All patients had urinary incontinence preoperatively. Post-operatively, 33 (66.0%) patients had urinary incontinence and 17 (34.0%) patients had no urinary incontinence. At the 6 month follow up, 17 (34.0%) patients had improvement in urinary incontinen **Neurological:** Preoperatively, all patients experienced severe pain. Post-operatively, the symptoms improved to moderate pain for all patients. At the 6 month follow up, Thirty five (70.0%) patients had improvement in back pain, 18 (36.0%) patients had improvement in motor function. **Adverse events**: NR	The back pain, motor function and urinary incontinence improve postoperatively in the majority of patients. The rate of symptomatic improvement was greatest for back pain, followed by motor, and then urinary improvement
Noguerra, 2004[236] N = 54 US	Other surgery surgical release with sectioning of the filum: all patients were placed in the prone position after induction of general anesthesia; mmidline incision was made in the lumbosacral junction; either an L5 or S1 laminectomy was performed to gain access to the thecal sac; once exposed, the thecal sac was opened, the filum terminale identified, and any adherent nerve roots carefully dissected off of it; the filum was then isolated from the remainder of the cauda equina by a cottonoid patty, coagulated and sectioned	**Bladder:** Preoperative clinical evaluation revealed daytime incontinence in 12 (92%) patients and urinary tract infection only in 1 (table 1). Of those patients with incontinence 6 also had urinary tract infections. Postoperative clinical evaluation showed improvem **Neurological:** N/A **Adverse events**: N/A	Older children with orthopedic problems or VATER's syndrome may have neuro-urological abnormalities that can improve or resolve after surgery, with some requiring anticholinergic therapy

Otto, 2023[237] N = 1 US	Other surgery Laminectomy with release of the filum terminale. Prior to any surgery, a spinal ultrasound was performed. This demonstrated the conus medullaris being non-dependently positioned at mid-L3 vertebral level with reduced cauda equina motion. Magnetic resonance imaging confirmed borderline low-lying cord terminating at mid-L3, but no other anatomic abnormalities of occult spinal dysraphism.	**Bladder:** Prior to surgical intervention, a urinalysis with microscopy was negative for blood, protein, nitrites, leukocyte esterase, or white cells. Additionally, a renal ultrasound was performed. This demonstrated bilateral mild pelviectasis, central and peripher **Neurological:** A physical exam prior to surgical intervention showed a bifid gluteal crease and a sacral dimple but was otherwise normal with intact lower extremities and without abnormal muscle tone or focal neurological deficits. Prior to initiating a treatment plan, urodynamic testing was attempted to confirm neurological dysfunction but could not be completed. Post-surgical urodynamic studies demonstrated detrusor-sphincter dyssynergia without detrusor overactivity. This confirmed the presence of neurological dysfunction as the most likely cause of vesicoureteral reflux, consistent with tethered cord syndrome. **Adverse events**: Reported that patient underwent laminectomy with release of the filum terminale with no complications.	Tethered cord syndrome is primarily diagnosed by clinical presentation, although imaging data is useful for defining the etiology and assessing the severity of sequelae. The majority of patients benefit from surgical release of a tethered cord, resulting in prevention or improvement of symptoms, although some require repeated procedures. In this case, a patient was appropriately diagnosed and treated for tethered cord syndrome and had stabilization of symptoms. Patients with typical clinical symptoms of tethered cord syndrome should receive appropriate treatment, even in cases of indeterminate imaging criteria.

Patil, 2016[238] N = 17 India	Other surgery Lipoma excision- patients were operated in prone position under general anesthesia with all the pressure points well protected; an elliptical or oval skin incision was made around the central most prominent part of lipomatous swelling, and skin flaps were raised in subcutaneous plane; dissection was done all around the central lipomatous component, reaching up to the lumbosacral and thoracolumbar fascia; dura was opened cranially and caudally from the site of defect and intradural component of lipoma was excised; detethering of cord was done; laminotomy was done when felt required; filum terminale was identified and divided at its lower and lowermost visible end; dura was closed primarily using 5-0 Prolene without the use of synthetic material in all cases followed by closure of lumbosacral or thoracolumbar fascia over it using Prolene 5-0; the average operative time was 90 min and average blood loss was 15 cc; bipolar cautery was usedafter subcutaneous dissection; in doubtful cases, nerve locator was used to differentiate neural tissue from connective tissue and sharp dissection with scissors was preferred; minivac suction drain was used in 11 (64.7%) cases with large dead space in subcutaneous plane; sutures were removed after 8–10 days and patient was followed regularly	**Bladder:** Two patients had fecal pseudoincontinence, whereas one patient developed constipation. One (5.8%) patient of lumbosacral LMM and 1 (5.8%) patient of sacral LMM had urinary incontinence postoperatively. **Neurological:** Objective improvement in lower limb motor function was observed in 3 (17.6%) patients and three patients had decreased lower limb power. Two patients developed altered sensations and weakness of lower limb about 2.5-3 years after initial LMM repair. They needed repeat detethering of cord. **Adverse events**: Two patients developed hydrocephalus after LMM repair for which low-pressure ventriculoperitoneal shunt was inserted. Wound infection occurred in 1 (5.8%) patient, whereas 7 (41.1%) patients developed seroma in wound which responded to repeated aspirations under aseptic precautions.	Early surgery is recommended for asymptomatic patients with lipomyelomeningocele to achieve satisfactory outcomes, while emphasizing close observation for those with residual lipoma and undivided filum terminale for potential progressive neurological changes

Samdani, 2010[239] N = 17 US	Other surgery Scoliosis surgery for seventeen patients with myelomeningocele with a minimum follow-up after fusion of two years	**Bladder:** NR **Neurological:** NR **Adverse events**: No patient experienced a shunt-related issue postoperatively. In addition, no new cranial nerve palsies, change in urological function, or upper extremity neurological deterioration occurred. One patient, whose MM motor level was at L-4, had moderate right quadriceps muscle weakness postoperatively, which improved to baseline function over 1 month. The etiology of the weakness was unclear as a postoperative CT was unremarkable. Although neurological complications were sparse, wound problems occurred in 4 (23%) of 17 patients, a rate similar to others reported in the literature	The study results suggested that spinal cord untethering may be unnecessary in patients with MM who are undergoing scoliosis corrective surgery and do not present with clinical symptoms of a tethered cord, even though tethering is radiographically demonstrated.
Shi, 2014[240] N = 6 China	Other surgery Multisegmental spinal-shortening osteotomy-were performed in patients, which required multilevel discectomy and facetectomy; the certain length gap created by the discectomy and facetectomy were then closed with serial compression through the domino connectors; temporary rods were replaced with permanent rods once final spinal column alignment was achieved; the shortening of the spine was measured at the anterior and posterior borders and the midpoint of the vertebral end plate on the lateral fluoroscopy	**Bladder:** Two (100%) patients with urological symptoms reported improvements, although deficits remained at the time of last follow-up. **Neurological:** Six patients with lower-extremity motor dysfunction improved and six noted complete resolution of preoperative lower-extremity sensory symptoms. Five (100%) reported immediate low back or lower extremity pain relief following MSSO. VAS pain scores of all six patients were greatly improved after surgery **Adverse events**: NR	The principal benefits of MSSO over detethering operations will be in preserving the symptomatic and functional neurological improvements with lasting results and potentially obviating the need for future reoperations.

Yang, 2013[241] N = 73 China	Other surgery In this series of surgical interventions, we first dissected the subcutaneous lipoma to the defect of the spinal cord and then removed it. During resection, excessive traction on the lipoma was avoided to prevent injury to the spinal cord that was connected to the lipoma. The dural membrane defect was revealed, with the lipoma growing in both directions, cephalically and caudally. Usually, a lipoma that grew cephalically entered the subdural space and was attached to the dorsal surface of the spinal cord, infiltrating it. In contrast, a lipoma that grew caudally remained outside the dural membrane. Next, the dural membrane on the cephalic side of the defect was excised and the lipoma was totally exposed. The lipoma was removed piece by piece using microscopic scissors or a laser knife or using ultrasonic suction for tumor shrinkage. After removal of the lipoma and decompression of the spinal cord, the liberated spinal cord was gradually elevated from the ventral side of the spinal canal. The spinal cord was gently teased to one side and was observed to be under traction, with the dural membrane growing to both sides of the spinal cord as well as to the end of the conus medullaris because of the defect in the dorsal dural membrane. The spinal cord and conus medullaris were then detached from the dural membrane using microscopic scissors to relieve tethered spinal cord. After this procedure, the spinal cord and conus medullaris were relieved and settled back to the ventral side of the spinal	**Bladder:** The patients experienced various degrees of improvement. Transient exacerbations of symptoms were seen in 5 patients. These patients had different symptoms such as increased frequency of stools, weak urine stream, and numbness or pain in the lower limbs. **Neurological:** The patients experienced various degrees of improvement. Transient exacerbations of symptoms were seen in 5 patients. These patients had different symptoms such as increased frequency of stools, weak urine stream, and numbness or pain in the lower limbs. After 1 to 2 weeks, these patients recovered gradually to their preoperative condition. The patients who were asymptomatic before surgery remained asymptomatic after surgery **Adverse events**: No complications such as cerebrospinal fluid leakage, wound infection, or infection of the central nervous system were observed	Surgical intervention is advised for the optimal excision, untethering, reconstruction, and neurological function rehabilitation in cases of lipoma of the conus medullaris

	canal. The dural membrane was then incised to further explore the filum terminale. Any filum infiltrated by lipoma was excised. Finally, the placode was closed using intermittent sutures. During operation, after removing the lipoma attached to the dorsal surface of the spinal cord, small amounts of tissues were removed from the interface between the lipoma and spinal cord for pathological examination.		
Yuan, 2023[242] N = 13 China	Other surgery Microsurgery with electrophysiological monitoring- patients were intubated in the prone position while under general anesthesia using orotracheal intubation; for meningocele, subcutaneous lipoma, or skin sinus, the mid-median straight incision was used, and a longitudinal fusiform incision was possible; the filum terminale of the tethered cord was identified and the fistula of the tethered cord was explored under the special microscope of neurosurgery; the filum terminale was cut after electrocoagulation, and the cyst was sutured and occluded with autologous fat; laminectomy was performed on some patients, and the connecting piece was repaired	**Bladder:** Preoperative residual urine and preoperative urodynamics were performed in 5 patients. After surgical treatment, all patients had different degrees of improvement in preoperative symptoms or signs. **Neurological:** NR **Adverse events**: NR	In sacral canal cyst patients, intraoperative use of a surgical microscope and electrophysiological nerve function monitoring can effectively reduce spinal cord and nerve damage and improve surgical safety

Zhou, 2017[243] N = 17 China	Other surgery One-stage posterior scoliosis correction procedure without preventive untethering without preventative untethering, the coronal Cobb angle, apical translation, the curve flexibility and the correction rate were recorded and analyzed to evaluate correction result; the Scoliosis Research Society-22 questionnaire, and the modified Japanese Orthopedic Association score were analyzed pre-operatively and at the 1-year follow-up evaluation to assess clinical outcomes and neurologic function	**Bladder:** No difference existed between the pre- and post-operative bladder function (p = 0.67) **Neurological:** All the patients underwent neurological physical examination after operation and in follow up time and the original seven patients who had complaints also underwent additional neural electromyography and urodynamic test. There was no new symptoms appeared after the scoliosis correction and none of the patients experienced deterioration in their neurological status after surgery. None of the patients underwent any kinds of tethered cord release until last follow up. The mJOA assessed neurologic function. No significant difference existed between the preoperative and follow-up evaluation total scores (p = 0.39) **Adverse events**: N/A	One-stage posterior scoliosis correction is a safe and effective surgical procedure for scoliosis patients with an asymptomatic tethered spinal cord, as it led to significant improvements in Cobb angles, apical vertebral translation, functional activities, pain, self-image
Ogiwara, 2011[244] N = 2 US	Repeat detethering NR	**Bladder:** Patient 1: At 4-month follow-up, cystometrography revealed improvement and the patient had urinary bladder continence.; Patient 2: At the 3-month follow-up the back pain and constipation had improved **Neurological:** NR **Adverse events**: NR	Cystometrography is useful for detecting the lesion and confirming the diagnosis of retethering

Ewelt, 2010[245] N = 15 Germany	Spinal cord transection The surgical technique consisted of laminectomy, adhesiolysis, cordectomy, and, in some cases, additional duraplasty. All cordectomies were performed at the upper thoracic level. Duraplasty was added in 5 instances.	**Bladder:** NR **Neurological:** Spasticity improved in only 2 patients but stabilized in 9. Spastic symptoms in the legs deteriorated further in 4 of 15 patients. The patient who reported excessive perspiration in the lumbar and sacral areas finally experienced an improvement after 3 months. Altogether, 14 of 15 patients showed no additional neurological deficits above the transection level with stabilization or even improvement in their motor and sensory function compared with the preoperative examination. Eight patients suffered further subjective deterioration, mainly in terms of spasticity and pain, but objectively presented with stabilization of their neurological status compared with the preoperative situation **Adverse events**: There were no adverse surgical events or any objective immediate functional deterioration associated with the operative procedure. All patients could be mobilized without restriction the day after surgery	Cordectomy can be a useful instrument to preserve functions of the upper extremities and to improve spasticity and pain in patients with severe myelopathy and tethered cord, syringomyelia, or arachnopathy of various etiologies

Garces, 2017[246] N = 1 US	Spinal cord transection After multiple unsuccessful attempts at untethering and complex plastics-assisted closure, a spinal cord transection with a "blind-pouch" closure of the dura at the level of T12/L1 was felt to be radical and unconventional but viable as an alternative that could stop the CSF leakage and definitively untether the spinal cord. The procedure was done via a midline approach just superior to the placode for T12 and L1 laminectomy followed by an intradural transection of the spinal cord just above the cord defect. The dura was closed, separating the placode and distal thecal sac from the "normal" spinal cord. In the postoperative period, the patient developed intermittent episodes of hypertension (SBP >200), bradycardia (heart rate <30), headaches, altered mental status, severe perspiration, and red flushing of the upper torso, face, and arms. The hypertension was refractory to oral antihypertensive medications	**Bladder:** NR **Neurological:** Lower back pain is improved; there was no ascension of any motor or sensory deficit and no further CSF leakage. **Adverse events**: NR	The author underscores the potential major side effect of autonomic dysreflexia resulting from elective spinal cord transection, emphasizing the importance of recognizing and treating it to prevent significant distress and morbidity
Kulwin, 2013[247] N = 16 US	Spinal cord transection We identified a subset of patients who had undergone sectioning of the filum terminale for tethered cord with a spinal cord syrinx	**Bladder:** All 11 patients had improvement in urinary function, defined by a reported reduction of urgency or incontinence with improved postoperative urodynamics **Neurological:** Both patients with gait disturbance improved postoperatively. Two (66%) of the 3 patients with scoliosis had stabilization or mild improvement of their curves (Cobb angle improved from 55° to 41° and from 29° to 26°, respectively). One patient progressed beyond 45° and underwent surgical correction **Adverse events**: N/A	Tethered cord release is recommended because it leads to significant clinical improvement, especially in terms of urodynamic studies, pain, and gait disturbances

Veronesi, 2018[248] N = 1 Italy	Spinal cord transection In a prone position, intraoperative sacral Rx fluoroscopy was used to locate the sacral hiatus and made a 4 cm skin incision, and the superficial dorsal sacrococcygeal ligament was partially removed to access the sacral canal, where they found a thicker than usual fatty tissue-wrapped filum terminale externum; this was isolated, coagulated, and dissected with a vessel loop, the surgery took about 20 minutes and was performed under general anesthesia due to the patient's clinical condition, with six months of follow up	**Bladder:** N/A **Neurological:** At the 3 and 6-month follow-up appointments, the patient showed remarkable improvement, he was no longer bedridden, could sleep supine, and was self-sufficient in daily activities, also his leg pain, dysesthesia, and muscle cramps were significantly reduced, occurring only occasionally and with mild intensity **Adverse events**: N/A	The minimally invasive surgical technique of sectioning the filum terminale externum has advantages, including fewer complications, smaller incision, minimal blood loss, less soft tissue injury, reduced post-surgery pain, and shorter hospitalization, with dramatic clinical improvement
Huang, 2015[249] N = 21 China	Spine-shortening vertebral osteotomy 21 patients (14 females and 7 males, average age 15.4 yr) underwent spine-shortening osteotomy without detethering, all of the patients had tethered cord; patients with main curve more than 90 ° underwent vertebral column resection, whereas the others had pedicle subtraction osteotomy performed; the average postoperative follow-up period was 45.2 months	**Bladder:** Urinary dysfunction and bowel incontinence present preoperatively in 3 patients all recovered by final follow-up. **Neurological:** At the final follow-up, the neurological deficits in 8 (80%) patients were significantly improved, whereas 2 (20%) remained unchanged. At final follow-up, 71.4% (5/7) patients reported improvement in motor function, 100% (3/3) had improved pain scores, and 75% (3/4) reported better sensory function after the spine-shortening osteotomy. **Adverse events**: 5 (23.8%) patients incurred complications including temporary neurological deterioration in 1 patient, urinary tract infection in 2 patients, cerebrospinal fluid leakage in 1 patient, and blood loss more than 5000 ml in 1 patient.	Spine-shortening osteotomy is a safe and effective treatment option for congenital scoliosis associated with a tethered cord, as it can achieve correction of the spine deformity and simultaneous reduction of cord tension

Huang, 2019[250] N = 51 China	Spine-shortening vertebral osteotomy Following general anesthesia and endotracheal intubation, the baseline potential of IONM was set and the intravenous prophylactic antibiotics were administered. The skin incision was made over the spinous processes. After exposure of the planned fusion levels, the pedicle screws were placed using standard free-hand technique. Osteotomies were generally performed at the apex of kyphosis or scoliosis for correction and spinal cord safety, but when the SSCM was at the apex, osteotomy would be suggested to be performed above or below it to avoid bony septum manipulation. Complete laminectomies were performed at the target osteotomy levels. Temporary rods were used prior to initiating the contralateral vertebral resection. The 3-column osteotomy was performed by removing the target vertebra as well as the intervertebral discs above and below (PVCR). The spine shortening distance was determined according to the magnitude of spinal deformity and the IONM results. An asymmetrical compression maneuver was applied to shorten the spinal column and correct the deformity gradually with more compression and spine shortening on the convex side. Additional laminectomies were often needed to resolve posterior spinal cord kinking during this procedure. The osteotomy gap must be closed gradually with bone-on-bone apposition under dedicated IONM. A structural cage or mesh	**Bladder:** NR **Neurological:** For the postoperative neurological function, 1 patient had muscle power improved postoperatively, 1 patient with new neurological deficit recovered to preoperative level at 1 yr postoperatively, the other 10 patients' neurological function maintained at preoperative level. In control group, 3 EP events during pedicle screw placement, 7 during osteotomy, and 5 during deformity correction were documented in 9 patients. Two patients had postoperative neurological deficits. One of them had nerve root deficit, which was relieved by a second operation. The other had transient spinal cord deficit, which recovered at 3 mo postoperatively **Adverse events**: In SSCM group, 2 EP events during osteotomy and 2 during deformity correction were documented in 3 patients	Single-stage spine-shortening posterior vertebral column resection with moderate correction is a viable treatment for CS associated with type I split cord malformation, offering safe spinal deformity correction and potentially avoiding neurological complications associated with detethering procedures

	was placed anteriorly when the gap cannot be completely closed due to severe spinal cord kinking or IONM events. At last, moderate convex compression and in situ bending were used to correct the scoliosis, whereas concave distraction should be implemented with caution of mechanical traction to the spinal cord. The overlying musculature, fascia, and skin were closed in anatomic layers after decortication and bone grafting. All cases were carried out under dedicated multimodal (5 modes: somatosensory evoked potential [SSEP], motor evoked potential [MEP], descending neurogenic evoked potential [DNEP], and triggered- and free-run electromyography [EMG]) IONM. The protocol of multimodality IONM was the same to that introduced in our previous study		

Ide, 2021[251] N = 8 Japan	Spine-shortening vertebral osteotomy Untethering surgery was performed in 1 case and spinal shortening osteotomy was performed in seven cases; spinal shortening osteotomy was performed at the level of L1, the laminae from T12 and L1 were resected, pedicle screws were placed bilaterally at 2 vertebrae above and 2 vertebrae below; then, temporary rods were fixed in place for column stability; from the base of the bilateral pedicles, the upper half of the L1 vertebral body was completely removed; after inserting the cage to adjust the shortening length, osteotomy sites were compressed using pedicle screws with somatosensory-evoked potentials, motor-evoked potentials, and ultrasonography; an optimal shortening length was considered when ultrasonography showed spinal cord pulsation and relaxation; no abnormalities were observed in spinal cord monitoring; shortening length was adjusted by changing the cage size; no further details for untethering surgery operation	**Bladder:** Bladder dysfunction was found in 6 cases, and 2 cases had improved urinary incontinence. One patient began to feel the urge to urinate, but still required clean intermittent catheterization. There was no improvement in the other 3 cases. **Neurological:** Clinical improvements were obtained in all 7 cases, and there was no exacerbation case. Back pain occurred in 2 patients before surgery, and both cases were improved. Lower limb pain existed in preoperative 6 cases and was reduced or eliminated in all cases. Lower limb muscle weakness was found in 7 cases, and improvement was observed in 6 cases. **Adverse events**: N/A	Spinal shortening osteotomy using somatosensory-evoked potentials, motor-evoked potentials, and intraoperative ultrasonography yields good clinical outcomes, including significant improvements in back pain, leg pain, muscle weakness, and bladder dysfunction, and is considered a useful surgical technique compared to detethering surgery

Kobayashi, 2023[252] N = 1 Japan	Spine-shortening vertebral osteotomy Shortening osteotomy with neurophysiological monitoring was performed using motor evoked potentials. Prior to surgery, magnetic resonance imaging revealed a low-lying conus medullaris extending to the level of S2 and surrounded by fat tissue at that level.	**Bladder:** Patient presented reporting a history of frequent urination in the last year. The patient's urinary disturbance improved 1 year after surgery, although magnetic resonance imaging did not show evidence of untethering. Patient had developed no recurrence at **Neurological:** Patient presented reporting a history of worsening leg numbness and urinary dysfunction over a period of five years, with more rapid decline in the previous year. The patient's leg numbness improved immediately after surgery, although magnetic resonance imaging did not show evidence of untethering. Patient had developed no recurrence at 2 years after surgery. **Adverse events**: N/A	In conclusion, spine-shortening osteotomy that preserves the caudal one-third of the pedicle and lamina with one-above and one-below instrumentation successfully reduced the spinal cord tension without causing neural damage.

Kokubun, 2011[253] N = 8 Japan	Spine-shortening vertebral osteotomy Surgical Procedure Spine-shortening osteotomy was performed at the level of L-1 in all but 2 patients, in whom it was performed at T-12 because previous surgeries performed extended up to the level of L-2 or L-3. The surgical procedure performed at L-1 is described below (Fig. 1). The laminae from the T11–12 facets to the upper half of the L-2 lamina and the L-1 transverse processes were exposed. Pedicle screws were placed bilaterally at the T-12 and L-2 levels such that they were positioned parallel to the upper margin of the T-12 vertebral body and the lower margin of the L-1 body, respectively; in addition, it was ensured that the lengths of the pedicle screws at T-12 that were out of the vertebral body were equal to those of the L-2 screws, which was confirmed radiologically. This screw arrangement avoided sagittal translation and anterior or posterior opening between the T-12 and L-1 vertebral bodies after the spine-shortening procedure. The lower half of the T-12 lamina and the T12–L1 facet joints were excised (Fig. 1A1 and B1). The osteotomy line of the T-12 lamina was placed slightly cranial to the lower margin of the T-12 body, which facilitated the subsequent removal of the T12–L1 intervertebral disc. The upper three-quarters of the pedicles and transverse processes, and the upper one-third of the lamina of the L-1 vertebra were then removed using a rongeur and an air drill with a diamond bur. The upper half of the L-1 body was drilled away through	**Bladder:** All patients showed no improvement in bladder function and 1 required urological surgery **Neurological:** In terms of motor function, only 1 patient showed an increase in score, by 2 points at the final follow-up appointment. On average, it was found that the score decreased by 6.5 points (range 1–15 points) in 4 patients at the final follow-up, although it increased or stabilized for a certain period after surgery in 3 of them. The sensory function was found to have improved or stabilized in 2 patients each at the final follow-up appointment. In contrast, it worsened in the other 4 patients but the decrease in the score was only 2 points compared with the preoperative score in 3 of the 4 patients **Adverse events**: No obvious intraoperative adverse events (such as nerve root injury) or postoperative infections occurred in any patients	Spine-shortening osteotomy is a feasible treatment option for adult tethered cord syndrome caused by a spinal lipoma due to its success in reducing spinal cord tension, stabilizing symptoms, and potentially delaying neurological deterioration

	the base of the partially removed pedicle on one side with a rod assembled with the pedicle screws on the opposite side, which prevented closure of the gap to be created. This was accomplished while still preserving the anterior longitudinal ligament. The osteotomy line was placed in a manner such that the T-12 upper and L-1 lower vertebral endplates would run parallel to each other after the spine-shortening procedure. The T12–L1 intervertebral disc was removed along with the posterior longitudinal ligament (Fig. 1A2 and B2). The same steps were accomplished on the other side with a rod assembled on the opposite side for the L-1 body and the T12–L1 intervertebral disc. The remaining part of the upper half of the vertebral body and posterior longitudinal ligament in front of the dural tube were resected using a Kerrison rongeur (Fig. 1A3 and B3). The gap created was closed by gradual compression applied to the pedicle screws at T-12 and L-2 using the rods as guides. The rods were then changed to shorter ones fit for the shortened spine (Fig. 1A4 and B4). Bone chips from the excised laminae and spinous processes were also placed over the T-12 and L-1 laminae for posterior fusion		

McVeigh, 2021[254] N = 41 US	Spine-shortening vertebral osteotomy Spinal column shortening osteotomy; a 6-mm diamond drill bit was used to drill the pedicle carefully, leaving a medial eggshell-thin rim of cortical bone to protect the dura; the size of the osteotomy gap was estimated using the width of the diamond drill bit, which was approximately 1.5 cm; this technique was used to continue drilling into the vertebral body toward midline; the anterior longitudinal ligament and the superior and inferior endplates were left intact; the nerve root one level below the level of the osteotomy was left skeletonized; after completing this process on one side, a temporary rod was placed on that side and the same process was completed on the contralateral side; to allow the force of closure to be evenly dispersed through all the screws, segment rods were positioned across the 2 pedicle screws above and below the osteotomy defect; the screws securing the temporary rod were loosened to allow for use of a compressor to close the defect in a controlled manner; after closure a temporary rod was secured in place and the short rods were replaced by a unitized permanent rod	**Bladder:** Urodynamics improved in 58.8%, remained the same in 35.3%, and worsened in 5.9%. Urodynamics and urology evaluation documented stable to improved bladder function in 16/17 patients in whom both pre- and postoperative urodynamics were performed. **Neurological:** Of the 30 patients included for analysis, significant subjective clinical improvement was seen in the preoperative symptoms of pain and weakness. For patient-reported PedsQL, 11 patients (57.9%) reported an improvement greater than the MCID, 5 patients (26.3%) had stable scores with no significant change, and 3 patients (15.8%) worsened with a decrease in score larger than the MCID. For parent- reported PedsQL, 10 patients (52.6%) showed significant improvement, 6 patients (31.6%) had stable scores, and 3 patients (15.8%) worsened. **Adverse events**: N/A	Spinal column shortening is a safe and effective alternative to traditional spinal cord untethering for tethered cord syndrome in children and emerging adults, based on objective formal urodynamics and positive patient- and parent-reported outcomes

Miyakoshi, 2009[255] N = 3 Japan	Spine-shortening vertebral osteotomy A total Spine System was used, pedicle screws were placed at T12 and L2, and specific vertebrae and intervertebral disc components were resected; the spine was shortened by 2 cm and stabilized with a pedicle screw-rod construct, and posterior bone grafting was done, and the patient wore a brace for 3 months, and complete bone union was achieved within 6 months without loss of correction with a 5-year follow-up	**Bladder:** There were no symptoms of bladder dysfunction **Neurological:** After surgery, the patient experienced the resolution of back pain, with no motor impairment **Adverse events**: No complications were reported during the course of the study or treatment	Spine-shortening vertebral osteotomy is a safe and effective surgical technique for tethered cord syndrome
Oktay, 2017[256] N = 1 Turkey	Spine-shortening vertebral osteotomy Somatosensory-evoked potentials, motor-evoked potentials, and free-run electromyography for guidance in the operation were utilized; an incision was made between the T9 and L5 vertebrae, allowing access to the L1 segment, bilateral pedicle screw implants were inserted from T10 to L5, excluding L1, using a free-hand technique, a laminectomy from T12 to L2 exposed the spinal cord; following the placement of a temporary rod, bilateral pedicles were removed, and the upper and lower L1 intervertebral discs were extracted, culminating in the complete removal of the L1 vertebral body; subsequently, a contoured permanent rod was placed on the other side, and the gap between T12 and L2 was meticulously closed with a compression force while closely monitoring electrophysiological signals during the correction procedure	**Bladder:** Intact bladder function **Neurological:** The patient's local kyphosis angle improved and was corrected to 16° from its initial range of 40 to 57° **Adverse events**: There has been no change or deterioration in the syrinx cavity or the patient's neurological examination and urodynamic tests	In progressive kyphosis associated with tethered cord syndrome, posterior vertebral column resection after untethering surgery represents a safe and efficacious but technically challenging option

Safaee, 2017[257] N = 1 US	Spine-shortening vertebral osteotomy After induction of general anesthesia the patient was placed prone on a Jackson table. The T12 level was localized by X-ray and a single skin incision only was made down the midline from approximately T10 to L2, but the fascia was left intact. A reference arc was placed on the L3 spinous process and an intraoperative O-Arm spin with Stealth navigation (Medtronic, Memphis, TN) was performed for registration of navigation. Intraoperative navigation was used to identify the entry points through the fascia for the pedicle screw placement. Pedicle screw entry sites were drilled and tapped using navigation guidance through the fascia. K-wires were then placed into the pedicles of T10, T11, L1, and L2 and used to dilate the soft tissue overlying the facets at these levels with a minimally invasive retractor tube system (MetRx, Medtronic, Memphis, TN). Facet location was confirmed by intraoperative Stealth navigation. Facets were denuded with monopolar cautery then drilled with a high speed burr followed by placement of allograft to facilitate facet arthrodesis. Pedicle screws were percutaneously placed at T10, T11, L1, and L2 with placement confirmed by intraoperative Oarm. The fascia overlying T11-12 and T12-L1 was then opened to perform laminectomies at T11-12 and T12-L1 to allow for decompression of the spinal cord, conus medullaris, and adjacent neural elements. A 3 column ‘‘egg shell” decancellation osteotomy	**Bladder:** Significant improvement in his urinary function with improved urgency and only intermittent elective straight catheterization **Neurological:** Lower extremity strength and sensation remained intact **Adverse events**: N/A	Spinal column shortening for adult TCS can be safely achieved through a mini-open approach

	of T12 was performed by first removing the pedicles of T12. Cancellous bone within the vertebral body was removed and the 3 column osteotomy was completed through this technique, preserving the superior and inferior endplates of T12. The posterior longitudinal ligament was identified and removed. Temporary rods were placed to prevent collapse and the posterior cortex of the vertebral body was removed with a central pedicle subtraction osteotomy central impactor. The osteotomy was closed with an approximate shortening of 1.5 cm. Motor evoked potential were stable throughout closure of the osteotomy. Permanent rods were secured in place and posterolateral arthrodesis was performed from T10 to L2 using local autograft bone. Bone graft was placed into the osteotomy site itself to ensure no gap in the osteotomy after closure. The fascia and skin were closed in the usual fashion after epidural drains were left in place.		

Yang, 2022[258] N = 32 China	Spine-shortening vertebral osteotomy Usually, osteotomies were carried out at the apex of the kyphosis or scoliosis for correction and safety of the diseased vertebrae if a bony split cord was present at the apex. All surgical procedures were carried out by the same senior surgeon. After the induction of general anesthesia and endotracheal intubation, the baseline potential of IONM was set and prophylactic antibiotics were administered through the intravenous route. A skin incision was made over the spinous processes. Exposure of levels was determined and pedicle screws were placed using a standard free-hand technique. A complete laminectomy was carried out at the target osteotomy levels. Then, temporary rods were placed onto the pedicle screws before the 3-column osteotomy according to the deformity. An asymmetric compression force was applied to shorten the spinal column and correct the deformity gradually to relieve SC tension, with more compression and shortening on the convex side. Often, additional laminectomies were needed to resolve kinking of the posterior SC during this procedure. A structural cage or mesh was placed anteriorly if the gap could not be closed completely due to obvious kinking of the SC or IONM events. Then, in situ bending and moderate compression at the convex side (but rarely concave distraction) were used to correct scoliosis to prevent an increase in SC tension. Finally, the overlying musculature, fascia, and skin were	**Bladder:** NR **Neurological:** NR **Adverse events**: Fifteen IONMs events occurred in 28.1% of patients. According to the surgical procedure, the changes in evoked potential were presented on 1 occasion upon screw insertion, 7 times at osteotomy, and 7 times at correction procedures. 3 patients showed transient injury to the SC postoperatively. 1 was diagnosed as syringomyelia at C6–T1, whose SC function decreased from Frankel E preoperatively to Frankel C postoperatively and recovered to Frankel E after a 6-month follow-up. One was diagnosed as diastematomyelia, whose SC function decreased from Frankel C preoperatively to Frankel B postoperatively, and recovered to Frankel C 1 year after surgery, and was maintained at a 6-year follow-up. One was diagnosed as tethered SC with syringomyelia at C1-3, whose preoperative SC function was Frankel E and decreased to Frankel B after surgery but recovered to Frankel E 3 months after surgery. A summary of IONM events and cases of SC injury is shown. Five medical complications occurred in 15.6%: hemothorax (3 cases), superficial wound infection (1), and active hemorrhage (1). All made a complete recovery after treatment.	Spine-shortening using a 3-column osteotomy seems to be safe and efficacious for treating a severe spinal deformity with an SCM

	closed in anatomic layers after decortication and bone grafting. The entire surgical procedure was carried out under dedicated multimodal IONM		
Abdulrazeq, 2023[259] N = 1 US	Surgical detethering During the procedure, a microscope is used to incise the dura, followed by the dissection and excision of the arachnoid layer and the filum terminale, which is then stimulated, cauterized, and sharply cut, the disconnected filum is removed, ensuring any tethered nerve roots are freed, with special care taken to release any remaining filum attached to the conus from the arachnoid layer, preventing future exposure to the dura, with a 6-months period of following up	**Bladder:** Pain resolved, with improvement in bladder function **Neurological:** N/A **Adverse events**: N/A	Transecting the filum terminale below the conus tip and removing the distal filum by detaching it from its intradural connections, aiming to minimize any remaining parts of the filum terminale
Abrahamsson, 2007[260] N = 20 Sweden	Surgical detethering N/A	**Bladder:** Postoperatively, 5 individuals had severe bladder dysfunction, 6 had moderate dysfunction and 9 had mild dysfunction, meaning that almost all returned to the milder presymptomatic level. Of the 11 cases of severe or moderate dysfunction 8 were caused only **Neurological:** N/A **Adverse events**: N/A	Untethering surgery for myelomeningocele leads to improved bladder function
Ailawadhi. 2012[261] N = 34 India	Surgical detethering Microsurgical detethering of low-lying cord was then performed in these patients.	**Bladder:** Urodynamic evaluation was performed in 24 patients who came for follow-up at 6 months. Bladder capacity improved from a mean of 218.8 ml before the operation to 237.6 ml (mean) postoperatively. However, this finding was not statistically significant (pair **Neurological:** Improvement in back ache/pain in the legs was seen in 83.3% patients at the time of the 6-month follow-up, whereas improvement in limb weakness, sensory symptoms and urological complaints was seen in 35.7, 50 and 40% of patients, respectively **Adverse events**: N/A	Surgical detethering primarily improves pain but has less impact on limb weakness and urological symptoms while highlighting the potential usefulness of urodynamic studies in assessing clinical improvement

Akay, 2000[262] N = 11 Turkey	Surgical detethering The surgical approach involved treating all spinal cord tethering lesions in a single operation; various techniques were employed for patients with spinal cord malformations, such as excising bony septa, removing lipomas, and reconstructing the spinal cord; follow-up periods ranged from 12 to 42 months	**Bladder:** Patients with urinary hesitancy and nocturnal enuresis symptoms showed improvement after undergoing surgery **Neurological:** Patients with low back pain, right sciatica, and left sciatica, as well as weakness in the right leg, showed improvement in their symptoms after undergoing surgery **Adverse events**: Some patients had no postoperative improvement	The patients presenting with low back pain and sciatica responded to surgery better than those with sphincter problems
Albright, 1999[263] N = 100 US	Surgical detethering Tether operation; analysis of the outcomes of five commonly performed pediatric neurosurgical operations; 1) initial shunt insertion; 2) first shunt revision; 3) craniotomy for brain tumor; 4) correction of sagittal synostosis; 5) release of tethered cords	**Bladder:** N/A **Neurological:** New neurological deficits developed in 6% of patients. **Adverse events**: Postoperative infections developed in 9% of patients. Retethering operations were needed once in 26% and twice in 3% of patients.	The Pediatric neurosurgical operations have provided valuable outcomes
Alexiades, 2022[264] N = 655 US	Surgical detethering Tethered spinal cord surgery	**Bladder:** N/A **Neurological:** N/A **Adverse events**: Surgical site infection rate was 6.7%, with 43% polymicrobial and 66% containing at least one gram-negative organism; half included an organism that was resistant to cefazolin, whereas only 32% of infections were completely susceptible to cefazolin.	Broader gram-negative antibiotic prophylaxis for patients undergoing tethered cord syndrome surgery, as the majority of surgical site infections in the study were caused by gram-negative and polymicrobial infections, with about half being resistant to cefazolin
Alsowayan, 2016[265] N = 22 Multiple countries	Surgical detethering Charts of patients with primary tethered spinal cords between 1998 and 2010 were retrospectively reviewed; patients that underwent before and after spinal cord untethering clinical and urodynamic studies evaluation with minimum of 5-years follow-up were included	**Bladder:** In Group A, all patients were continent without the need of either anticholinergics or CIC after untethering; In Group B, at the last follow-up, 87.5% were continent, 14.3% required anticholinergics, and 12.5% were incontinent; In Group A, 16.7% of patien **Neurological:** Neuro-orthopedic symptoms improved in 81.8% of patients, stabilized in 9.1% of patients, and worsened in 9.1% of patients **Adverse events**: N/A	Sacral cord untethering appears to be beneficial for patients with primary tethered spinal cord, as it results in improved clinical and urodynamic outcomes
Altiok, 2016[266] N = 20 US	Surgical detethering NR	**Bladder:** NR **Neurological:** During the follow-up, 1 (5%) patient improved, 7 (35%) were stable, and 12 (60%) worsened. Ten out of 20 patients (50%) ultimately required definitive spinal surgery **Adverse events**: NR	A selective approach for youth with lumbosacral level myelomeningocele and progressive curves less than or equal to 45° may result in scoliosis stabilization and avoidance of definitive surgery

Alzahrani, 2016[267] N = 23 Other	Surgical detethering Continence status was assessed in children aged greater than or equal to 5 years; patients were considered continent if they were dry for greater than or equal to four hours socially continent if they stayed dry most of the day using maximum 1-2 pads/day; categorical data were compared using the Fisher-Exact test and continuous variables were compared using the Wilcoxon Signed Rank test; a p-value < 0.05 was considered significant	**Bladder:** The median EBC for the entire cohort before SCU was 258 (range 111-450) mL. This was expected to reach 277.5 (range 131-478) mL at the time of follow-up UDS. The median actual TCBC before SCU was 218 (range 34-439) and became 213 (range 102-600) mL on fol **Neurological:** Neuro-orthopedic symptoms improved in 13/20 (65%) and stabilized in 7/20 (35%), while no patients developed new or worsening symptoms **Adverse events**: N/A	Surgical cord untethering could improve symptoms and prevent progression

Arad, 2006[268] N = 23 Israel	Surgical detethering The patient is placed in the supine position, prepped, and draped, and the skin is incised in a midline incision and separated from the fascia below; after fascial opening and laminectomy tailored to the case, the dura is opened, the spinal cord released from the tethering cause, and cauda equine roots undergo microsurgical neurolysis; the dura is closed as watertight as possible using 4-0 or 5-0 nylon running sutures; subsequently, the defect in the paravertebral fascial layer is assessed and the size and depth of the defect are related to the dimensions of the pathology causing the tethering; skin flaps are elevated laterally above the plane of fascia and muscle, then the fascia is then elevated from the underlying muscle in a lateral to medial direction to the point where the perforator vessels emerge, fascia flaps are then turned over medially towards the defect, based on the paravertebral vascular supply of these vessels; the concept of this technique is to provide a second layer of watertight coverage between the dura and the skin	**Bladder:** N/A **Neurological:** N/A **Adverse events**: One patient suffered superficial necrosis and infection of the skin suture line, which healed secondarily	The use of a technique involving watertight closure of the fascial layer, potentially with turnover fascial flaps and paraspinous muscle flaps, for the closure of large congenital defects associated with spina bifida occulta to prevent cerebrospinal fluid leak and infection

Archibeck, 1997[269] N = 88 US	Surgical detethering One hundred thirty-three tethered spinal cord release procedures in 88 consecutive patients were performed, the diagnosis of tethered spinal cord was suspected by progressive clinical symptoms and confirmed by magnetic resonance imaging studies in a majority of cases (76 of 133)	**Bladder:** 33% of patients presented with urologic symptoms; improvement in bladder function and strength was found in more than one third of patients **Neurological:** N/A **Adverse events**: The average number of orthopedic procedures per year before release (0.28/year) was found to increase after initial release (0.39/year; $p < 0.05$). These data demonstrate the frequent need for operative revision after index tethered-cord release, especially in children with spinal dysraphism. In addition, the need for orthopedic procedures after tethered spinal-cord release frequently persists.	The authors acknowledge the remaining uncertainties in the neurosurgical and orthopedic treatment of tethered spinal cord patient and emphasize the need for further prospective studies to understand better the effects of untethering on specific diagnoses and subsequent treatment
Artmann, 1989[270] N = 1 Germany	Surgical detethering The fixation was detached and the filum was cut. A second conus with a diameter of about 5 mm and drawing further downward was found. When this cord was stimulated, contractions of the detrusor muscle and movements of the feet resulted. Therefore, this conus was not cut. Spinal cord and ilium terminale, however, were untethered by detaching the fixation on the level of lumbosacral angel and laying them unfixated relaxed in the midline at the end of the operation	**Bladder:** The neurogenic bladder dysfunction persisted **Neurological:** After surgery the painful symptoms disappeared so that the patient was able to walk without pain by the time she was transferred to the rehabilitation center **Adverse events**: NR	The post-operative remission of most of the symptoms proves the success of the treatment

Bakker-Niezen, 1984[271] N = 25 Other	Surgical detethering This intervention involves performing laminectomy to access the spinal cord and associated structures, it is used to address various conditions, including tight filum terminale, lipoma of the filum terminale, diastematomyelia, and lipomyelomeningocele; the key aspects of the procedure include distinguishing and cutting the filum terminale, removing lipomas when necessary, and decompressing the conus medullaris and nerve roots while preserving neural tissue; the dura is often opened to release fibrous bands and tight structures, allowing free movement of the spinal cord and nerve roots. In some cases, it may not be possible to completely remove lipomas, but the procedure aims to free neural structures; this intervention is used in cases with various combinations of these conditions in pediatric patients; the follow-up period varied from three months to three years	**Bladder:** Bladder function, initially, was normal in thirteen children, was preserved in twelve but deteriorated after operation in one child. In all the seven children with secondary incontinence, bladder function improved. **Neurological:** All six patients with pain obtained relief. The foot deformity and scoliosis did not change after operation but progress has been arrested. The motor weakness of the lower limbs and the gait disturbances have been corrected or improved in seven cases but are unchanged in seventeen. Only one patient has had deterioration of the motor function after a short period of arrest. **Adverse events**: The complications were four minor wound infections and three CSF leaks which stopped after restoring the previous hydrocephalus drainage.	Early surgical intervention is essential for the treatment of tethered spinal cord syndrome in children to prevent neurological damage
Bao, 2007[272] N = 60 China	Surgical detethering Patients underwent laminectomies to repair the associated dysraphic anomalies such that the filum could be sectioned to untether the cord	**Bladder:** Two patients in the low-lying/lumbosacral lipoma group experienced an increase in anal/urethral sphincter dysfunction and in motor impairment after surgery **Neurological:** Neurological function in most affected children was improved after surgery. However, some patients experienced no changes in function. Two patients in the low lying/lumbosacral lipoma group experienced an increase in anal/urethral sphincter dysfunction and in motor impairment after surgery **Adverse events**: NR	When neurological signs accompany such changes, early severing of the filum is indicated regardless of conus position

Basar, 1997[273] N = 26 Turkey	Surgical detethering Urological aspects of the tethered cord syndrome before and after untethering was studied preoperatively and postoperatively via cystometry with a duration of follow-up between 5 and 22 months	**Bladder:** Voiding difficulties improved in 5 out of 8 cases, with 4 patients experiencing improved urinary incontinence, there were no changes in the other four patients, 67.0% showed symptomatic improvement, and vesicoureteral reflux improved in 5 cases but worsen **Neurological:** N/A **Adverse events**: Some patients did not show any improvement following the untethering procedure, and there were no cases of complete improvement in any of the patients	Improvement in urological findings can be achieved if the untethering operation is performed as early as possible
Beaumont, 2007[274] N = 34 US	Surgical detethering Surgical untethering of two groups: tethered cord syndrome alone and tethered cord syndrome + terminal syringomyelia; the incidence of terminal syringomyelia was 29%; only 1 patient underwent surgical drainage of the syrinx, whereas all other patients underwent tethered cord release alone; more specific details unavailable	**Bladder:** Few patients experienced improvement in their bladder and bowel function **Neurological:** All patients who were asymptomatic preoperatively remained so postoperatively; in the tethered cord syndrome + terminal syringomyelia group, all patients either clinically improved after tethered cord release or improved and became asymptomatic; in the tethered cord syndrom only group, most patients improved or became asymptomatic; ithe tethered + terminal syringomyelia group, 50% of patients were asymptomatic before surgery, and none of these asymptomatic patients experienced symptoms postoperatively while all symptomatic patients with motor, sensory, gait, and pain deficits in this group showed clinical improvement, similar to 12 out of 15 symptomatic patients in the tethered cord group without syringomyelia **Adverse events**: Two patients experienced no change in their symptoms, and one patient, who initially had only preoperative scoliosis, experienced worsening of the scoliosis	Tethered cord release alone may be sufficient to improve preoperative symptoms and terminal syringomyelia may be an associated phenomenon that does not mandate separate treatment

Begeer, 1989[275] N = 42 Netherlands	Surgical detethering Surgical detethering; full procedure said to be fully described in an earlier publication cited as reference 1	**Bladder:** A number of patients observed an enhancement in their bladder function **Neurological:** Motor dysfunction, foot deformity, and back or leg pain showed improvement **Adverse events**: Wound infection, cerebrospinal fluid leakage, decompensation of hydrocephalus, meningitis	Operating on patients with spina bifida occulta who have tethered cord syndrome carries no greater risks than operating on those with spina bifida aperta, and the postoperative results support the arguments in favor of preventive surgery in spina bifida occulta patients
Bhimani, 2019[276] N = 3682 US	Surgical detethering Patients underwent laminectomy, with release of tethered spinal cord,	**Bladder:** One patient was readmitted because of neurogenic bladder **Neurological:** Out of 3,682 patients, 30 day post operative outcomes for neurologic conditions were as follows: 5 had a seizure, 2 had CVA/stroke or intracranial hemorrhage, 1 was in a coma for >24 hours, and 1 had nerve injury **Adverse events**: The readmission rate was 5.9% and reoperation rate 2.7%; 8.1% patients had at least one complication in the 30day postoperative period; the most common postoperative complication was superficial wound complication (3.1%), followed by superficial incisional surgical site infection (2.1%), urinary tract infection (1.6%), and deep wound disruption (1.4%).	It was acknowledged that tethered cord release is generally safe but still carries a risk of complications in the pediatric population

Blount, 2005[277] N = 14 US	Surgical detethering The surgical procedure involved performing laminectomy, identifying the point of maximal adhesion, and transecting the spinal cord just rostral to this point, ensuring a low transection to minimize damage to intercostal muscles; surgery was conducted under general anesthesia in a latex-free environment, with patients positioned prone; a high-speed drill or rongeur was used for laminectomy, and the procedure was performed under an operating microscope; the dura was opened, arachnoidal adhesions were dissected, and the pia mater was coagulated and divided with subpial aspiration; a retraction of at least 1 cm was often observed between the cut ends of the spinal cord; the dura was closed in a watertight fashion, and the wound was closed in sequential watertight layers; patients remained flat for 2 to 5 days postoperatively and were then allowed to ambulate in a wheelchair	**Bladder:** Two patients demonstrated a temporary change in bladder behavior but did not change over all continence/hygiene capability. **Neurological:** Neurologically, all patients retained the same functional level that they demonstrated preoperatively. As mentioned earlier, three patients had minimal although not functionally significant movement in the lower extremities that was lost with spinal cord transection (SCT). Three patients reported transient periumbilical loss of sensation that was not present preoperatively. None of these neurological changes adversely affected these patients' overall wellbeing. No patient who underwent SCT demonstrated any loss of neurological function associated with instrumented fusion. **Adverse events**: N/A	Spinal cord untethering can be beneficial for a carefully selected group of myelodysplastic patients with repetitive cord tethering as a safe and effective procedure with consistent pain improvement, minimal complications, and a low risk of long-term recurrent tethering

Boemers, 1995[278] N = 36 Netherlands	Surgical detethering Thirty-six children with tethered spinal cord due to neurospinal dysraphism were assessed clinically and urodynamically before and after surgical untethering; sexual function was evaluated in 14 boys before and after neurosurgery; in young boys, the assessment was by parental observation and was considered normal if erections had been observed regularly, or if the child had mentioned having an erection at any time; older patients were asked if they had achieved voluntary erections and whether or not they were able to ejaculate; the mean follow-up was 91 months and the mean follow-up after neurosurgery was 34 months	**Bladder:** Changes in bladder-sphincter function after untethering are usually transient and often the result of partial denervation. Although a small group of children seem to benefit from untethering, others can become worse and the individual outcome cannot be pr **Neurological:** N/A **Adverse events**: Seven children had temporary changes of bladder/sphincter function; two developed detrusor overactivity with sphincter dyssynergia and five had signs of bladder denervation. Long-term follow-up showed no permanent changes of lower urinary tract function in 94% of 34 patients.	Changes in bladder-sphincter function after untethering surgery can be unpredictable, with potential complications, and recommends caution in considering prophylactic untethering in patients with occult spinal dysraphism
Boor, 1993[279] N = 25 Germany	Surgical detethering NR	**Bladder:** NR **Neurological:** NR **Adverse events**: NR	Surgical intervention is advised for tethered cord syndrome, as it can lead to improvements in somatosensory evoked potentials and help in diagnosing and assessing prognosis, particularly for secondary tethered cord cases

Browd, 2009[280] N = 3 US	Surgical detethering Three patients with spinal cord tethering underwent detethering surgery involving the use of the carbon dioxide laser; one patient demonstrated a lumbosacral lipomyelomenigocele, 1 had a thoracic intradural dermoid with a dermal sinus tract, and 1 had spinal cord retethering secondary to a previously repaired lumbosacral myelomeningocele; all 3 patients underwent standard posterior approaches using a midline incision; intraoperative electrophysiological monitoring was used in all cases; during intradural dissection, the carbon dioxide laser was used preferentially for sharp dissection and coagulation	**Bladder:** At six-month follow-up, all 3 patients presented with stability in bowel and bladder function **Neurological:** N/A **Adverse events**: N/A	Fiber-mediated CO2 laser energy delivery is a safe and efficient tool for microsurgical spinal cord detethering procedures, emphasizing its advantages in terms of minimal depth of penetration, minimal thermal spread, improved ergonomics, and ease of operative implementation

Bruzek, 2019[281] N = 25 US	Surgical detethering Patients underwent surgical untethering operations and some patients had previously undergone lipomyelomeningocele repair or untethering prior to presentation at the institution, while others received primary untethering at the institution; syrinx was defined as a spinal cord cyst with specific criteria on magnetic resonance imaging, including minimum axial width and signal characteristics, changes in the syrinx were defined based on alterations in length or width; scoliosis was defined by a specific Cobb angle, and improvements or worsening of scoliosis were also defined with specific criteria; the average follow-up duration was 8.42 years (range 1.35–15.85 years)	**Bladder:** Among the patients with worsening symptoms or deficits, clinical symptoms included progressive bowel or bladder dysfunction (n = 2) **Neurological:** Clinical indications for surgery included prophylactic untethering to prevent future neurological symptoms (n = 11), worsening neurological symptoms (n = 9), scoliosis (n = 4), and terminal syrinx (n = 4). Worsening neurological symptoms included progressive extremity weakness, worsening pain, progressive bowel or bladder dysfunction, increased spasticity, and difficulty with ambulation. At initial presentation, 15 out of 25 patients were symptomatic, with various symptoms, including scoliosis, pain, urinary or bowel dysfunction, motor deficits, and numbness/tingling. After surgery, there was no significant change in syrinx length, but some patients showed improvement in syrinx width. Changes in syrinx size varied based on the underlying pathology. Patients with myelocystocele had the largest change, with a decrease in width and an increase in length of their syrinx. There was no clear relationship between syrinx resolution/progression and symptomatic improvement after surgery. Some patients had improved symptoms, while others did not. Regarding scoliosis, some patients who underwent fusion had improvement, while others did not. Improvement did not consistently correlate with syrinx size changes. **Adverse events**: All 4 patients with sensory disturbance (including numbness or tingling) had unchanged or worse symptoms at follow-up and no syrinx improvement. Among the patients with worsening symptoms or deficits, clinical symptoms included progressive extremity weakness or numbness (n = 5), worsening pain (n = 3), progressive bowel or bladder dysfunction (n = 2),	For patients with tethered cord and syrinx, the decision to operate should prioritize addressing tethered cord-related symptoms and treating the primary spinal dysraphism rather than relying on changes in syrinx size

		increased spasticity (n = 1), and difficulty with ambulation (n = 1).	
Caird, 2008[282] N = 1 UK	Surgical detethering The patient underwent surgical release of the filum terminale through an L5–S1 laminectomy. There was no fatty tissue noted within the filum. The cut end of the filum was noted to recoil rapidly in a rostral direction	**Bladder:** NR **Neurological:** Postoperatively, his back pain resolved and he was able to walk unaided by the 5th postoperative day. He remained continent and was discharged after 12 days **Adverse events**: NR	Tethered cord syndrome is a complex and poorly understood phenomenon; in particular, controversy surrounds the diagnosis and treatment of patients with a radiologically normal conus. This case not only illustrates a therapeutic potential for patients with syringomyelia, but also challenges our understanding of the pathophysiology of this intriguing clinical condition
Cha, 2018[283] N = 106 Korea	Surgical detethering Pediatric patients who underwent untethering surgery for spinal dysraphism with available intraoperative baseline bulbocavernosus reflex; the bulbocavernosus reflex response during surgery was classified into loss or maintenance; post-operative voiding function was determined as worsened or maintained based on history, postvoid residual urine measurement, and urodynamic study; data regarding demographics, diagnosis, pre-operative voiding difficulty, re-untethering, syrinx, and abnormalities in electromyography were collected for analysis	**Bladder:** Sensitivity, specificity, and positive and negative predictive valuesof BCR loss: At 6 months, 14 patients (13.9%) showed worsened voiding function. The voiding function of nine patients worsened despite intraoperative BCR maintenance, and that of 10 pati **Neurological:** Among the 15 patients (with loss of intra-operative BCR), mild spinal cord injury was confirmed during procedure in one patient and neural injury was suspected by the surgeon in seven patients; hence, the surgery did not proceed any further. Of the 8 patients with neural injury, which was confirmed or suspected during surgery, four (50%) showed worsened voiding outcome at discharge. (2) Of the 15 patients, seven had no definite finding suggestive of neural injury identified by the surgeon intraoperatively. In one patient, BCR loss was observed when the nerve roots were pulled up due to untethering. Of the seven patients, one (14.3%) showed worsened voiding outcome at discharge. **Adverse events**: N/A	Intraoperative assessment of bulbocavernosus reflex during untethering surgery in children with spinal dysraphism can predict bladder function 6 months post-operatively with high specificity

Chern, 2011[284] N = 45 US	Surgical detethering Patients underwent sectioning of the filum terminale; the incision for a simple tethered cord release is usually half-inch long with minimal muscle dissection, and only partial laminectomy is required; the average operating time is less than 1 hour and patients are usually kept in the supine position for 1 to 3 days after surgery to prevent cerebrospinal fluid leak; the patients were observed for an average of 31 months (range 8–70 months) after their index untethering procedure; no patients underwent a second untethering procedure	**Bladder:** N/A **Neurological:** Thoracic location of scoliosis and preoperative curve magnitude greater than 35 ° correlated significantly with scoliosis progression (P < 0.05). Scoliosis correction and spinal fusion seemed safe and effective after tethered cord release in our series. Five of nine patients (56%) with curve progression after untethering required scoliosis surgery. **Adverse events**: After tethered cord release, worsening of coronal spinal balance occurred in 9 of 45 patients (20%). In these nine patients, five underwent spinal fusion, one worsened despite fusion. Operative morbidity associated with tethered cord release included one transient urinary retention that resolved in 48 hours, and one pseudomeningocele formation that required reoperation for CSF leak repair. There was no operative mortality. Scoliosis correction and spinal fusion were performed in five patients. There were no surgical complications associated with scoliosis surgery after untethering.	In patients with scoliosis associated with tethered cord syndrome, spinal cord untethering may prevent or reverse scoliosis progression
Cornette, 1998[285] N = 22 Belgium	Surgical detethering The untethering procedure's primary goal was to restore movement in the lower part of the spinal cord by partially removing excess of fatty tissue, cutting the fibrous and fatty connection between the spinal cord's inner and outer portions, and if feasible, severing the filum, neither electromyography nor somatosensory evoked potentials were employed, and to ensure a clear cerebrospinal fluid space behind the spinal cord, the dura was repaired using a dural substitute, with mean follow-up time of 58 months	**Bladder:** Urinary function was successfully restored **Neurological:** Normal neurological function was fully restored **Adverse events**: A few patients did not experience resolution of their condition	Neurosurgical correction of tethered cord in children born with occult spinal dysraphism and tethered cord may be beneficial when upper motor neuron symptoms appear, but early untethering in children presenting with upper motor neuron symptoms at birth may lead to poorer outcomes

Cornips, 2012[286] N = 25 Netherlands	Surgical detethering NR	**Bladder:** Seventeen children presented with urologic symptoms and/or signs, which improved in 13, stabilized in three, and deteriorated in one **Neurological:** All children presented with some neurologic symptoms and/ or signs, which improved in 20 and stabilized in 5 **Adverse events**: We observed one superficial wound infection (case 20) treated with an 8-day course of antibiotics, and two cerebrospinal fluid leakages, including one child (case 14) in whom the wound was closed intracutaneously, and another child (case 19) in whom a secondary untethering (the only one in this series) was performed. No child suffered permanent sequelae	Children showing strong clinical suspicion for Tethered Filum Syndrome, with or without abnormal MR findings, are likely to benefit from surgery
Daszkiewicz, 2007[287] N = 59 Other	Surgical detethering Microsurgical laminotomy; Mean follow-up time was 4.4 years	**Bladder:** Improvement of sphincter function less pronounced than neurological improvement **Neurological:** Functional improvement in 19 patients (32.2%); deterioration of neurological function in 13 patients (21.6%) **Adverse events**: Surgical wound infection/meningitis developed in 5 patients (8.4%)	Surgical detethering is advised for children with tethered cord syndrome due to the notable improvements observed in outcomes

Day, 2020[288] N = 208 US	Surgical detethering NR	**Bladder:** Postoperative full UDS was performed in 59 patients, 38 (64.4%) of whom showed clinical improvement. Postoperative anorectal manometry studies were performed in 7 patients, with 4 (57.1%) showing clinical improvement. Thirty-seven patients self-reported i **Neurological:** Improvement following detethering was noted in 168 patients (81%) in all four categories of presenting symptoms. Scoliosis was the least improved preoperative symptom, improving in only 8 patients (8/44 [18.2%]) and remaining stable in 23 (23/44 [52.3%]). The remaining 13 (29.5%) patients continued to exhibit curve progression, with 12 (27.3%) patients going on to have at least one subsequent orthopedic procedure for their scoliosis **Adverse events**: Complications included 3 CSF leaks requiring readmission for wound revision, 1 case of pulmonary edema following extubation, 1 surgical site infection requiring antibiotics, and 1 patient with headache and perianal numbness. There were no operative deaths	Surgical detethering resulted in a positive outcome

Di, 2009[289] N = 2 US	Surgical detethering Novel endoscopic technique for surgical untethering of the spinal cord by filum sectioning. Both patients underwent a lumbar hemilaminectomy and sectioning of the filum terminale endoscopically without assistance of loop and microscope. The 8 month patient underwent an endoscopic L5 hemilaminectomy, intradural exploration, and sectioning of the thickened, fatty filum. The 10 year old patient underwent a L4 endoscopic hemilaminectomy and sectioning of the fatty filum under electrophysiological monitoring.	**Bladder:** Two patients (ages 8 months and 10 years) presented with leg weakness, urine and bowel dysfunction, low back and neck pain, and thickened, fatty filum terminale. The elder patient presented with clinical incontinence and abnormal urodynamic studies. Speci **Neurological:** The parents of the 8 month old observed weakness in both legs, and difficulty in standing. **Adverse events**: N/A	We report the first application of the neuroendoscopy for TC release via hemilaminectomy through an approximately 2-cm incision. The two TC cases here were identified due to the fatty filum. Conventionally, surgical management of tethered cord involves an open laminectomy and exposure of the cauda equina, although some authors have advocated a limited laminoplasty to preserve midline elements. Our novel endoscopic approach, centers a spinal level below the conus, preserves midline structures, and provides adequate exposure of the filum and entire cauda equine via a hemilaminectomy. Although only limited surgical series have been reported concerning the sole use of the endoscope for tethered card release, it seems clear that it offers some advantages either in reducing invasiveness or in allowing safer management, thus helping to lower complication rates and therefore improve results.

Dias, 2023[290] N = 967 US	Surgical detethering The Centers for Disease Control and Prevention's National Spina Bifida Patient Registry data was used to examine the following: 1) the time course of tethered cord release among adults (≥ 21 years of age) with myelomeningocele; 2) variability in the time course of tethered cord release among each of the 35 participating clinics; 3) the relationship(s) among functional lesion level, ambulation status, prior treatment for hydrocephalus and Chiari malformation, and time course of tethered cord release; and 4) the influence of sex on age-related rates of tethered cord release in adulthood.	**Bladder:** N/A **Neurological:** The study group had both a better functional motor level ($p < 0.001$) and ambulation status ($p < 0.001$) than the remaining adults at the time of their first assessment as adults. In multivariable (Cox proportional hazards) analysis, the risk of first tethered cord release during adulthood was not independently influenced by best functional lesion level or ambulation status prior to TCR, but it was influenced by sex (male patients had decreased risk; OR = 0.31, 95% CI 0.16–0.62, $p < 0.001$), prior treatment for hydrocephalus (those who underwent prior treatment had decreased risk; OR 0.21, 95% CI 0.20–0.42, $p < 0.001$), and prior treatment for Chiari malformation (those who underwent prior treatment had greater risk; OR 3.84, 95% CI 1.50–9.88, $p = 0.005$). **Adverse events**: N/A	This was the first study to systematically examine the frequency, time course, and associated risk factors for first-time tethered cord release among adults with myelomeningocele who were followed in the National Spina Bifida Patient Registry. The overall frequency of first-time tethered cord release in this population was 4.9%, but there was a significantly greater proportion of adult females. There was no significant variability between clinics after correction for mean clinic age. There were no correlations between first time tethered cord release and either functional lesion level or ambulation status, but prior treatment for hydrocephalus (lower frequency) and Chiari malformation (higher frequency) were encountered. We recommend more detailed analysis of these adult patients to further define the factors that contribute to their decline as well as their long-term outcomes.
Dushi, 2011[134] N = 29 Switzerland	Surgical detethering Spinal untethering was performed with at least 2 years of urodynamic follow-up	**Bladder:** Some patients experienced an improvement in urological function. **Neurological:** Some patients experienced improvement in neurological function. **Adverse events**: There was no improvement in urodynamic scores in some patients, and they experienced worsening neurological conditions.	The urodynamic score is a useful tool for monitoring children with lipomyelomeningocele as it correlates well with the presence of symptoms.

Edstrom, 2022[291] N = 95 Sweden	Surgical detethering All surgeries were performed by either of three attending pediatric neurosurgeons. Patients were routinely administered a single prophylactic dose of cefuroxime (50 mg/Kg) or clindamycin (25 mg/Kg) in the case of known penicillin allergy. With the patient in the prone position, a posterior midline approach was used. A single level laminotomy was performed at L4, below the conus. In most cases, an ultrasonic bone scalpel was used (Misonix Inc., Farmingdale, NY, USA). Under the microscope, the dura was incised in the midline and was held open by sutures. The arachnoid was dissected sharply, and the FT was identified visually and divided after coagulation. In all cases, watertight dural closure was performed, and the lamina reinstated using resorbable sutures in the supraspinal ligaments and thoracolumbar fascia. The surgical wound was closed in layers. No intraoperative neurophysiological monitoring was used. Postoperative management included a tapered protocol of intravenous analgesics (morphine, clonidine, paracetamol). In addition, all patients were kept at fat bed rest for 48 h to reduce the risk of CSF leakage.	**Bladder:** For the symptomatic cohort, surgery was associated with a significant improvement in both bladder ($p=0.002$) and sensorimotor function ($p < 0.001$), with 48% showing improvement in bladder function and 42% improvement in sensorimotor function **Neurological:** For the symptomatic cohort, surgery was associated with a significant improvement in both bladder ($p=0.002$) and sensorimotor function ($p < 0.001$), with 48% showing improvement in bladder function and 42% improvement in sensorimotor function **Adverse events**: N/A	Surgical untethering in pediatric patients is safe and significantly improves bladder and sensorimotor function, and recommends a proactive approach to surgery based on radiological findings, even in the absence of preoperative symptoms, due to the potential risks associated with conservative treatment

Fabiano, 2009[292] N = 22 US	Surgical detethering Patients included in the study underwent a standard surgical lysis of the filum terminale through a single-level laminoplasty. Intraoperative neuromonitoring was not used. A cut portion of the filum terminale was sent for pathologic review	**Bladder:** Twenty-one patients underwent preoperative urodynamic testing. One patient with back pain, scoliosis, leg length discrepancy and a lumbosacral dimple did not undergo preoperative urodynamics. Of these 21 patients, 14 had abnormal results, 6 had normal res **Neurological:** Overall, 16 patients improved after surgical untethering, 4 patients experienced no change in their preoperative symptoms, and 2 patients reported symptom progression after surgery (table 4). Of the patients demonstrating improvement, 5 of 16 (31%) had only subjective improvement, and 11 (69%) had both subjective and objective improvement (table 5). Objective improvement was defined as the improvement of a previous neurologic examination finding, improved bladder control, or improved urodynamic test results. Improvement after surgical untethering correlated with the number of designated clinical categories in which a patient had positive preoperative findings. Two of 2 patients with preoperative findings in 4 categories had improvement postoperatively; 4 of 5 with preoperative findings in any 3 categories improved; 9 of 10 with preoperative findings in any 2 categories improved, and 1 of 5 with preoperative findings in any 1 category improved (2 = 9.40, p = 0.024). Patients presenting with abnormal findings in at least 2 categories were more likely to improve after untethering than those with preoperative abnormalities in only 1 category (from 88 to 20%, p = 0.009) **Adverse events**: There was no surgical mortality or neurologic morbidity. There was 1 cerebrospinal fluid leak and 1 wound infection. Neither the level of the conus medullaris (p = 0.65), the presence of a minimal amount of filum terminale fatty infiltration (p = 0.56) nor the presence of a spinal cord syrinx	Spinal cord untethering is a treatment option for occult tight filum terminale syndrome. Further evaluation of the relationship between preoperative findings and surgical outcomes may facilitate the selection of surgical candidates

		(p = 0.36) correlated with postoperative outcome. In all cases, cauterized connective tissue was found during surgical pathology review of the cut filum sections (patients with other surgical pathology findings had been previously excluded from the study)	
Fernandez-Portilla, 2021[293] N = 27 Mexico	Surgical detethering Surgical detethering of tethered cord patients greater than three years old with fecal incontinence and anorectal malformations with a follow-up duration of at least six months	**Bladder:** Regarding bowel control, 5 patients (18%) achieved what was defined as partial continence, and 10 (37%) achieved total bowel control; however, 12 cases (44%) remained in need of management with enema. With respect to urinary control, seven patients were c **Neurological:** As mentioned earlier, 22 patients (81%) had some degree of clinical or physiological involvement of the lower extremities. After detethering surgery, however, only six patients (22%) displayed lower extremity symptoms. No somatosensory evoked potential study was carried out postoperatively. **Adverse events**: NR	Detethering surgery significantly improved bowel and bladder control in ARM patients with fecal incontinence, with surprising recovery of control even in patients with a poor prognosis
Fitz, 1975[127] N = 24 Canada	Surgical detethering All patients underwent myelography in a supine and prone position. At operation the filum is identified, two adjacent silver clips are put across the distal end, and the filum is cut between the clips. The clips will usually separate 5 to 25 mm, often dramatically. Postoperative spine films will confirm this separation.	**Bladder:** Upon presentation and confirmation of a tethered conus, 5/24 patients reported urinary incontinence, 5/24 reported other bladder problems, 2/24 reported bladder dysfunction. After operation, 4/8 reported improvement in sensory loss and 6/8 reported improv **Neurological:** Out of 24 patients, 9 had abnormal reflexes, 8 experienced sensory loss, 8 experienced weakness, 5 experienced scoliosis, and 3 experienced low back pain. After operation, 2/5 reported improvement in urinary incontinence and 3/5 reported improvement in other bladder problems. **Adverse events**: N/A	Operative results are difficult to evaluate in a growing child whose neurological status is normally changing. Over-all there is a definite improvement of at least some symptoms in our series. At worst there is a halting of symptom progression. Even children with bladder difficulties have improved. There seems to be a better improvement in those with only a tethering without associated intradural masses, possibly reflecting a lesser degree of abnormality.

Flanders, 2022[294] N = 51 US	Surgical detethering All patients underwent tethered cord release surgery with a single neurosurgeon; a detailed analysis of the patients' preoperative presentation, intraoperative neuromonitoring data, and postoperative course was performed	**Bladder:** N/A **Neurological:** Most patients remained neurologically stable when comparing preoperative and postoperative manual motor testing. **Adverse events**: Postoperative motor levels when tested on average at 4 months were largely unchanged when compared to preoperative levels. Unlike the motor signals, 46 (90%) of patients had unreliable or undetectable lower extremity somatosensory evoked potentials (SSEPs) prior to the tethered cord release.	Surgical intervention is advised for fetal myelomeningocele closure based on strong evidence of neural tract preservation, emphasizing the importance of somatosensory function in the ultimate rehabilitation for functional recovery
Flanigan, 9189[295] N = 8 US	Surgical detethering N/A	**Bladder:** In general, there were no dramatic changes in postoperative urodynamics compared with preoperative studies. The 1 patient with a normal preoperative study (J. W.), remained normal at one month postsurgery. Five of 6 patients with areflexic bladders preope **Neurological:** N/A **Adverse events**: N/A	There was a slight improvement in postoperative urodynamics in some patients with neuropathic bladders due to tethered cord syndrome
Fluss, 2024[296] N = 1 US	Surgical detethering Correct kyphoscoliosis involved pedicle screw placement and L1 laminectomy, lateral decompression through hemivertebrae excision, intradural detethering at L4, and completion of T11–L2 fusion, with intraoperative neuromonitoring and appropriate preoperative preparations, including the use of fluoroscopy to ensure accurate screw placement	**Bladder:** N/A **Neurological:** Some improvement in scoliosis deformity and neurological function **Adverse events**: N/A	Treat scoliosis associated with tethered cord syndrome in a single surgical procedure where possible, as detethering may help halt the progression of scoliosis and vice versa

Fone, 1997[297] N = 39 US	Surgical detethering We retrospectively reviewed 39 patients with a tethered spinal cord to evaluate whether surgical release positively influenced urological symptoms or urodynamic findings; the patients were divided into 2 groups: group 1-11 with occult spinal dysraphism and group 2-28 with secondary spinal cord tethering after previous closure of a myelomeningocele or resection of a lipomyelomeningocele; diagnosis was confirmed in all cases by magnetic resonance imaging or spinal ultrasound; a comprehensive urodynamic evaluation was done immediately preoperatively and 2 to 21 months (mean 7) postoperatively	**Bladder:** In group 1 the most common preoperative urodynamic finding was hyperreflexia, which improved or resolved after untethering in 62.5% of the patients. Four adults also reported improved bladder sensation or decreased urgency. In group 2 the most common urod **Neurological:** Of the 3 patients undergoing surgery to prevent neuro- logical deterioration 1 had improved urodynamic findings and 2 had no change. Group 2 appeared to have a greater neurological benefit. Only 4 patients reported decreased uri- nary leakage or improved urinary control but 8had improved lower extremity function. Atotalof 16 patients had nosymp tomatic change. Of patients who underwent surgery to pre- vent neurological deterioration 1 had improved and 4 had worsened urodynamic results, 1 had improved sensation of the lower extremities and 2 had no change. **Adverse events**: 48% of patients had worsened patterns in detrusor hyperreflexia in group 2	Early surgical intervention may improve urological symptoms and urodynamic patterns in patients with occult spinal dysraphism
Foo, 2022[152] N = 16 Singapore	Surgical detethering Surgery for detethering is performed under intraoperative neuromonitoring; briefly, an elliptical incision around the cutaneous lesion of interest is opened and traced inwards to its entry into the spinal canal; next, laminectomy is performed after widening the interlaminar space to expose the tract's attachment to the dura; under microscope visualization, the dura is opened; after ensuring hemostasis, the dura is closed primarily with continuous monofilament sutures	**Bladder:** patients who experienced bladder dysfunction preoperatively (n=3), remained unchanged after surgery. **Neurological:** All patients who underwent prophylactic intent surgery (n¼13, 81.2%) remained neurologically intact during the entire duration of follow up. Amongst patients who underwent therapeutic intent surgery (n=3, 18.8%), their pre-existing neurological deficits remained unchanged after surgery. **Adverse events**: Wound-related issues were encountered in four patients (25%). Three of them had superficial wound infections that were treated conservatively with systemic antibiotics. The remaining patient had a deep surgical wound infection associated with CSF leak, requiring surgical repair and prolonged antibiotics.	Early recognition and timely intervention are crucial for managing focal nondisjunction of primary neuralisation and a multidisciplinary approach to achieve favorable outcomes is recommended

Foster, 2014[298] N = 52 US	Surgical detethering All patients underwent tethered cord release	**Bladder:** N/A **Neurological:** 82% of symptoms were improving or resolved an average of 4.5 months following surgery in younger children, 47% of symptoms improving or resolved at 4.8 months after surgery in the older children. **Adverse events**: N/A	Statistically significant gain in height-for-age percentiles in children undergoing surgical release of tethered cord
Frainey, 2014[299] N = 96 US	Surgical detethering A retrospective chart review of pediatric patients with a diagnosis of tethered cord who underwent tethered cord release from 1995 to 2005 was performed, and analysis was limited to patients who had primary tethered cord release by one of two neurosurgeons who had greater than 1-year follow-up, and who were old enough to have continence status assessed (age > 6 years unless definitively toilet trained earlier); patients with other associated forms of spinal dysraphism (lipomyelomeningeocele, spinal lipomas, sacral agenesis), anorectal malformations, and genitourinary anomalies were excluded; pre and post tethered cord release urodynamics, radiographic studies, functional orthopedic status, and urologic outcomes were assessed; urodynamic results were categorized by three blinded urologists into one of three urodynamic patterns: (1) normal, (2) indeterminate, and (3) high risk	**Bladder:** Statistical analysis revealed that neither pre- nor post tethered cord release urodynamics were correlated with post-TCR urinary continence. However, post-operative urodynamics approached significance with p Z 0.087. Multiple subgroup analyses were also c **Neurological:** N/A **Adverse events**: At latest follow-up, 20% were either incontinent or utilizing clean intermittent catheterization (CIC).	Isolated cutaneous lesions and preoperative continence status are positive predictors for post-tethered cord release continence in patients with filum terminale lipomas and lipomyelomeningoceles
Fukui, 2011[300] N = 33 Japan	Surgical detethering NR	**Bladder:** 55% complained of postoperative LUTS in terms of problems in activities of daily life. Having urinary incontinence together with voiding difficulty was the most severe complaint of the lower urinary tract affecting the daily life identified by 39%. Urinar **Neurological:** NR **Adverse events**: NR	Surgical untethering showed significant improvement in urological symptoms in tethered cord patients

Gadhvi, 2023[301] N = 26 India	Surgical detethering Tethered cord release with multimodality intraoperative neuromonitoring. Transcranial motor evoked potentials, triggered clectromyography, and free-running electromyography were used during procedures using the Medtronic NIM-ECLIPSE E4 SD™ system.	**Bladder:** Sphincter motor evoked potentials were recordable in only 16 out of 26 patients (61.5% of the total) as 10 patients had bladder dysfunction preoperatively. During the intraoperative period, transcranial motor evoked potentials amplitude was decreased in f **Neurological:** Transcranial motor evoked potential was monitored in 20 cases, while in six cases it was not recordable due to preoperative low power in the lower limb. No new neurological deficits were found postoperatively. **Adverse events**: N/A	All 26 patients being monitored with transcranial motor evoked potentials, triggered clectromyography, and free-running electromyography during tethered cord surgery, where we were successfully able to identify nerve roots from fibrous bands which are difficult to distinguish otherwise and were helpful to neurosurgeons to let off nerve roots supplying muscles. In addition, we were able to identify filum terminale, which helped neurosurgeons in separating filum from nerve roots. Multimodality intraoperative neuromonitoring in the form of transcranial motor evoked potentials, triggered clectromyography, and free-running electromyography is a very useful technique that should be used during all detethering procedures to identify filum terminal during surgery and minimize risk to the nerve roots postoperatively.
Gao, 2016[302] N = 82 China	Surgical detethering A retrospective analysis of 82 adult patients (17 male cases, 82% and 24 female cases, 59%) with tethered cord syndrome treated by surgery was conducted between March, 2005 and December, 2015, with an average age of 31.6 years and average disease course of 6.7 years; all the 82 cases of patients received nerve electrophysiology monitoring assisted microsurgery, after surgery all patients were followed up for an average of 2.5 years	**Bladder:** Bladder dysfunction after complete release had an effective rate of 86.4%; Bladder dysfunction after partial release had an effective rate of 50%; Bladder dysfunction after no release had an effective rate of 33.3% **Neurological:** According to Hoffman grading system, the neurologic symptoms were improved in 22 patients (27%), stabilized in 60 patients (73%). Of 10 cases with lipoma tethered spinal cord, corresponding symptoms were improved in 2 cases. Of 32 cases with tethered spinal cord caused by dermoid cyst and epidermoid cyst, the symptoms were improved in 6 cases. Of 40 cases without occupying lesions of tethered spinal cord, the symptoms were improved in 14 cases. **Adverse events**: N/A	Surgical treatment on adult patients with TCS can improve the neurologic deficits which are associated with the course of disease, early treatment has much better curative effect

Garces-Ambrossi, 2009[303] N = 29 US	Surgical detethering Initial incision, paraspinal muscle retraction, laminectomy or exposure, use of FloSeal in the lateral gutters, opening the dura mater, placement of tack-up sutures, identification of the tethering cause, and releasing the spinal cord using coagulation and microscissors; once the spinal cord was completely freed and neurophysiological monitoring remained stable, the wound was irrigated, and the dura was closed with 5-0 Prolene sutures	**Bladder:** 50% of patients saw an improvement in bladder dysfunction **Neurological:** 70% of patients experienced improvement in lower extremity weakness, and patients who presented with asymmetrical weakness ($p = 0.0021$, HR = 5.7) or lower extremity hyperreflexia ($p = 0.037$, HR = 4.1) had a higher likelihood of experiencing improvement in motor weakness **Adverse events**: N/A	Most patients experienced improvement, reflecting the positive effects of surgical release
Garg, 2014[304] N = 24 India	Surgical detethering N/A	**Bladder:** Bladder symptoms improved in six patients (50%) **Neurological:** Weakness improved by at least one grade in seven patients (77.8%). **Adverse events**: Did not encounter any immediate postoperative wound site-related complication	In case of symptomatic patient with low-lying cord, detethering is an advisable option
Geyik, 2015[305] N = 162 Turkey	Surgical detethering Surgical release and intraoperative neurophysiological monitoring were conducted for all patients, with an average follow-up period of 47 months, ranging from 2 to 120 months	**Bladder:** Urological improvement was seen in 3 patients (11.5%) **Neurological:** 53 patients (61.6%) experienced relief from back pain, neurological improvement was noted in 5 patients (17.2%) **Adverse events**: Three patients had cerebrospinal fluid leakage	Surgical treatment for tethered cord syndrome should be individualized for each child patient
Geyik, 2016[306] N = 46 Turkey	Surgical detethering Releasing of the spinal cord from the adhesions associated with the correction of the associated malformations (split cord malformation, lipomeningocele, etc.) was performed in all patients	**Bladder:** The mean bladder capacity was in preoperative period 269.15 cm3 (SD = 136.18 cm3) and 182.73 cm3 Table 1 The causes of primary and secondary tethered cord syndromes Etiology Primary TCS Secondary TCS Thick filum terminale Previous spinal intradural surge **Neurological:** NR **Adverse events**: NR	Surgical intervention is recommended for children older than 10 years with tethered cord syndrome as they are more likely to benefit, with a focus on improving bladder capacity, post-voiding residual urine volume, and bladder compliance

Gharedaghi, 2014[307] N = 42 Iran	Surgical detethering The surgery was performed using laminectomy or laminotomy, and detethering of the spinal cord by removing the lesion or dissecting the tight filum terminale	**Bladder:** After 3 years of follow up, LBP and motor disorders improved significantly in 14 and 15 children respectively. Sensory disorders in 8 cases, muscle stiffness of the spinal region in 10 cases, contractions on the lower extremities in 5 cases, sphincter dys **Neurological:** After 3 years of follow up, LBP and motor disorders improved significantly in 14 and 15 children respectively. Sensory disorders in 8 cases, muscle stiffness of the spinal region in 10 cases, contractions on the lower extremities in 5 cases, sphincter dysfunctions in 13 cases, and intestinal disorders in 3 disappeared. The scoliosis angle decreased in 4 cases, and 9 cases showed signs of a halt in the progression of scoliosis. In the adult group, LBP in 5 cases, motor disorders in 4 cases, sensory disorders in 4 cases, dysesthesia in 2 cases, muscle stiffness of the spinal region in 1 case, contractions of the lower extremities in 1 case, and sphincter disorders in 1 case improved. Two patients showed progressive scoliosis without surgical intervention and 1 patient underwent surgery to correct the scoliosis **Adverse events**: Subsequent complications of surgery were observed in 4 patients; 3 of which was leakage and one pseudomeningocele. While infection and neurological deterioration was not present in the observed patients, one person showed retethering of the spinal cord, and so underwent surgery again. From the 17 cases that were referred to us, 14 underwent orthopedic surgery consequently after the detethering surgery	Early surgical intervention yielded better results

Gluncic, 2011[308] N = 4 US	Surgical detethering Patients underwent concurrent Chiari decompression and cord detethering operations; patients had progressive symptoms referable to Chiari Type 1 malformation (i.e., headache and swallowing difficulty) with recurrent progressive symptoms referable to spinal cord tethering (i.e., gait instability)	**Bladder:** N/A **Neurological:** All patients reported significant or complete early postsurgical resolution of CM1 symptoms as well as symptoms related to TCS. One to three months postoperatively, MRI demonstrated decompression of the CM with significant or complete resolution of their presenting symptoms. **Adverse events**: All surgeries were uneventful with no intraoperative or perioperative complications. No patient experienced cerebrospinal fluid leakage or other surgical complications.	Concurrent posterior fossa decompression and spinal cord untethering are safe options in cases of Chiari malformation type 1 with coexisting tethered cord syndrome and severe progressive symptoms from both conditions
Gross, 1993[309] N = 42 Germany	Surgical detethering The patients underwent microscopic neurosurgical untethering of the spinal cord. Myelolysis was performed microscopically with resection of epidermoids and lipofibroma. In every case the defect was between the L2 and S3 vertebrae combined with an open spinal canal. Postoperative examination usually was done within 4 weeks after untethering. Our review concentrates on those patients. Of the 21 patients 18 had a secondary tethered cord syndrome and 3 had occult spinal dysraphism.	**Bladder:** Of the 35 patients who underwent urological examination preoperatively 21 had urological symptoms (as initial symptoms in 4). A total of 11 patients could specify the desire to void preoperatively and 1 of them became worse after untethering, while 3 othe **Neurological:** NR **Adverse events**: NR	Surgical detethering can provide significant benefits, particularly in improving bladder function and reducing urinary incontinence

Gross, 2013[310] N = 12 France	Surgical detethering Surgical treatment of the tethered cord was performed in all of the patients. The procedure was initiated with a laminectomy on at least three vertebral levels. The treatment of a residual spinal canal stenosis was necessary in two patients. Then, the dura mater was opened on its midline. A meticulous dissection of the arachnoiditis allowed untethering the cord and roots. The procedure concluded with an expansile duraplasty with a supersized synthetic tissue (Neuro-Patch, B-BRAUN Medical, Melsungen, Germany). The duraplasty was tacked up to the paraspinal muscles laterally, and to the spinous processes at both extremities of the zone of laminectomy	**Bladder:** NR **Neurological:** All patients who presented with motor loss benefited from surgery as a first-line treatment, with a median delay time of 2 months (min=1; max=4). In contrast, all of the patients who presented with isolated neuropathic pain were first treated with oral anticonvulsants. Because of failed medical treatment, surgery was later proposed and performed in all of these patients. The median time between the onset of pain and the surgery was 50 months (min=6; max=103) in these patients. All of the patients' motor loss was improved by surgery. The improvement on the motor score ranged from 1 to 7 points (median=3 points). In three patients, this improvement allowed the patient to gain one motor level **Adverse events**: NR	In traumatic spinal cord injury patients, a tethered cord may be responsible for localized clinical and radiological changes termed "perilesional myeloradiculopathy," which necessitates cord release surgery

Guerra, 2006[311] N = 24 Canada	Surgical detethering The children were assessed preoperatively with urodynamic studies, which was repeated a mean of 6.4 months after tethered cord release; clinical and urodynamic outcomes were compared between the two periods; the diagnosis of tethered cord was based on history and physical examination, and all children underwent spinal cord magnetic resonance imaging; complete urological evaluation was done, including ultrasound of the upper tract; intraoperative urodynamics were used to guide the manipulation of nerve roots and avoid injury to the lower urinary tract innervation; intravesical and intrarectal pressure were recorded using standard urodynamic equipment and pelvic floor muscle activity was monitored during surgery with electromyography and intrarectal electrodes; clinical outcomes were evaluated for the last six month period preoperatively and for a mean follow up of 6 months after surgery	**Bladder:** Seven of the 14 toilet trained patients (50%) had daytime incontinence associated with urgency and frequency preoperatively and only 1 (7%) remained incontinent after surgery. All 7 patients who were continent preoperatively remained continent following s **Neurological:** N/A **Adverse events**: 14 patients had diurnal incontinence preoperatively; Constipation was noted in 10 of 24 patients and urinary tract infections developed in 25% of the patients; Four patients with low bladder capacity and/or low compliance preoperatively did not improve	Tethered cord release is beneficial in terms of clinical and urodynamic outcomes, particularly for patients with abnormal urodynamics and neurogenic detrusor overactivity
Gupta, 1999[312] N = 18 India	Surgical detethering 18 patients with Tethered Cord Syndrome were diagnosed via MRI and surgical tethering was performed over a five-year period.	**Bladder:** Sphincter dysfunction improved in only two out of six patients **Neurological:** After surgery, the symptom that was most commonly relieved was pain, which disappeared in eight out of nine patients. In two patients with trophic ulceration of the feet, there was a remarkably rapid healing of these ulcers after surgery **Adverse events**: NR	Surgical detethering is an effective intervention for all adult tethered cord syndrome patients with a confirmed diagnosis, especially those experiencing persistent back/leg pain, neurological problems, or skeletal deformities

Hajnovic, 2007[313] N = 22 Slovakia	Surgical detethering Analyzed the time-lag between the onset of symptoms and the first therapy, as well as the severity of impairment and the long-term outcome; evaluation included patient history, follow-up, neurological examination and magnetic resonance imaging or computed tomography scan; urodynamic assessment or electromyography were performed; all patients underwent a surgical operation for their tethered spinal cord syndrome	**Bladder:** N/A **Neurological:** Nine out of 22 patients in the series showed improvement in their symptoms. Virtually all patients operated within the first year of the disease demonstrated improvement, while only 25% of those operated at a later stage experienced improvement. The reasons for this difference remain unclear, with discussions around vascular impairment, mechanical impact, and neuronal death. It is unlikely that there is an acceleration of neuronal apoptosis after one year of the disease. The explanation may lie in neurophysiology, where the spinal medulla is a complex neuronal network with limited plasticity. Stress that disrupts its physiological capacity may lead to the development of "bypasses" to preserve specific functions, which can become fixed over time. Retracing such pathological pathways is challenging, as the function of affected organs is usually still maintained. **Adverse events**: Two patients worsened after surgery or despite it, and 11 remained unchanged without further progress. There was a direct correlation between the time elapsed and the therapy's outcome. Patients whose symptoms improved had an average time span of about 16.7 months between disease recognition and surgery, whereas those who remained unchanged had an average time span of 52.4 months.	Virtually all patients operated within the first year showed a subsequent improvement of symptoms. Only 25% of patients operated at a later stage achieved some measure of improvement.

Haro, 2004[314] N = 21 Japan	Surgical detethering Intraoperative electrophysiologic monitoring is employed during untethering, this procedure involves the careful release of fibrous tissues and any connections of sacral or coccygeal nerve roots to the spinal cord, which extend cranially from the spinal cord, also compound muscle potentials are consistently recorded to monitor the function of lower extremity muscles, the anal sphincter, and the external urethral sphincter, scalp and/or spinal cord stimulation is used to assess whether any neural elements are involved during the release of the spinal cord	**Bladder:** Few patients experienced improvement in bladder function **Neurological:** All patients reported significant improvement in their pain, also there was notable progress in the cases of three patients who exhibited enhanced muscle power deficits and reduced sensory disturbances in their lower extremities, Moreover, among the ten patients who initially had sensory disturbances in their lower extremities or around their perianal lesion before surgery, eight patients experienced an improvement postoperatively, as well as improvement in the progression of leg deformity in two of these patients **Adverse events**: One patient experienced a neurogenic bladder dysfunction and sensory disturbance in the legs when they reached 12 years of age	Surgical treatment of tethered cord syndrome in adults can lead to favorable improvement in urinary dysfunction and sensorimotor impairment, particularly when surgery is performed shortly after onset and when the cranial movement of the conus medullaris is observed on MRI

Hayashi, 2021 [315] N = 51 Japan	Surgical detethering The policy of performing surgery if diagnosed regardless of symptoms were retrospectively reviewed to evaluate long-term surgical outcomes; patients were followed over 100 months; patients underwent de-tethering surgery with the partial removal technique; pre- and postoperative clinical and radiological data were reviewed to analyze the outcomes of surgery and identify potential risk factors for re-tethered cord syndrome	**Bladder:** All patients underwent untethering surgery and 6 developed postoperative complications, including aggravation of neurogenic bladder in 5 patients (temporary urinary retention, n = 3 and dysuria, n = 2); long term results - of the 51 patients, 12 (23.5%) e **Neurological:** Of the 51 patients, 12 (23.5%) experienced neurological deterioration due to ReTCS including neurogenic bladder in 11 patients, lower-leg symptoms in 7 patients, and lumbar pain in 1 patient; those patients then underwent untethering surgery for ReTCS. **Adverse events**: All patients underwent untethering surgery and 6 developed postoperative complications, including aggravation of neurogenic bladder in 5 patients (temporary urinary retention, n = 3 and dysuria, n = 2) and CSF leakage requiring surgery in 1 patient. On univariate analysis, a lipoma type of lipomyelomeningocele (OR 11, 95% CI 2.50–48.4; p = 0.0014), patient age at the time of surgery (OR 0.41, 95% CI 0.14–1.18; p = 0.0070), and the mean patient growth rate after surgery (OR 2.00, 95% CI 1.12–3.41; p = 0.0040) were significant factors associated with ReTCS. Cox proportional hazard models showed that a lipoma type of lipomyelomeningocele (HR 5.16, 95% CI 1.54–20.1; p = 0.010) and the mean growth rate after surgery (HR 1.88, 95% CI 1.00–3.50; p = 0.040) were significantly associated with the occurrence of ReTCS.	More complex lesions and rapid patient growth after surgery appear to be associated with a higher risk of recurrent tethered cord syndrome

He, 2009[316] N = 11 China	Surgical detethering The surgical untethering utilized for all patients in this study encompassed a comprehensive approach, which included laminectomy, complete untethering of the spinal cord, and the excision of any concurrent spinal lesions, such as osseous spines in cases of split cord malformations, intradural lipomas, and teratomas, with particular attention to excising the bony septum and surrounding dural cleft in patients with split cord malformations; spinal cord release was accomplished through the sectioning of dorsal paramedian roots, fibrous bands, and the thick filum, while lipomas were excised or debulked as extensively as feasible, and all individuals were subsequently subjected to follow-up evaluations spanning a range of 13 to 46 months, with a mean follow-up duration of 19 months	**Bladder:** Sphincter dysfunction improvements were observed in only 2 out of the 5 patients **Neurological:** All patients experienced varying degrees of pain relief and improvements in neurological sensory and motor functions **Adverse events**: N/A	Surgical detethering yields positive outcomes in patients with tethered cord syndrome

Hendrick, 1983[317] N = 86 Unclear/Not reported	Surgical detethering Some 86 patients were treated by laminectomy, usually of L4, L5, and SI. On opening the dura the conus, unless abnormally low, was not usually visualized, but the thick tight filum with its associated lipoma (in 25 cases) could be identified in the majority of cases. In patients in whom the filum was not grossly thickened, it was obviously tight. An associated large vein was on occasion helpful in identification of the structure	**Bladder:** Improvement of bladder dysfunction was dramatic. In the three patients who presented with bladder dysfunction alone, there was reversion to normal control. Fifteen patients who presented with bladder and associated lower limb or back pain had a return of **Neurological:** Two-thirds of the patients with weakness in the lower extremities were improved to such a degree that no orthopedic surgery was required. They either developed a normal gait or required a minor surgical procedure, such as a plantar fasciotomy in the case of pes cavus. Eighteen patients had no improvement in their motor deficit. In no case was there any progression of their symptomatology following surgery. The degree of motor improvement was almost directly related to the length of time the symptoms had been present prior to operative treatment. There was a significant improvement in the sensory deficit in all 18 patients with this finding. Eight had return of normal sensation, and 10 were significantly improved, so that in five patients with trophic ulcers, there was no longer any problem with skin healing. No patients suffered sensory loss as a result of surgery **Adverse events**: NR	Early intervention is recommended to prevent disability and life-threatening complications in patients with developmental anomalies

Herman, 1993[318] N = 153 US	Surgical detethering All 153 patients underwent tethered cord release operations, 100 patients underwent this operation after primary closure of a myelomeningocele, 53 patients underwent this operation after repair of a lipomyelomeningocele; a carbon dioxide laser was used to perform the detethering operation; follow-up was obtained in all cases with an average of 4 years	**Bladder:** Urinary control and social continence improved in 33% of myelomeningocele patients and 36% of spinal lipoma patients. Complete return of urinary continence was seen in 2 myelomeningocele patients and 4 spinal lipoma patients. **Neurological:** Preoperative Clinical Signs: There were 6 main presenting signs and symptoms. New or progressive weakness involving one or both lower extremities represented 55% of the myelomeningocele group and 47% of the spinal lipoma group. A change in gait requiring added support to ambulate represented 54% of the myelomeningocele group and 44% of the spinal lipoma group. New or progressive scoliosis with a curvature greater than 7° was noted in 51% of the myelomeningocele group and 11% of the spinal lipoma group. Pain localized to the back and legs was present in 32% of the myelomeningocele group and 57% of the spinal lipoma group. Progressive foot deformities or hip dislocation were present in 11% of the myelomeningocele group and 32% of the spinal lipoma group. New urinary incontinence was noted in 6% of the myelomeningocele group and 21% of the spinal lipoma group. Other complaints included new or progressive stooped posture and spasticity. Post-operative Results: Motor strength improved by at least one spinal level in 79% of patients with myelomeningocele, and 52% of patients with a spinal lipoma, indicating significant motor function enhancement. Unexpected motor function improvement was noted in 24 patients with myelomeningocele who were initially believed to have a stable level. Gait, walking endurance, and stance improved in 72% of myelomeningocele patients and 59% of spinal lipoma patients. Orthopedic foot deformities and hip dislocation were corrected in 54% of myelomeningocele patients and 71% of spinal lipoma patients. Scoliotic curvature was	Re-operation for patients with myelodysplasia and progressive neurologic deficits is advised, as the results show evidence of tethered cord in all cases, with a significant portion experiencing improvement following release surgery and low morbidity

		corrected by at least 7° in 51% of myelomeningocele patients and 33% of spinal lipoma patients. Progression of curvature occurred in 5 patients, all of whom had severe preoperative curvature, necessitating spinal fusion. Long-term progression was seen in 37% of patients, while 63% remained stable or improved. Pain relief was achieved in 91% of myelomeningocele patients and 90% of spinal lipoma patients. **Adverse events**: Cerebral spinal fluid leak was the most common postoperative complication, affecting 6 myelomeningocele patients and 4 spinal lipoma patients. The majority of cases were managed with bed rest, and only a few required wound revision. Pseudocysts formed in 2 myelomeningocele patients and 1 spinal lipoma patient, necessitating defect repair. Wound infections were observed in 3 myelomeningocele patients and 2 spinal lipoma patients, treated with local wound care and antibiotics. Overall, no mortalities were reported, and the majority of patients experienced favorable outcomes with a notable improvement in neurological function.	
Hoffman, 1976[319] N = 31 Canada	Surgical detethering Laminectomy in lumbrosacral area	**Bladder:** Bladder/bowel incontinence improved in 2 of 3 patients **Neurological:** Motor/sensory loss in limbs improved in 20 of 22 patients **Adverse events**: NR	The child with a spina bifida occulta, particularly if he has a cutaneous manifestation of this disorder, who presents with low back pain, an immobile spine, scoliosis, weakness of a leg or sensory loss or both, or a neurogenic bladder can harbor a tethered spinal cord. This abnormality far outnumbers the more obvious forms of spinal dysraphism which cause a progressive neurological disorder in childhood. A diagnosis of tethered spinal cord requires a strong clinical suspicion and specialized myelographic technique. Ordinary myelography will virtually always fail to show the lesion and thus mitigate against a basically correctable lesion

Houser, 1994[320] N = 26 US	Surgical detethering The release of a tethered cord was performed using optical magnification, a carbon dioxide laser, and electromyography, with a six-month follow-up	**Bladder:** There were no significant changes in leak point pressure and bladder compliance, with one patient's hydronephrosis worsening, two stabilizing, and one improving, while clinical status remained unchanged in 16 patients, improved in 4, and worsened in 6, in **Neurological:** N/A **Adverse events**: 35% (9 patients) experienced new issues, including hydronephrosis, urinary tract infections, or urinary incontinence	Surgical release of a tethered cord improved the urological status in less than a quarter of the patients in this series
Hsieh, 2006[321] N = 17 US	Surgical detethering Retrospective review of records of children who underwent surgical release of a tethered cord at a single institution between 2001 and 2003 and identified 17 children (nine girls and eight boys) who had undergone both preoperative and postoperative urodynamic evaluation; preoperatively, 10 (59%) of the children with a tethered cord had abnormal urodynamic study results, only two (20%) of these patients had urological symptoms, all seven patients with normal preoperative urodynamic study results had normal results after detethering; five (50%) of the 10 children with abnormal preoperative urodynamic study results, the postoperative urodynamic study demonstrated improved or normal urodynamics	**Bladder:** Because the preoperative UDS results were abnormal in 59% of the children in our study who underwent detethering, a UDS should be considered as part of the preoperative evaluation in all cases of tethered cord in children. With regard to voiding function, **Neurological:** N/A **Adverse events**: N/A	Surgical detethering is considered safe for children with normal preoperative urodynamic studies results, with the potential for improved voiding function, mainly if performed before the age of 1 year

Huttmann, 2001[322] N = 54 Germany	Surgical detethering The first operation resulted in complete untethering of the spinal cord in 44 (82%) of 54 patients, untethering was incomplete in five patients with lipomas, in three with arachnopathy, in one with split cord malformation combined with a dermoid, and in one with primary arachnoid adhesions; there was some correlation between surgical findings and the preoperative course: minor forms of spinal cord malformation such as a tight terminal filum or a lipoma attached to the cord by only a fibrous band were seen most often in Group 1 patients (in 10 [59%] of 17), split cord malformations most frequently in Group 2 patients (nine [35%] of 26), and complex lipomas in Group 3 patients (10 [78%] of 13)	**Bladder:** 50% of our patients with more recent onset of urinary problems experienced improvement following cord untethering **Neurological:** N/A **Adverse events**: 10 patients with incomplete untethering developed recurrent symptoms 5 years after surgery compared with only seven (16%) of 44 patients in whom complete untethering was achieved	Surgical release of the tethered cord can lead to significant improvement in symptoms without substantial risk of deterioration, especially if symptoms of pain and spasticity are present
Hwang, 2017[323] N = 12 Korea	Surgical detethering Using different combinations of stimulation parameters—number of stimulation pulses: 4 or 8 pulses, interpulse interval: 1, 2, or 5 msec, and polarity of stimulation: biphasic or monophasic—the authors compared the relative mean amplitude of 10 BCR responses (rmaBCRs) to each combination of parameters of all infants (age < 24 months) who had undergone an untethering operation for tethered cord syndrome between May 2013 and February 2014 at a single institution and whose baseline BCR had been elicited during surgery	**Bladder:** NR **Neurological:** NR **Adverse events**: NR	Using a biphasic 8-pulse stimulation with 2-millisecond intervals is recommended as the optimal stimulation paradigm for monitoring intraoperative bladder contraction responses in infants

Inoue, 2017[324] N = 41 Japan	Surgical detethering Patients aged 7 years and older who underwent repair of anorectal malformation and spinal magnetic resonance imaging from January 1995 to December 2008 were reviewed retrospectively; untethering surgery was performed in all patients who were diagnosed with tethered cord, regardless of the presence or of neurological symptoms; clinical symptoms reflecting anorectal, urinary, and lower limb function were compared between patients complicated with tethered cord (n = 17) and those without tethered cord (n = 14); the median postoperative follow-up period was 9.1 years	**Bladder:** The current status of anorectal function is shown in Table 3. Most of the patients always had an urge to defecate without developing constipation in both groups. There were no significant differences in the functions of voluntary bowel movement and the de **Neurological:** Both groups improved from baseline **Adverse events**: N/A	For patients with anorectal malformation and tethered spinal cord, long-term functional outcomes following untethering surgery are comparable to those without tethered cord syndrome, suggesting that prophylactic surgical detethering should be considered as a treatment of choice to optimize neurological functional outcomes

Iqbal, 2016[325] N = 50 Other	Surgical detethering The surgical technique for division of thickened filum terminale is as follows. After induction of general anesthesia, the patient was positioned prone on two bolsters placed underneath the patient. The L5–S1 space (depending on the radiology, a space above was also used in some cases) was localized with fluoroscopy, reducing the injury of any low-lying sacral cell bodies. A small midline incision was made and dissection was extended down in a standard fashion to expose the inferior aspect of L-5, part or all of S-1, and S-1 laminectomy was performed. With microscopic guidance, a midline dorsal durotomy was performed and dural edges were held up with stitches. After opening the arachnoid, the filum could be recognized by typical dorsal midline location, bluish discoloration, anteriorly located vessels, and infiltrating fat (Figs. 1, 2). Intraoperative neurophysiological monitoring was used to distinguish functioning neural elements from the terminal filum. We did not have this facility at our institution and since we sectioned the filum at around the L5–S1 level in the majority of cases, monitoring was not essential. A suture was placed in the filum to send a specimen for pathology. We first coagulated and then sectioned the filum. A meticulous layered closure was done at the end	**Bladder:** Of the 39 patients that presented with urinary impairment, 46% improved. **Neurological:** Eighty five percent of the patients with thickened filum terminale showed improvement postoperatively. Sixty six percent of the patients with diastematomyelia, 60% with lipoma and 46% with myelomeningocele improved postoperatively. Sixty two percent of the patients with paraperesis improved postoperatively, while 37% remained stable and only one patient deteriorated. Of the six patients with paraplegia, only one improved. Of the 15 patients that presented with back and leg pain, 93% percent improved postoperatively. Of the 38 patients with decreased power in lower limbs, 42% improved and 57% stabilized postoperatively **Adverse events**: N/A	Outcome of patients with TCS varies according to pathology and severity of symptoms. Diastematomyelia and thickened filum had the best outcome. The Karachi TCS severity scale is a valid tool for future studies

Ishisaka, 2020[326] N = 57 Japan	Surgical detethering Patients underwent sectioning of the filum terminale and postoperative outcomes of symptoms and magnetic resonance imaging findings were evaluated; medical records were retrospectively reviewed for the size of syringomyelia, urologic findings, presence or absence of minor abnormal findings on magnetic resonance imaging, duration of follow-up, and clinical outcomes; patients were followed up for at least 1 year after surgery, the mean follow-up period was 3.3 years (range 1–9 years)	**Bladder:** In one of the patients in the asymptomatic group prior to surgery, bladder dysfunctions were observed at 5 years after surgery and was diagnosed as retethering. The patient underwent additional untethering surgery. **Neurological:** N/A **Adverse events**: N/A	Sectioning the filum terminale is an effective intervention for patients with terminal syringomyelia associated with tethered cord syndrome, as it was found to improve symptoms and prevent further deterioration in most cases, with low perioperative complications
Ishisaka, 2023[327] N = 1 Japan	Surgical detethering Spinal cord untethering. Spinal cord tethering and a thickened fatty filum with a 3 mm diameter area of T1 hyperintensity was confirmed by magentic resonance imaging. The patient underwent surgery in the prone position. Neurophysiological intraoperative electromyographic monitoring and monitoring of the bulbocavernosus reflex were used.	**Bladder:** Voiding cystourethrography showed no bladder morphology abnormalities or vesicoureteral reflux preoperatively. The postoperative course was uneventful. **Neurological:** The patient remained neurologically intact. **Adverse events**: N/A	Our report emphasizes a 1 cm option for minimally invasive untethering by sectioning the filum terminale. In conclusion, there is an urgent need for endoscopes and technology that will lead to further evolution of surgical techniques and benefits to patients.
Iskandar, 1998[328] N = 34 US	Surgical detethering N/A	**Bladder:** Of the 18 patients with bowel and bladder dysfunction, 11 improved, one worsened, and six were unchanged **Neurological:** Of the 27 patients with motor or sensory complaints, 13 improved, two worsened, and 12 were unchanged **Adverse events**: Non neurological surgical complications consisted of one spinal fluid leak and five pseudomeningoceles, all of which were successfully treated either conservatively or surgically	Although surgery in adults involves greater risk of neurological injury than in children, it is a low-risk procedure with encouraging results. Because neurological deficits are generally irreversible, early surgery is recommended

Iskander, 2001[329] N = 34 US	Surgical detethering N/A	**Bladder:** Of the 18 patients with bowel and bladder dysfunction, 11 improved, one worsened, and six were unchanged **Neurological:** Of the 27 patients with motor or sensory complaints, 13 improved, two worsened, and 12 were unchanged **Adverse events**: Non neurological surgical complications consisted of one spinal fluid leak and five pseudomeningoceles, all of which were successfully treated either conservatively or surgically	Although surgery in adults involves greater risk of neurological injury than in children, it is a low-risk procedure with encouraging results. Because neurological deficits are generally irreversible, early surgery is recommended
Iyer, 2022[330] N = 18 US	Surgical detethering Patients had a detethering surgery two years prior to a spinal deformity correction procedure; radiographs were taken in all patients prior to the detethering procedure (pre-detether) and at the most recent visit prior to spinal deformity correction (most recent post-detether); these radiographs were used to collect the major coronal curve for each patient at each time point (pre and post detether); the difference between major coronal curve at the pre-detether visit and the post-detether visit was calculated for each patients; the primary outcome was curve progression, which was defined as a >10° increase in major coronal curve between pre-detether and post-detether visits; additional outcome measures included curve stabilization within 10° and curve improvement >10°	**Bladder:** N/A **Neurological:** N/A **Adverse events**: Five (27.8%) patients had curve progression > 10° at a follow-up of 3.2±1.2 years. Patients with curve progression > 10° were older at the time of detethering when compared to those without (5.6±2.8 vs. 3±2.7 years, p=0.084)	Untethering at a younger age is linked to a reduced rate of scoliosis progression, emphasizing the importance of early investigation for intraspinal pathology and considering tethered cord syndrome release alongside scoliosis management as a potential intervention to delay or avoid scoliosis surgery

Jackson, 2019[331] N = 8 US	Surgical detethering Ponseti technique used to determine if clubfoot associated with tethered cord syndrome was more resistant than isolated clubfoot	**Bladder:** NR **Neurological:** Out of all the subjects in the TCS group, 75% of them (6/8 subjects, 9/12 feet) had a tethered cord release posttenotomy. The incidence of deformity recurrence was higher among subjects who had a tethered cord release posttenotomy (56%, 5/9) as compared with pretenotomy (0%, 0/3). **Adverse events**: NR	Clubfoot associated with tethered cord syndrome (TCS) requires more casts for correction and carries an increased risk of deformity recurrence compared to isolated clubfoot cases
Johnson, 1995[332] N = 15 US	Surgical detethering NR	**Bladder:** NR **Neurological:** None of the symptomatic, operated patients had normal cord motion. Those who had slight or moderate decrease in the cord motion remain stable or were better following surgery except 2 children. Both children had syringohydromyelia with scoliosis as their primary indication for surgery. Of the 7 children who had a severe decrease in cord motion, 3 remain stable, 1 improved initially but subsequently worsened, and 3 were worse following surgery **Adverse events**: NR	Surgical detethering may be more effective in younger patients with tethered cord syndrome, they are more likely to experience better outcomes compared to older patients
Kadri, 2008[333] N = 22 Other	Surgical detethering Dentethering and dura plasty	**Bladder:** In patients with myelomeningocele at birth or spinal lipoma, 4 (36%) of patients improved their urinary and motor functions, 3 improved their motor function with a stable urinary function, 2 did not show any changes, 2 deteriorated. In patients with prima **Neurological:** In patients with myelomeningocele at birth or spinal lipoma, 4 (36%) of patients improved their urinary and motor functions, 3 improved their motor function with a stable urinary function, 2 did not show any changes, 2 deteriorated. In patients with primary tethered spinal cord associated with skin sings of occult spine dysraphism, 6 patients (54%) improved their urinary and motor functions after the untethering procedure, 3 improved their motor function with a stable urinary function, 2 did not show any changes. **Adverse events**: N/A	Untethering operation is a mandatory procedure for patients suffering from tethered spinal cord, results of such a procedure is better in patients with myelomenigocele at birth or spinal lipoma than patients with primary tethered spinal cord.

Kang, 1997[334] N = 60 Korea	Surgical detethering NR	**Bladder:** Sphincter dysfunction improved in 5 of 18 patients **Neurological:** Sensorimotor deficits improved in 8 of 15 patients **Adverse events**: NR	The surgical outcome was gratifying in relation to pain and motor weakness, but disappointing in the resolution of bowel and bladder dysfunction. Of these 20 patients with TCS, preoperative deficits improved after surgery in 11 patients (55%), remained stable in 7 (35%), and worsened in 2 (10%)
Kang, 2002[335] N = 75 Korea	Surgical detethering Neuro-imaging and intraoperative findings allowed classification of lipomyelomeningocele into three types: type I, type II, and type III; the patients were divided into two groups by age: group A (51 patients), from birth to 3 years, and group B (24 patients), from 3 to 24 years; for prevention of retethering of the cord, a mega-dural sac rebuilding procedure was performed in 15 patients, with a mean postoperative follow-up period of 4 years	**Bladder:** Postoperatively, 3 patients showed an improvement in bladder functions (2 in group A, 1 in group B), 9 patients showed no change in bladder dysfunction (4 in group A, 5 in group B), and 1 patient in group B had aggravated bladder dysfunction after surgery **Neurological:** Preoperative neurological deficits improved after surgery in 29 patients (39%), remained stable in 28 (37%), changed slightly in 13 (17%), and worsened in 5 (7%) **Adverse events**: Preoperative deficits were worsened in 7% of patients with Lipomeningomyelocele; Retethering of the cord with neurological deterioration occurred in 5.3% of the 75 patients	Early diagnosis and optimal surgical detethering are crucial for treating patients with Lipomeningomyelocele, emphasizing the potential preservation of residual neurological functions, and recommends the use of mega-dural sac repair during untethering and decompression surgery to prevent cord retethering

Kang, 2006[336] N = 42 Korea	Surgical detethering The aims of operation were reduction of mass effect from lipoma, maximal untethering of the spinal cord, and prevention of retethering. Therefore, the operative procedures included subtotal, less aggressive resection of lipoma, meticulous untethering of the spinal cord, pial reconstruction, redundant duraplasty with a lyophilized dura if indicated, and tacking up of the dura. In all the cases, we performed electrical stimulation of roots and observed motor responses during operation. Complete untethering was possible in the majority of cases (35 of 42). Causes for incomplete untethering included taut ventral root(s) (n=4), taut dorsal roots (n=1), distal root intermingled with the fatty filum terminale (n=1), and conjoined root (n=1). Among cases with taut roots, motor responses were observed in two cases. Despite the cautious untethering procedure, root damages occurred in four cases, dorsal root damages in two, and fine ventral root damages in the other two	**Bladder:** Preoperative urologic symptoms, such as incontinence or absence of dry period between diaper exchange, dribbling at crying, and weakening or interruption of stream, were observed in 23 cases. Of these, 16 cases showed abnormalities on UDS but seven cases **Neurological:** Preoperative neurologic examination revealed abnormalities (including sensory, motor, or reflex changes) in 35 of 42 cases; among these, 16 cases proved normal on UDS preoperatively. The UDS findings of seven cases without neurologic abnormalities were normal in five and hyperreflexic bladder in two. After untethering, the UDS findings were normal in two and abnormal in five among neurologically intact group. In neurologically abnormal group, eight cases were normal and 27 cases abnormal on postoperative UDS. There were no statistical differences between neurologically normal and abnormal groups in preoperative and postoperative UDS findings. At the last follow-up, all the neurologically normal cases (n=7) showed favorable voiding pattern and so did 19 of 35 cases in neurologically abnormal group. This difference was of statistical significance (p=0.033) **Adverse events**: NR	Early surgery at 12 months or younger is recommended for better anticipated urologic results

Kang, 2009[337] N = 83 Korea	Surgical detethering All tethering was individually treated using an intra-operative monitoring system, including somatosensory evoked potential and urodynamic study; the portions adherent to the dura were sharply dissected away, leaving the rest of the mass gliding freely within the dural sac to maintain the functional neural elements; all dural defects were closed with lumbodorsal fascial grafts (9 cases) or Gortex (15 cases); tethering lesions (lipomas) were maximally debulked and complete untethering of the cord was then performed; at the close of surgery, mega-dural reconstruction was performed	**Bladder:** 63% of patients presented with bladder dysfunction and 42% presented with bowel dysfunction; postoperatively, 33.3% of patients with sphincter dysfunction improved **Neurological:** N/A **Adverse events**: N/A	It is concluded that while surgical intervention is excellent for resolving pain and sensorimotor deficits, it may be less effective for bladder dysfunction, emphasizing the importance of early diagnosis and timely surgical release for a successful outcome in this population
Kaplan, 1988[338] N = 20 US	Surgical detethering A handheld carbon dioxide laser operating at 10 watts in continuous mode was utilized, the laser beam was focused for cutting and defocused for vaporization; this technique was employed to completely release the neural placode from the surrounding tissue, while in some cases, the spinal cord was directly exposed and visible in communication with subcutaneous fat or bony structures; subsequently, the dura was reconstructed over the exposed spinal cord	**Bladder:** Improvements in urodynamic parameters for 60% of the patients (12 out of 20), pressure-volume curves shifted right, and uninhibited contractions decreased preoperatively in the nine patients with this pattern; the 12 patients experiencing symptomatic impr **Neurological:** N/A **Adverse events**: 8 patients did not experience any improvement in their urodynamic parameters, and from a clinical perspective, they continued to present challenges in terms of management	Early recognition of urological symptomatology, and accurate diagnosis and neurosurgical repair can be beneficial for patients with the tethered cord syndrome
Kayaba, 2003[339] N = 5 Japan	Surgical detethering N/A	**Bladder:** Anal canal resting pressures before and after untethering surgery, respectively, were 51.3 +/- 23.9 cm H_2O and 57 +/- 11 cm H_2O, compared with that of 73.2 +/- 23.7 cm H_2O in controls. There was no significant statistical difference. The mean anal canal s **Neurological:** N/A **Adverse events**: N/A	Fecodynamic studies allow the detection of neurogenic disturbances of the anorectum in symptomatic and asymptomatic patients with tethered cord syndrome

Kim, 2014[340] N = 44 Korea	Surgical detethering Investigation through urodynamic studies, detethering procedure, and a subsequent 6-month follow-up	**Bladder:** Urodynamic scores improved, p = 0.033 **Neurological:** N/A **Adverse events**: Several patients encountered significant urodynamic complications, including febrile urinary tract infections, the necessity for clean intermittent catheterization, augmentation cystoplasty, and vesicoureteral reflux, and persistent urinary incontinence despite being on high doses of anticholinergic medications	The Meyrat UD scoring system is a valuable tool for evaluating urological function after detethering surgery in patients with spinal cord tethering

Kirollos, 1996[341] N = 22 UK	Surgical detethering To allow proper evaluation and assessment of operative achievement, a grading system was developed based on the intraoperative observations at the end of the untethering procedure; the cord is completely untethered in Grade I, partly in Grade II and remains tethered in Grade III regardless of whether decompression was performed or not; four patients were asymptomatic at the time of surgery, and were diagnosed after presenting with cutaneous stigmata of spinal dysraphism; their ages were 5, 8, 12 and 54 months, and all had spinal lipomas as the tethering factor; the 18 symptomatic patients, presented mainly with one or more of the following deficits: motor weakness, sensory disturbances, poor urinary bladder control, or foot deformity; for the different intraspinal lesions, grading of I,II and III, was developed for each pathology; all patients underwent operative treatment aiming at untethering the spinal cord and freeing the nerve roots; surgery was performed for neurological deficits in 15 cases and as a prophylactic procedure in the four asymptomatic patients, three cases underwent surgery for progressive foot deformity in isolation without significant motor weakness; postoperative follow-up period ranged from 2 to 44 months	**Bladder:** Two patients improved in terms of bladder control and one in motor function, all three had Grade I untethering **Neurological:** Early postoperative neurological complications (irreversible new or accentuated neurological deficit occurring within 1 month of surgery) occurred in two patients, one patient who presented with poor urinary bladder control experienced permanent worsening of the urinary incontinence postoperatively; in another patient worsening of pre-existing lower limb weakness was noted postoperatively but improved to the preoperative state 2 months later **Adverse events**: Three patients had persistent cerebrospinal fluid discharge from the operative incision, and all required reoperation for dural repair; the mean length of hospital stay of complicated cases was 22.8 days (range 16±35), as compared to a mean of 10.5 days in uncomplicated cases (range: 5±16); these complications were correlated with the grade of untethering	The grade of untethering was correlated with the type of pathology encountered, postoperative results, and whether previous surgery was performed or not

Klinge, 2022[342] N = 116 US	Surgical detethering All cases were surgically treated in a standardized fashion with intraoperative electromyographic neuromonitoring by a single neurosurgeon. Surgery was performed through a lumbar interspinous approach 1 vertebral level below the conus. Following durotomy under microscopic magnification, a segment of at least 2 cm of the FT was excised. The dura was closed primarily and sealed with fibrin sealant (Tisseel, Baxter, Deerfield, Illinois, USA) and a Duraform patch (Natus Medical Inc, Pleasanton, California, USA). Patients were subjected to a 24-hour bed rest post surgery	**Bladder:** That analysis reveals that bowel and bladder symptoms improved most following surgery, while at least 1 moderate-severe neurologic symptom was still present in many cases at the second and third visits **Neurological:** Neurological symptoms declined from 98.7% to 46.7% of patients in hEDS-TCS group, and from 100% to 72.4% in TCS group **Adverse events**: A temporary or permanent worsening of the clinical condition during the follow-up period was recorded in 10/78 hEDS and 5/38 TCS cases (12.8% vs. 13.9%). In the hEDS-TCS group, a surgical revision for a pseudomeningocele and a subsequent tethering of cauda structures were recorded. In the TCS group, 1 tethering of cauda structures and a filum terminale hemorrhage required surgical revision	It suggested that individuals with hypermobile Ehlers-Danlos syndrome may have limited elasticity in their filum terminale, which can lead to tethered cord syndrome, and that filum terminale excision may benefit those patients without a low-lying conus
Kondo, 1986[343] N = 15 Japan	Surgical detethering Myelography and urodynamic studies were conducted before the untethering operation	**Bladder:** Bladder function normalized in 47% of patients and improved in 20% **Neurological:** Some patients showed improvements in motor and sensory bladder function, along with detrusor contractility **Adverse events**: Two cases experienced aggravated bladder function, and six cases had unimproved or worsened orthopedic conditions	We conclude that neurogenic bladder secondary to the tethered cord syndrome is curable provided that the underlying pathological condition is recognized properly and an operation is performed early

Kothari, 1995[344] N = 39 US	Surgical detethering NR	**Bladder:** Six patients (15%) improved, 32 remained stable, and 1 deteriorated clinically. Improvement consisted of a descent in the motor and sensory level in 3 patients, return of lower extremity reflexes in 2 patients, and improved urinary control in 1; deteriora **Neurological:** Six patients (15%) improved, 32 remained stable, and 1 deteriorated clinically. Improvement consisted of a descent in the motor and sensory level in 3 patients, return of lower extremity reflexes in 2 patients, and improved urinary control in 1; deterioration consisted of a more cephalad motor and sensory level **Adverse events**: NR	The study recommends serial electromyography/urodynamic studies as a useful adjunct to clinical observation for patients at risk of spinal cord tethering, citing improvement in motor units, sacral reflexes, and bladder dynamics, along with the early detection of recurrent tethering in some case

Koyanagi, 1997[345] N = 34 Japan	Surgical detethering Patients with tethered cord syndrome and occult spinal dysraphism treated surgically, and untethering of the spinal cord were performed in all patients; partial removal of the lipoma was done in 32 cases of lumbosacral lipoma; dural-plasty was performed using a freeze-dried dura in most of these cases; two patients with associated syringomyelia immediately rostral to the lipoma were treated by syringo-subarachnoid shunting performed at the same time as the untethering procedures; postoperative follow-up periods in the 34 patients ranged from 5 months to 11 years (mean 5.3 years); pre and postoperative urological examinations were performed and the diagnosis of neurogenic bladder was made on the basis of abnormal urological examinations (residual urine, deformity of bladder, reduced capacity of bladder, vesicoureteral reflux, detrusor-sphincter dyssynergia, etc) or clinical symptoms (urinary tract infection, frequent urination, incontinence, difficulty in voiding, etc)	**Bladder:** Postoperative follow-up periods in 8 patients who had not shown any neurological or urological abnormality ranged from 1 to 11 years (mean 6.5 years) - only 1 patient develop neurogenic bladder which was diagnose by urological examination 1 year after sur **Neurological:** Aymptomatic group (n=8): 1 patient developed neurogenic bladder, which was diagnosed by urological examination 1 year after surgery. The other 7 patients have remained neurologically and urologically intact. Symptomatic group (n=26): 5 patients showed improvement of the neurogenic bladder, taking the form of disappearance of residual urine or urinary incontinence. In 2 of these 5 cases, motor weakness of the legs was also improved. In 1 patient motor weakness of the legs improved. Thus, 6 of 26 patients (23%) in our series had improvement of their neurological symptoms after untethering surgery. For 15 patients (58%) the symptoms remained unchanged (see case 4). Five (19%) out of 26 patients developed motor weakness of the legs (3 cases) or experienced worsening of a foot deformity (2 cases) during follow-up. **Adverse events**: There was no operative mortality or severe morbidity in this series. Postoperative subcutaneous fluid collection at the operative site was noted in 9 patients (26%), 3 of whom required surgical repair while the fluid collection was transient in the other 6. In 1 patient recovery was complicated by meningitis, which was cured by the administration of antibiotics. Two patients showed a transient decrease in anal tonus after surgery.	Untethering surgery is effective in preventing progressive neurological deterioration in patients with tethered cord, and the low proportion of symptom improvement in symptomatic patients underscores the importance of early prophylactic surgery

Lee, 2006[346] N = 60 Canada	Surgical detethering Under continuous intraoperative electrophysiological monitoring, including monitoring of bowel and bladder function, to achieve complete untethering of the spinal cord, which required lumbosacral laminectomies to expose the conus medullaris and cauda equina adequately, and the terminal filum was identified using anatomical methods and confirmed by the absence of EMG activity before clip ligation and sectioning	**Bladder:** Among patients with urological dysfunction, 50% reported subjective improvement in their condition, while it remained unchanged in 45% of patients **Neurological:** The majority of patients, around 78% with back pain and 83% with leg pain, showed noticeable improvement, and patients with preoperative motor weakness were more likely to experience improvement compared to those with sensory deficits, but the neurological status of 90% of patients either improved or remained stable **Adverse events**: Cerebrospinal fluid leakage, a superficial wound infection, meningitis, and urinary tract infection, also there were instances of temporary unilateral lower-limb numbness and exacerbated foot weakness	Surgery for adult tethered cord syndrome can be performed safely with a low risk of permanent neurological complications, and most patients experience improvement in pain and neurological dysfunction
Lee, 2012[347] N = 33 Korea	Surgical detethering Intraoperative electrophysiology monitoring was not utilized; most patients achieved complete untethering, and some had fibrous bands left uncut, which resembled nerve roots, resulting in incomplete untethering; when the syrinx cavity was concealed within neural tissue, direct management of the syrinx was typically not performed, only one patient had syrinx cavity aspiration, which was conducted using a 26-gauge needle due to a large syrinx index, close proximity to the dorsal cord surface, and significant pressure in the operative area	**Bladder:** N/A **Neurological:** The majority (97%) did not experience permanent syrinx enlargement, eight patients had complete syrinx disappearance, while ten had reduced syrinx size, also nine patients had a stable syrinx post-surgery, and four initially experienced a transient increase in syrinx size, which later stabilized; only one patient showed reenlargement of the syrinx after a period of improvement and underwent a second operation, changes in syrinx size were not statistically correlated with clinical symptoms, and the patients were stratified based on preoperative syrinx size, but no significant differences were found in terms of preoperative symptoms, postoperative symptom progression, or radiological syrinx outcomes **Adverse events**: N/A	Untethering alone may suffice for managing syringomyelia associated with tethered cord

Lee, 2001[348] N = 53 US	Surgical detethering The surgical procedure involved laminectomies to expose the dura, and intraoperative ultrasonography was used to locate the cyst and any tethering; for solitary cysts without tethering, a syringosubarachnoid shunt was placed and for tethered spinal cords, adhesions were released through microdissection and neurophysiological monitoring; the ultrasound image was repeated to check for cyst collapse; if untethering was not achieved or a persistent cyst was present, a short syringosubarachnoid shunt was inserted; the patients were kept at bedrest for 48 hours after surgery, and clinical follow-up was performed at an average of 23.9 months; postoperative magnetic resonance imaging was obtained from most patients	**Bladder:** N/A **Neurological:** Of the 45 patients with at least one year of clinical follow-up (8 lost to follow-up within a year): 73% (33 patients) had satisfactory results, which means they experienced resolution of one or more of the presenting signs/symptoms without deterioration. 20% (9 patients) remained unchanged. 7% (3 patients) had worsening motor functions, and one of these three patients also had increased spasticity. Surgical intervention improved the motor symptoms in 56% (15 out of 27) of the patients. It improved spasticity in 46% (12 out of 26) of the patients. Sensory loss was halted and improved in 45% (10 out of 22) of the patients. Gait disturbance improved in 47% (8 out of 17) of the patients. Axial and/or radicular pain syndrome improved in 36% (13 out of 36) of the patients. Minimal symptomatic relief resulted from the operation in terms of paresthesia, sphincter dysfunction, or autonomic dysreflexia. There was no statistically significant difference in terms of clinical presentation between patients with or without cord tethering. **Adverse events**: Two patients (11%) in the shunt-only group needed a shunt revision. One of these patients required two additional shunt revisions over a 24-month period. Three out of nine patients (33%) who underwent both untethering and shunting procedures had clinical recurrence and MRI evidence of ventral cord retethering. Six of nine patients (67%) who underwent both untethering and shunting developed transient weakness for 3-6 months after surgery, although five recovered motor strength to near baseline.	Untethering surgery, either alone or in combination with expansile duraplasty to expand the subarachnoid space, is an effective treatment for post-traumatic syringomyelia associated with cord tethering

Lee, 2012[349] N = 12 US	Surgical detethering NR	**Bladder:** Six children were toilet trained before detethering. Of these patients 3 had voiding complaints preoperatively, while 3 had no urological issues. Postoperatively all 6 of these children had voiding complaints at various times. Overall, 10 of the 12 childr **Neurological:** NR **Adverse events**: NR	Spinal cord detethering is not effective for patients with Currarino syndrome based on their study, as it did not show conclusive evidence of urodynamic improvement, and ongoing voiding complaints persisted in patients
Levi, 2013[350] N = 86 US	Surgical detethering Closure primarily involved advancing and approximating bilateral paraspinous muscles at the midline, followed by mobilization of lumbosacral fascia flaps; various approaches were used based on the defect's width and location, including involving periosteum, latissimus, or gluteal muscles for a layered closure, with a period of ranging from 12 to 144 months	**Bladder:** Improvement in bowel/bladder function **Neurological:** Improvement in motor, sensory function with back pain **Adverse events**: Skin flap dehiscence, skin flap necrosis, hematoma, seroma, skin subcutaneous infection, revision surgery by a plastic surgeon, and cerebrospinal fluid leak	Local soft tissue rearrangement in tethered cord repair improves closure by adding a vascularized tissue layer
Lim, 2023[157] N = 164 Singapore	Surgical detethering The surgical procedure for detethering fatty filum terminale involves making a partial laminotomy, opening the midline of the dura, performing direct stimulation to confirm the location resecting while minimizing residual tissue, primarily closing the dura with sutures, applying TachoSil to aid in sealing, and closing the remaining layers of the wound; surgery for prophylactic intent Detethering surgery for therapeutic intent	**Bladder:** N/A **Neurological:** Although there was improvement in the various neurological deficits, the improvements were not complete (47.6% motor deficits...) **Adverse events**: There were 11 cases with surgical complications: 9 (5.5%) were wound related and 2 (1.2%) were pseudomeningoceles; 3 patients (1.8%) required surgical treatment (1 wound infection, 1 wound dehiscence, and 1 pseudomeningocele). There were no cases of overt CSF leakage. Separately, 11 patients (6.7%) required postoperative clean intermittent catheterization.	Detethering surgery for fibrofatty filum terminale is a relatively safe procedure and can be performed prophylactically. Nonetheless, the risks of postoperative clean intermittent catheterization should be emphasized during the preoperative counseling process.

Macejko, 2007[351] N = 79 US	Surgical detethering We completed a retrospective review of 475 cases of tethered cord release performed at a single institution between 1995 and 2002; of these surgeries 173 were performed in children younger than 3 years; clinical outcomes, and preoperative and postoperative urodynamic and radiographic studies were evaluated; average follow-up was 5.2 years	**Bladder:** At follow-up 49 patients (62.1%) had no urological complaints and 30 (38%) had urological problems. A total of 20 children (25.3%) had minor problems (constipation, delayed toilet training or other) and 10 (12.7%) had major problems (need for clean interm **Neurological:** N/A **Adverse events**: 38% of patients had urological problems at follow-up; 25.3% had minor problems (i.e., constipation or delayed toilet training); 12.7% had a need for clean intermittent catheterization, febrile urinary tract infection or reflux	In young children undergoing tethered cord release, most do not experience urological problems, but a few may have significant issues postoperatively
Maher, 2009[352] N = 13 US	Surgical detethering NR	**Bladder:** Of the 7 patients with urinary symptoms, 5 reported postoperative improvement, 2 reported no change or worsening symptoms. Each of the symptomatic patients with postoperative improvement reported a decrease or complete elimination of episodes of urinary i **Neurological:** NR **Adverse events**: NR	In patients undergoing multiple repeat spinal cord untethering operations, measuring bladder function is more useful than sphincter electromyography when selecting candidates for surgery and for measuring surgical outcomes
Maurya, 2016[353] N = 21 India	Surgical detethering All the patients underwent elective surgery that included detethering of the conus and management of the tethering disease as indicated; intraoperative electrophysiologic monitoring (of bilateral L4, L5, S1, and perianal myotomes) was used in all cases and an intraoperative image intensifier was used to identify the L5 spinous process, partial L5 or S1 laminectomy/laminotomy and exposure of the dura were achieved; once the dural tube was identified, 6 mL of cerebrospinal fluid was obtained before any durotomy was performed; thus, clear cerebrospinal fluid was obtained in all cases; detethering of the filum was then performed using the operating microscope	**Bladder:** Surgical detethering saw improvement in 60% of patients with bladder symptoms **Neurological:** No other complications occurred in this series, nor did any patient develop fresh neurologic deficits. Gait issues and motor deficits were the most common signs detected on neurologic examination, noted in 8 patients (38%) each. Overall, 5 patients (of the 11 who had deficits preoperatively, 46%) improved to normal or near-normal neurologic status and the 10 patients who were asymptomatic and intact remained so. **Adverse events**: N/A	The surgical detethering in tethered cord syndrome patients resulted in a reduction of cerebrospinal fluid markers associated with anaerobic metabolism and neuronal injury, as well as improved electrophysiologic functioning of the spinal cord, indicating potential benefits of the intervention

McGirt, 2009[354] N = 27 US	Surgical detethering All patients with meningomyelocele underwent tethered-cord release for worsening pain and/or worsening urinary function	**Bladder:** Ten (83%) of 12 patients reported significant improvement in back, lower-extremity, or perineal pain; 12 (86%) of 14 experienced improvement in lower-extremity motor dysfunction; and 12 (80%) of 15 experienced improvement in urinary dysfunction. Median ti **Neurological:** Ten (83%) of 12 patients reported significant improvement in back, lower-extremity, or perineal pain; 12 (86%) of 14 experienced improvement in lower-extremity motor dysfunction; and 12 (80%) of 15 experienced improvement in urinary dysfunction. Median time to resolution of pain, motor, and urinary dysfunction was 5.2, 4.8, and 5.7 months, respectively. Of 21 patients experiencing symptomatic improvement, 16 (76%) improved within 6 months of surgery. Of the 14 patients with a history of myelomeningocele repair, 64% experienced improvement of their TCS-associated declining motor deficits, 57% showed improvement in their preoperative pain, and 71% demonstrated improvement in their TCS-associated declining bladder function. Overall, 10 (37%) experienced retethering at a mean of 39.2 months after surgery, and all required revision untethering. For patients experiencing retethering, the incidence of deformity progression was 60%, similar to those not experiencing retethering (53%). Four (40%) of the 10 patients undergoing revision untethering experienced improvement of progressing motor deficits, five (50%) experienced improvement in preoperative pain, and 4 (40%) experienced improvement in TCS-associated declining bladder function. **Adverse events**: NR	Close monitoring of pediatric TCS-associated scoliosis patients is advised, especially those with severe curves (>40°) or lower Risser grades (0-2), for potential curve progression after spinal cord untethering, as they are at higher risk

McLone, 1986[355] N = 50 US	Surgical detethering Untethering achieved in all cases	**Bladder:** Group A: 17 of 18 patients had intact motor function; Group B: 12 of 15 patients had normal motor function; Group C: 9 of 17 patients had normal motor function **Neurological:** Group A: 1 patient had improved incontinence; Group B: 7 of 15 patients had normal urological function; Group C: 11 of 17 patients had normal urological function **Adverse events**: Complications were found in 13 patients, including infection, meningitis, and pooled CSF	Proper management of the patient with spinal lipoma now requires early prophylactic resection of the lipoma and untethering of the spinal cord
Mehta, 2011[356] N = 59 US	Surgical detethering Medical records of patients were reviewed, which included all hospital records, pre- and post-operative clinic notes and pre- and postoperative imaging studies; no other surgical information provided except tethered cord release was performed on children born with a myelomeningocele with symptoms of Chiari II malformation	**Bladder:** N/A **Neurological:** (75%) showed improvement, but none of them resolved completely, the size of syrinx and the position of cerebellar tonsils remained unchanged after the untethering procedure **Adverse events**: Few patients did not experience any changes, and some had worsened conditions	Mild to moderate Chiari I malformation symptoms may respond to spinal cord untethering, but tethered cord release should not be the primary treatment for severely symptomatic Chiari I malformation, where alternative interventions like Chiari decompression or shunt revision may be needed to preserve neurological function and quality of life
Meyrat, 1993[357] N = 9 Switzerland	Surgical detethering The following surgical procedures have been performed: 6 laminectomies or hemilaminectomies and 3 osteopathic laminotomies with transection of filum in all patients, subtotal or total excision of a lipoma in 5 and excision of a bony spur in one patient with diastematomyelia; preoperative investigation included in all patients conventional x-ray of spine, magnetic resonance imaging, and in 6 patients a voiding cystourethrogram; urodynamic evaluation and anorectal manometry were performed in all patients preoperatively and 6 months after surgery	**Bladder:** Transitory clinical bladder dysfunction appeared in one patient. On the contrary, voiding disorders disappeared in one child as well as fecal disorders in another. Urodynamic and anorectal manometric findings remained pathological in those children. Two u **Neurological:** N/A **Adverse events**: Postoperatively, bladder dysfunction regressed in one child and fecal disorders in another	The use of urodynamic evaluation and anorectal manometry is advised as essential tools for early detection, monitoring, and management of bladder and anorectal neurogenic dysfunction in children with primary tethered cord, potentially guiding surgical decisions for asymptomatic patients and aiding in postoperative diagnosis, particularly for cord retethering

Morizawa, 2022[358] N = 62 Japan	Surgical detethering Sixty-two patients were enrolled in this study, the changes in urodynamics and voiding cystourethrogram parameters were compared before untethering surgery and 6 months after untethering surgery, these parameters were bladder volume, bladder deformity, vesicoureteral reflux during voiding cystourethrogram, detrusor overactivity, bladder compliance, and post-void residual volume in urodynamics	**Bladder:** Bladder volume during voiding cystourethrogram and bladder compliance increased significantly from 89.8 +/- 49.5 mL to 114.5 +/- 50.5 mL (P = 0.0069) and 10.2 +/- 6.2 mL/mmH2O to 17.0 +/- 13.3 mL/mmH2O (P = 0.0008), respectively, at 6-month follow-up. Six **Neurological:** N/A **Adverse events**: N/A	Untethering surgery is recommended for patients with filum lipoma, as it significantly improves bladder function and urodynamics
Mualem, 2023[359] N = 33 US	Surgical detethering Defining pre- and postoperative radiological parameters for assessment of surgical outcomes in tethered cord syndrome	**Bladder:** NR **Neurological:** NR **Adverse events**: Postoperative complications were observed in 6 patients (18.18%). The complications observed were wound infection in 3 patients (9.09%), CSF leak in 1 patient (3.03%), and new neurological deficits in 3 patients (9.09%)	In surgically treated patients with TCS, certain preoperative radiological parameters may be important in predicting postoperative surgical outcomes; these parameters can be evaluated and reported to indicate patients at high risk for complications. Further prospective multicenter research is warranted to offer robust evidence of association of patient outcomes with preoperative radiological parameters in TCS
Murakami, 2018[360] N = 3 Japan	Surgical detethering NR	**Bladder:** NR **Neurological:** Other patients were neurologically normal and continued to do well at follow-up **Adverse events**: Postoperatively, Case 1 had urinary infection several times and a tendency for constipation, indicating the existence of bladder and bowel dysfunction	The decision to cut the cord-like structure for untethering should be made with careful intraoperative neurophysiological monitoring

Mutah, 2014[361] N = 1 Other	Surgical detethering Patient was placed in a prone position with the head resting on a doughnut-shaped headrest; abdominal compression was prevented with foam rubber bolsters placed underneath chest and abdomen; under general anesthesia long midline incision following the spinous processes from L4 to S4 with a plain knife Hemostasis of the sub-dermal layers and other ensuing areas was achieved using a warm compression, aspiration and electro coagulation; a section of the fascia of the spinal muscles on the spinous crest of L4 followed by separation of the spinal muscles from the vertebral arches was done; laminectomy of L4 helped localize the normal dural margins; dura mater was linearly opened from L4 to S4 and suspended with silk sutures N°3/0; intraoperative observation was a cord fixed to subcutaneous tissue and a thick filum terminale extending to S1; neurosurgical microscope permitted to gradually detach the spinal cord from subcutaneous tissue and carefully free the spinal nerves; spinal cord was then re-inserted into the vertebral canal; sequential closure of dura mater with silk suture N° 5/0, repositioning of para-vertebral muscles with polylactine910 suture N° 3/0 and skin with polyamide 6 suture N°1	**Bladder:** A 12 months post-surgery, the patient could control defecation, and achieve proper micturition. **Neurological:** N/A **Adverse events**: Postoperative cerebrospinal fluid leakage without complicating infections occurred but was reinforced with sutures.	Following the surgical procedure, the patient observed a degree of improvement in bladder and bowel function

Nakanishi, 2013[119] N = 26 Japan	Surgical detethering During surgery, posterior displacement of the terminal filum was observed in the subarachnoid space. The cranial end of the terminal filum was drawn cranially and disappeared after sectioning in all cases. In 10 patients, the terminal filum was no more than 2 mm in diameter, and no fatty tissue was detected on MRI studies or on microscopic findings during surgery. In the other 4 patients, the terminal filum was larger than 2 mm in diameter and had associated fatty tissue. Sections were collected for histological evaluation in all cases, and the 14 samples were stained with H & E. Japanese Orthopedic Association (JOA) Scores were used to assess pain post-operatively in the patients. A full JOA score is 29 points: 9 points for 3 subjective symptoms, 6 points for 3 clinical signs, and 14 points for 7 activities of daily living and urinary bladder function. Patients were followed for 12 - 84 months.	**Bladder:** N/A **Neurological:** Improvements in the JOA score were observed at the final follow-up in all patients. The mean JOA score was 20.3 ± 3.0 (range 17–25) before surgery, and the score was improved significantly to 25.3 ± 3.1 (range 19–29) at the final follow-up ($p < 0.001$). **Adverse events**: N/A	Patients with occult tethered cord syndrome exhibit significant posterior positioning of the terminal filum and anterior positioning of the cauda equina on prone MRI, indicating a potential difference in elasticity between the two structures
Nazar, 1995[362] N = 32 US	Surgical detethering Section of the filum terminale was performed using the microscope through a single level laminotomy and a 5-mm dural opening	**Bladder:** Postoperatively, urological symptoms and urodynamic studies failed to improve in 1 patient (patient 29). This patient was not toilet trained and had had symptoms for 4 years. He also had a small thoracic spinal cord cavitation without other neurological s **Neurological:** NR **Adverse events**: NR	Postoperatively, the majority of patients (97%) experienced significant (>50%) relief of their symptoms

Nisheljeet, 2022[363] N = 28 Other	Surgical detethering NR	**Bladder:** The study revealed that 50% (n = 14) of the respondents who are in the age group <5 years old, underwent untethering surgery and subsequently had a significantly lower frequency of UTI compared to spina bifida individuals who are in the age group >5 years **Neurological:** NR **Adverse events**: NR	Spina bifida individuals may procure healthy bladder and bowel continence for the rest of their lives provided that neurosurgical and urological treatments were sought soon after birth and continues into adulthood
Ogiwara, 2012[158] N = 161 Japan	Surgical detethering Untethering was performed for symptoms in 126 patients (78.3%), and for prophylaxis in 35 patients (21.7%); included one level laminotomy at L4 or partial laminectomy of lower L3 and upper L4 in older patients; dura was incised and a filum terminale was identified by its pale color and midline location, surgical untethering was performed using a microscope; neurophysiologic intraoperative monitoring was used; filum was coagulated by bipolar and sectioned; dura was closed primarily using 4-0 Neurolon with interlocking; laminoplasty was performed using sutures after laminotomy or small bone particles were put back after laminectomy; the paraspinal muscles and the fascia were closed using 2-0 Surgilon, in addition, the fascia was sutured using 3-0 Surgilon, and 3-0 Prolene with “Figure of Eight” technique; the dermal layer was approximated using 4-0 or 3-0 PDS suture; the epidermal layer was sutured using 5-0 Ethilon; they all were kept lying flat for 8 days	**Bladder:** N/A **Neurological:** The untethering of a tethered spinal cord by transecting a fatty filum terminale is a relatively straightforward procedure that can prevent or ameliorate neurological symptoms **Adverse events**: No intra-operative complications were observed. None of the patients experienced a CSF leak postoperatively; postoperative MRI demonstrated pseudomeningocele, a fluid collection outside the limits of the dura and within the soft tissues, in 0.6% of patient; no patients developed wound infection; one patient (0.6%) experienced retethering of the filum; the overall complication rate was 1.2%; no specific outcomes partitioned out for prophylaxis vs symptoms group	Maintaining patients in a flat position for an extended duration following the transection of a tight filum terminale appears to reduce the incidence of cerebrospinal fluid leakage and pseudomeningocele formation; no specific author conclusions about prophylaxis just a mention that recently surgical untethering of a tight filum for prophylaxis has also been advocated and performed and there is ongoing debate of prophylactic surgeries for tethered cord

Ohe, 2000[364] N = 8 Japan	Surgical detethering In detail, radical operations were performed for lipomeningocele between 1 day and 15 months (mean 3 months) after birth, for meningomyelocele between less than 1 day and 2 months after birth (mean 4 days), and for meningocele on the day of birth	**Bladder:** Six (75%) of the 8 patients had some measure of improvement; tests of bladder function showed that bladder compliance was improved objectively in 2 (29%) of 7 cases (cases 1 and 2). Subjectively, stress incontinence disappeared in case 1, and uresthesia h **Neurological:** Concerning motor and sensory function, all (100%) 5 cases with progressive spasticity (cases 2, 7 and 8) and/or pain in the legs (cases 3, 5 and 8) revealed improvement soon after untethering. Neurological worsening was not seen after the operation in any of these patients. Comparison of the SBNS estimates of neurological status before and after surgery revealed that the motor, sensory or bowel/bladder score was graded up by 1–2 points after surgery in 4 cases (cases 1, 2, 3 and 7). **Adverse events**: There were no significant complications of dural patching with silicone rubber sheeting, although subcutaneous CSF leakages were temporarily seen in 2 cases	Early untethering is highly recommended for secondary tethered cord syndrome and suggests the use of silicone rubber sheeting as a dural substitute to prevent spinal cord adhesion based on their satisfactory operative outcomes and minor complications
Ohhara, 1980[365] N = 2 Japan	Surgical detethering Laminectomy (patient 1) and removal of lipoma (patient 2)	**Bladder:** NR **Neurological:** Symptom free (patient 1) and fair condition (patient 2) **Adverse events**: NR	NR
Oi, 1990[366] N = 100 Japan	Surgical detethering	**Bladder:** Bladder dysfunction showed subsequent improvement. **Neurological:** Pain and motor function improved, with no neurological deterioration observed. **Adverse events**: In some cases, the degree of motor impairment stayed the same.	Post-surgery MRI elongation of the spinal cord in myeloschisis patients, indicated by a low-placed conus medullaris, doesn't always signal a functional issue like tethered cord syndrome. While abnormal conus medullaris placement is common, only more severe cases might cause future neurological decline. Additionally, late onset progressive neurological deterioration in patients after lipomeningocele repair may stem from mass effects rather than being directly associated with tethered cord syndrome.

Pang, 1982[367] N = 22 US	Surgical detethering NR	**Bladder:** Sphincter dysfunction improved in 5 of 13 patients **Neurological:** Sensorimotor deficits improved in 10 of 15 patients **Adverse events**: One death due to meningitis related to CSF leak	The surgical outcome was gratifying in relation to pain and motor weakness but disappointing in the resolution of bowel and bladder dysfunction. Early diagnosis and adequate release of the tethered conus are the keys to successful management
Pastuka, 2022[159] N = 1 Other	Surgical detethering Fetoscopic repair: laparotomy with lower-segment transverse incision was performed and the uterus was exteriorized, ultrasound was used to determine the exact position of the placenta on the anterior wall; the 3.5 mm ports were inserted into the uterus using the Belfort technique, with our own modifications; the optical port was inserted through all layers of the uterine wall, including the amniotic membrane, and secured with two opposing sutures; the same technique was used for the two surgical ports; adiode laser beam was used to separate the muscle (2 mm length), up to the level of the amniotic membrane; humidified CO2 heated to 37.7 C was infused into the amniotic cavity while the amniotic fluid was gradually removed; adequate pressure inside the amniotic cavity was maintained using carbon dioxide insufflation (0.6 L/min; range: 12–15 mm Hg) to prevent uterine contractility	**Bladder:** At 12 month post-delivery, micturition diary revealed signs of urinary retention (10–40 mL of residual urine). To date, the child has made no attempts at controlled micturition. A urodynamic test revealed a neurogenic bladder of normal volume, and unstabl **Neurological:** Neurological examination at 11 months postdelivery revealed: head circumference of 43.5 cm, closing frontal fontanelle, cranial nerves without any signs of damage, axial hypotonia, decreased muscle tone in the lower extremities, tendon reflexes present apart from ankle reflexes, absent pathological reflexes. Psychomotor development of the child is slightly retarded. Ultrasound test of the bifid spine revealed a mobile medullary cone, positioned at L3. No clinical signs of tethering were observed. **Adverse events**: N/A	Prenatal open spina bifida repair using the fetoscopic approach to insert the ports into the exteriorized maternal uterus may be an effective method of treating myelomeningocele
Phi, 2004[368] N = 16 Korea	Surgical detethering Patients received surgical detethering of the spinal cord shortly after diagnosis, with follow-up periods ranging from 3 to 123 months	**Bladder:** N/A **Neurological:** Some patients experienced neurological improvements while others showed deterioration **Adverse events**: CSF leakage, new-onset hypesthesia, new-onset low back pain, and retethering	Adult Tethered Cord Syndrome presents diversely, with surgery halting neurological worsening in many cases, yet symptomatic and functional improvements are limited, influenced by factors such as delayed diagnosis and complex conditions

Phuong, 2002[369] N = 45 US	Surgical detethering Contracture release after meingomyelocele repair	**Bladder:** N/A **Neurological:** N/A **Adverse events**: 88% of patients required one or more operation from 1-9 years later (mean 3.5 years)	The results strongly support considering an untethering procedure in patients with repaired meningomyelocele at the onset of symptoms of tethered cord
Pierz, 2000[370] N = 21 US	Surgical detethering NR	**Bladder:** NR **Neurological:** Postoperatively, 20 patients remained unchanged; however, one patient developed a loss of two motor levels after the detethering procedure. Despite immediate reexploration, no source for this complication was identified **Adverse events**: The detethering procedures resulted in eight complications in six patients. Anaphylactic reactions occurred in three cases before the discovery of the association between latex allergies and myelodysplasia. One patient developed an immediate postoperative loss of two functional neurological levels that was initially thought to be owing to subdural hemorrhage. Immediate surgical reexploration failed to identify a Cause, and preoperative function was not regained. One patient had an associated cerebral spinal fluid leak postoperatively that was treated surgically. One patient had a transfusion reaction, and two had postoperative wound infections. One infection occurred in a patient treated at an outside institution, and the other occurred as a deep dural graft infection that required surgical removal of the graft	While patients with scoliosis curves of less than 40 degrees may experience some improvement following a detethering procedure, those with curves exceeding 40 degrees or involving thoracic neurologic levels do not show any scoliosis improvement

Poonia, 2016[371] N = 169 US	Surgical detethering This was a single-center retrospective review of all children who underwent release of a spinal cord–tethering lesion that was not associated with a substantial fascial or dural defect (i.e., simple spinal cord detethering) during 2 epochs: prior to and following the institution of a protocol for discharge on postoperative day one; outcomes included the need for and timing of nonroutine care of the surgical site, including return to the operating room, wound suturing, and nonsurgical evaluation and management	**Bladder:** 15.0% required hospitalization for longer than 2 days after surgery. None had a wound-related complication identified on postoperative day 1 or 2. The most common reasons for prolonged inpatient stays included constipation (n = 5) and urinary retention (n **Neurological:** N/A **Adverse events**: N/A	Shortening the inpatient monitoring period after tethered spinal cord surgery does not increase the risk of complications, with a reoperation rate similar to longer recumbency periods
Prabhu, 1995[372] N = 2 US	Surgical detethering Detethering operation	**Bladder:** N/A **Neurological:** Pain was no longer present after surgery. **Adverse events**: N/A	Patients performed a "heels over head" maneuver to eliminate the liyperlordosis and obtained symptomatic relief before surgery

Proctor, 2001[139] N = 16 US	Surgical detethering The goal of surgery was removal of the fibrous or bone septum, resection of any other local spinal cord attachments causing tethering, and exploration for associated tethering-related anomalies such as dorsal tethering bands or thick filum, which can be seen in the majority of patients. Following the detethering procedure, the dura was closed posteriorly with or without placement of a patch graft, whereas anterior dural defects were left open. The patients were kept flat postoperatively for an average period of 72 hours and were then allowed to progressively advanced to full activity levels	**Bladder:** NR **Neurological:** NR **Adverse events**: There was only one early surgery-related complication: one patient developed a cerebrospinal fluid leak that required wound reexploration on postoperative Day 10. No source for the leak was found, and the patient recovered uneventfully with bedrest. This patient went on to make an excellent recovery with complete resolution of preoperative symptoms. Late surgery-related complications were relatively rare as well. Two patients have required a second operation for retethering. One of the patients experienced symptomatic back and leg pain and required reexploration 4 years after her first surgery. Of note, this patient harbored a complex intradural lipoma, which makes the case unique in this series. At the second surgery, dense arachnoid adhesions were found and surgically released. Now 6 years postsurgery, the patient is once again experiencing worsening back pain. A third exploration for tethering is being considered, although the source of the pain is unclear; she also has progressive scoliosis, which will require spinal fusion. One other patient in the series in whom surgery was previously performed by the senior author in 1979, presented 8 years later (during the study period) with tethered cord syndrome that required reoperation. She has done well since the second operation, which was 13 years ago. At this point, three of the patients have required spinal fusion for progressive scoliosis after the initial detethering surgery. This is not necessarily a failure of the surgery and can be related to progression of the preexisting scoliosis caused by underlying VB anomalies. A fourth patient is experiencing progressive L1–2 kyphosis 11 years after surgery. She has no clinical or MR imaging evidence of retethering, but at age 13 will	Patients with spinal cord meningeal cysts typically tolerate surgery well with few complications, experiencing rare neurological deterioration, but in cases of retethering, intervention is needed. Although surgery stabilizes or improves bowel and bladder function and relieves pain, preexisting vertebral column deformities often progress, necessitating spinal fusion in most cases. Urodynamic studies is effective in patients to assess spinal cord dysfunction, guide surgical decisions, aid in perioperative management.

		probably require spinal fusion. Another patient, mentioned above because of the need for a second detethering procedure, may also need spinal fusion. All patients with subsequent deformity of the spine had initially presented as infants or toddlers for their surgery, and this complication was not seen in the adult-onset patients in whom the skeleton was mature.	
Pusat, 2017[373] N = 30 Turkey	Surgical detethering Section of the fibrous bands, removal of bony septums, and cutting the filum terminale (FT) were the surgical techniques for TCS patients.	**Bladder:** N/A **Neurological:** There was no neurological deterioration in any patient after surgery **Adverse events**: N/A	Electrophysiological studies, specifically somatosensory evoked potentials, can offer valuable insights for surgical decision-making in tethered cord syndrome and spinal intradural tumors patients, but the author recommends further clinical studies with different electrophysiological modalities to gain a more comprehensive understanding of the effects of surgery in these cases.
Quinsey, 2018[374] N = 8 US	Surgical detethering Surgery for tethered cord release and/or neurofibromatosis types 1 and 2 in pediatric neurosurgical patients	**Bladder:** Of the 5 patients who presented with urinary dysfunction, 3 experienced complete resolution of their symptoms, and 1 reported improved symptoms. The patient who had a large bladder capacity without contraction based on urodynamic testing did not report im **Neurological:** Tethered cord symptoms improved to various degrees: 3/8 patients experienced complete resolution of their back pain and lower-extremity symptoms, and 5/8 reported improvement in their symptoms; 1 patient who presented with new ankle clonus and hyperreflexia experienced resolution of these symptoms. **Adverse events**: N/A	Surgical detethering has a positive impact on patients with tethered cord syndrome

Rajpal, 2007[375] N = 61 US	Surgical detethering The authors studied the medical records of 61 adult patients who underwent surgical untethering for spina bifida occulta at three institutions between 1994 and 2003; patients who had undergone prior myelomeningocele repair or tethered cord release surgery were excluded; the most common intraoperative findings were lipomyelomeningocele (41%) and a tight terminal filum (36%); the follow-up duration ranged from 10.8 to 149.5 months	**Bladder:** Within the group of 21 patients with bowel and/or bladder dysfunction, 13 (62%) improved, six (29%) remained unchanged, one (5%) worsened, and one (5%) experienced initial improvement but a late recurrence. **Neurological:** N/A **Adverse events**: Surgical complications included three wound infections, one cerebrospinal fluid leak, and two pseudomeningoceles requiring surgical revision. One patient developed acute respiratory distress syndrome and sepsis postoperatively and died several days later	Surgery carries a relatively low risk and offers the potential for neurological improvement or stabilization

Rakip, 2022[376] N = 54 Turkey	Surgical detethering All patients were treated following standard surgical principles. Surgical treatment was aimed at primary spinal malformation, and surgery was performed upward from the most caudal area of the cord. This rule did not apply to diastematomyelia. Under general anesthesia and intraoperative neurophysiological monitoring (IONM), patients were positioned prone. Midline intrusion was performed at the S1 to S2 level. After the paraspinal muscles were sequenced, a laminectomy was performed using a high-speed drill or Kerrison's rongeur. The ligamentum flavum and adipose tissue were then removed. The microscope was placed in the operation area. The dura mater was opened from the midline and fixed to the paravertebral muscles with sutures. After exposing all the nerve roots, filum terminale, and arachnoid bands, the filum terminale was selected using IONM. The filum terminale contains large vessels, is whitish, and looks lighter than roots. The IONM probe was used to determine whether the tissue was neural, as this helped avoid cutting one of the roots instead of the tense filum terminale. The roots were pulled back sideways, and the filum terminale was cut. All connective tissues and the conus medullaris connected to the caudal part of the spinal cord were released. After hemostasis was achieved watertight, duraplasty was performed using 5.0 sutures. Using fibrin adhesive products, anatomical layers are	**Bladder:** Compared with the preoperative period, 70, 70, and 54.5% of the patients with the aforementioned disorders showed functional improvement in motor, sensory, and urinary functions, respectively. Following surgery, 85.7, 83.3, and 50% of patients in group 2 **Neurological:** Compared with the preoperative period, 70, 70, and 54.5% of the patients with the aforementioned disorders showed functional improvement in motor, sensory, and urinary functions, respectively. Following surgery, 85.7, 83.3, and 50% of patients in group 2 experienced functional improvements in motor, sensory, and urinal functions, respectively **Adverse events**: CSF fistula, wound infection	Due to the greater occurrence of other congenital spinal anomalies accompanying TCS, both preoperative symptoms and clinical findings are more severe in the pediatric group than in the adult group, and postoperative results may be more negative.

	tightly closed. If accompanied by diastematomyelia, the bone septum or fibrous band were resected before the untethering procedure.		
Reigel, 1994[377] N = 262 US	Surgical detethering Patients records who underwent spinal cord release were reviewed for sex, age at first primary myelomeningocoele repair, functional level of lesion, age at the time of operation, and operative findings; patients were followed for 1-20 years	**Bladder:** NR **Neurological:** NR **Adverse events**: Progression of scoliosis plateaued or declined following release of tethered cord in patients with lumbar and sacral level lesions, however, tether release did not halt the progression of scoliosis in the thoracic level group; tethered cord release alter the course of lordosis in L1 through L3 level lesions, but had little effect on the normal progression of lordosis in patients with L4, L5, or sacral level lesions; tethered spinal cord appears to be associated with a decrease in incidence and magnitude of kyphosis	Tethered spinal cord release is beneficial for controlling scoliosis in patients with lumbar and sacral function levels but has little impact on thoracic levels, and the intervention appears associated with a decrease in the incidence and magnitude of kyphosis
Robbins, 2015[378] N = 7 US	Surgical detethering All of the laminectomy procedures for filum detethering were performed without preoperative or intraoperative neurophysiologic monitoring, as is routine at this institution for uncomplicated filum detethering.	**Bladder:** Symptoms resolved in 3 of 4 patients **Neurological:** Symptoms resolved in only patient with neurological issues **Adverse events**: N/A	Surgical detethering is recommended as a viable intervention for perineal pain or hypersensitivity in tethered cord syndrome patients when this symptom is present in conjunction with other suggestive symptoms, as it can lead to a favorable outcome and pain relief

Romagna, 2013[379] N = 27 Germany	Surgical detethering Indications for surgery comprised radiologically proven congenital tethering of the spinal cord with or without concomitant lipomas or filum terminale lipoma, consistently combined with new or worsening symptoms (e.g. pain, sensorimotor deficits or insufficient bladder control). Applied surgical approaches were laminotomy in 16 cases, extended fenestrations in three cases, laminoplasty in one case, relaminectomies in five cases, and two patients with spinal dysraphic conditions did not require removal of bony structures. Standard microsurgical techniques consisted in sectioning the filum terminale, its neighboring vessel and dissecting additional tethering adhesions if present. Lipoma resection was performed in a microsurgical piecemeal fashion, occasionally the Cavitron Ultrasonic Surgical Aspirator (CUSA) was used, especially for central debulking of the lipoma. This debulking was aided by continuous electrophysiological neuromonitoring with somatosensory evoked potentials (SSEP), combined with motor evoked potentials (MEP) and electromyogram with direct nerve root stimulation of the lower limb muscles and the anal sphincter as described in Krassioukov et al	**Bladder:** 18/27 patients (66.7 %) showed a minimal persistence of preoperative symptoms, while abnormal findings were unchanged or improved (Odom's score: "good"). Moreover, 5/27 patients (18.5 %) had a relief of all preoperative symptoms, especially regarding pain **Neurological:** 18/27 patients (66.7 %) showed a minimal persistence of preoperative symptoms, while abnormal findings were unchanged or improved (Odom's score: "good"). Moreover, 5/27 patients (18.5 %) had a relief of all preoperative symptoms, especially regarding pain and abnormal findings improved (Odom's score: "excellent"). Finally, 2/27 patients (7.4 %) reported a definite relief of some preoperative symptoms and other symptoms unchanged or slightly improved (Odom's score: "fair"), while 2/27 patients (7.4 %) had unchanged/exacerbated symptoms especially regarding urinary dysfunction (Odom's score: "poor"). **Adverse events**: NR	Adult patients with symptomatic tethered cord syndrome benefit from detethering, particularly in terms of alleviating lower back and radicular pain
Rotenstein, 1996[380] N = 13 US	Surgical detethering Tethered spinal cord release	**Bladder:** N/A **Neurological:** N/A **Adverse events**: Tethered spinal cord influences the growth rate of children with myelomeningocele.	Tethered cord release has a positive impact on neuro-orthopedic changes and may also influence growth patterns

Saha, 2020[381] N = 32 India	Surgical detethering Between 2003 and 2017, surgical intervention in 32 adult patients with tethered cord syndrome was performed at Park Clinic, Kolkata; the mean duration of follow-up was 3.2 years	**Bladder:** 17 patients presented with bladder symptoms and 24% saw improvement in bladder symptoms post-operatively **Neurological:** 70% of patients saw improvement in motor deficits and 39% of patients saw improvement in sensory deficits; Neurological improvement, either motor or sensory improvement, was found in 11 of the 15 who underwent neuromonitoring; In the group that had undergone surgery without neuromonitoring, only 7 out of the 17 improved **Adverse events**: N/A	Surgery is recommended for tethered cord syndrome as it significantly reduces pain through untethering and corrects spinal deformities, with some improvement in sensory and sphincter issues, while highlighting the importance of neuromonitoring for better outcomes
Sala, 2013[112] N = 47 Italy	Surgical detethering Neurophysiological mapping of the conus-cauda is performed through direct stimulation of these structures and bilateral recording from segmental target muscles	**Bladder:** 26 patients experienced bladder/anal dysfunction postoperatively (12 improved, 12 stabilized, and 2 worsened) **Neurological:** Postoperatively, 21 patients had motor impairments (11 improved, 9 stabilized, and 1 worsened); 12 patients had sensory impairments (4 improved, 7 stabilized, and 1 worsened); 2 patients had back/leg pain or sciatica (2 improved) **Adverse events**: Two out of 47 patients presented a transient neurological worsening; In six patients, an unexpected muscle response was evoked by stimulating tissue macroscopically considered as not functional	The use of intraoperative neurophysiology, particularly mapping techniques and MEP/BCR monitoring, is recommended, in pediatric tethered cord surgery, as they help identify and spare functional neural tissue, potentially leading to modifications in surgical strategy and improved neurological outcomes
Sarwark, 1996[382] N = 59 US	Surgical detethering All patients underwent a complete urological evaluation, including urodynamic study; surgical detethering operations were not described	**Bladder:** N/A **Neurological:** Several patients in the study demonstrated notable improvements in back pain, scoliosis angle, motor function, and spasticity **Adverse events**: A total of 12 patients experienced worsened progressive scoliosis, nine patients showed no improvement in spasticity, while three patients exhibited no improvement in motor function, Additionally, four patients had retethering	Tethered cord release in symptomatic low lumbar and sacral level children with myelomeningocele appears to benefit, especially regarding stabilization of scoliosis in selected patients, back pain at the site of closure, and prior decline in motor function. Results in the cases with spasticity were more equivocal

Sarwark, 1997[383] N = 33 US	Surgical detethering	**Bladder:** N/A **Neurological:** There was an 82.4% improvement rate in scoliosis for patients with preoperative curves of 45° or less, alongside improvements in spasticity, motor function, and the resolution of pain **Adverse events**: Some conditions showed no improvement, while others exhibited a worsening status	This study highlights the effectiveness of tethered spinal cord release in children with myelomeningocele, showing significant benefits in managing scoliosis and improving back pain, without worsening neurological symptoms. Specifically, 75% of patients saw stabilization or improvement in scoliosis within the first year, and those with preoperative curves of 45° or less had an 82.4% improvement rate.
Satar, 1995[140] N = 21 US	Surgical detethering Of the 21 patients, 19 underwent detethering surgery	**Bladder:** Urodynamic findings improved in 16% and remained unchanged in 68% and worsened in 26%. **Neurological:** Neurological examination improved in 6% and remained unchanged in 95%. **Adverse events**: N/A	Older children and adults with occult spinal dysraphism are at a higher risk of presenting with irreversible urological and neurological issues
Seki, 2016[162] N = 31 Japan	Surgical detethering Surgical untethering with a period of 116 months of median follow-up	**Bladder:** In the univariate analysis, the presence/absence of preoperative bowel bladder dysfunction, and symptoms were strongly associated with the risk of children and adolescents with TCS ($p<0.05$) **Neurological:** Among the symptomatic patients, 10.5% experienced improvement in preoperative deficits after surgery, and 89.5% remained stable, and in the group of asymptomatic patients, 8.3% experienced worsened symptoms after surgery, while 11.7% remained stable, there was also a significant difference between the two groups at the final follow-up ($p<0.01$) **Adverse events**: Some patients experienced sensory disturbances	Prophylactic surgery is recommended for asymptomatic tethered cord syndrome in patients aged <34 months or as soon as possible, based on the findings, which showed a significant improvement in neurological prognosis with this approach and emphasized the importance of careful follow-up for prompt reintervention in deteriorating cases

Selcuki, 2000[384] N = 77 Turkey	Surgical detethering Of these, 17 patients in whom the filum terminale was cut to detether the conus medullaris had NLCM and normal thickness filum terminale (NTFT), and these constituted the first group, namely the primary tethered cord group. The remaining 60 patients, who underwent surgery because of secondary tethered cord, constituted the second group and had a conus level below the L1–2 disc space	**Bladder:** Primary TCS: In group 1 there were 10 patients (58.8%) with a good outcome (SBJ+OBJ+), 3 (17.6%) with a fair outcome (SBJ+,OBJ–), and 4 (23.5%) with a poor outcome (SBJ–OBJ–). Secondary TCS: According to the urodynamic studies, there were 10 patients (28 **Neurological:** NR **Adverse events**: While there was no mortality in either group, 3 patients (5%) had complications affecting the incision for which medical treatment was required	Patients should be considered for untethering surgery after establishing common multidisciplinary concepts and conducting team studies to evaluate and select tethered cord cases
Selcuki, 2014[385] N = 56 Turkey	Surgical detethering Patients with tethered cord secondary to various developmental lesions, maximum effort was made to release the spinal cord with sharp dissection; patients with split cord malformation, the bony septum and the dural sheath were removed; patients with a fatty filum terminale, the fila terminalia were cut; an intraoperative neurostimulator was used to identify the roots to be preserved; the mean duration of follow-up was 10 months 27 days	**Bladder:** Neurogenic bladder was detected in 56.25% patients, hydronephrosis and detrusor sphincter dyssynergia in 6% of patient. **Neurological:** N/A **Adverse events**: 1 patient died in the postoperative first day due to pulmonary embolism.	The author suggests that tethered cord syndrome may warrant treatment in the elderly, even in the absence of a low-lying conus and thick filum
Selcuki, 2018[386] N = 7 Turkey	Surgical detethering A standard L5 total laminectomy, and an intradural untethering operation were conducted using a surgical microscope to cut the filum terminale, a structure within the spinal cord, with neuromonitoring was also carried out during the surgery to ensure the safety of the procedure for 21 months and 28 days following up	**Bladder:** N/A **Neurological:** Patients reported relief from various neurological symptoms, including headaches, leg pain, leg numbness, scoliosis, suboccipital headaches, arm numbness, as well as weakness **Adverse events**: N/A	Untethering procedure should be considered in patients with symptomatic Chiari malformation Type I who show abnormalities in somatosensory evoked potentials even if they have normal lumbar MRI findings and no tethered cord syndrome symptoms

Selden, 2006[387] N = 5 US	Surgical detethering In the prone position, after induction of general endotracheal anesthesia, and with a Foley catheter in place, each patient underwent sectioning of the terminal filum. A bilateral superiosteal approach was undertaken along a single, midlumbar spinous process and lamina. A high-speed drill with footplate was used to perform a total single-level laminoplasty. The interspinous ligament at the caudal end of the exposure was sectioned sharply and the lamina swung away from the underlying dura mater. Under microscopic magnification, a 5-mm durotomy was made and the terminal filum was gently lifted up to the plane of the dura and over a red vessel loop of standard caliber. Before sectioning, a digital photomicrograph of the terminal filum and vessel loop was obtained. The terminal filum was cauterized and divided, and a small tissue specimen was sent for permanent pathological evaluation. The dura was closed in watertight fashion, the laminoplasty segment was secured anatomically with suture, and soft-tissue closure was performed in layers. Patients were positioned horizontally and received nursing care on a general care floor. Two days later, the Foley catheter was removed, and the patients were mobilized. On the afternoon of the 2nd postoperative day, following ultrasonographic confirmation of adequate bladder emptying, the patients were discharged.	**Bladder:** Voiding dysfunction improve- ment was characterized as mild in two patients and moderate to marked in four. In the four patients whose preoperative complaints included voiding and lower-extremity dysfunction or pain, lower-extremity improvement was more p **Neurological:** NR **Adverse events**: There were no operative or perioperative complications. No patient suffered from aseptic meningitis, pseudomeningocele, or other delayed complications	Significant improvement in voiding dysfunction can be achieved through surgical lysis of the terminal filum in children with normal lumbosacral spines

Sharif, 1997[388] N = 33 Other	Surgical detethering Surgical untethering with mean of 15 - 20 months of follow up after surgery	**Bladder:** Bladder function improved **Neurological:** Symptoms associated with tethered cord syndrome improved, including enhancements in sensation, bladder function, and gait **Adverse events**: One of the participants had cerebrospinal fluid leakage and required surgery to repair	Tethered cord release can lead to either improvement or the arrest of the progression of neurological deterioration, suggesting the potential benefit of the intervention
Shields, 2019[389] N = 1 US	Surgical detethering N/A	**Bladder:** Second urodynamic study (UDS) conducted 4 months after surgery revealed poor bladder compliance but no vesicoureteral reflux **Neurological:** N/A **Adverse events**: N/A	The author recommends close collaboration between pediatricians, pediatric urologists, and pediatric neurosurgeons for early diagnosis and management of tethered cord syndrome in children presenting with suspicious cutaneous manifestations or associated abnormalities, emphasizing the need for spinal ultrasound or lumbar MRI in high suspicion cases
Shields, 2022[390] N = 1 US	Surgical detethering N/A	**Bladder:** N/A **Neurological:** Four years postoperatively, the lower extremity weakness persisted along with the in-toeing gait which was attributed to femoral anteversion. The patient underwent a right subtalar arthrodesis with tendon transfer. She continued to walk with a limp, and her feet were still weak bilaterally, both of which had been present since before the TCR without any improvement. When the patient was 20 years old, EDX studies of the lower extremities were requested. On exam, weakness of both lower extremities was noted, primarily of flexion and extension of the toes. There was also weakness of the dorsiflexors of the ankles and plantar flexors. Patellar and Achilles DTRs were absent bilaterally. Pinprick sensation was decreased in the dorsal and plantar aspects of the feet bilaterally. The upper extremities showed normal muscle strength and sensations; deep tendon reflexes could not be elicited **Adverse events**: N/A	Patients with Charcot-Marie-Tooth disease and tethered cord syndrome benefit from tethered cord release surgery

Shinjo, 2019[391] N = 22 Japan	Surgical detethering NR	**Bladder:** We observed newly diagnosed postoperative urinary dysfunction in one patient (Case No. 6) and exacerbation of pre-existing urinary dysfunction in two patients (Case No. 4 and 22) **Neurological:** NR **Adverse events**: NR	BCR monitoring during untethering surgery in infants and children under general anesthesia was found to be a feasible method to prevent postoperative urinary and bowel dysfunction.
Shukla, 2018[392] N = 20 India	Surgical detethering N/A	**Bladder:** Of the 13 patients with motor complaints, 6 (56.2%) patients showed improvement of at least 1 MRC grade and in remaining 7 patients (53.8%) power remained stable after surgery. **Neurological:** Of the 13 patients with motor complaints, 6 (56.2%) patients showed improvement of at least 1 MRC grade and in remaining 7 patients (53.8%) power remained stable after surgery. **Adverse events**: Complications of surgery were cerebrospinal fluid (CSF) leak (n = 3, 15%) and wound infection in 1 (5%). Two patients (10.0%) had pseudomeningoceles, while one patient (5.0%) had active CSF leakage from the wound. Barring the last patient who required lumboperitoneal shunt, all were managed conservatively.	Surgical untethering is recommended for all symptomatic adult Tethered Cord Syndrome patients due to the substantial improvement in symptoms and the low risk of complications associated with the procedure.
Shweikeh, 2015[393] N = 7397 US	Surgical detethering N/A	**Bladder:** N/A **Neurological:** N/A **Adverse events**: The average complication rate was 7.2%, a positive trend with increasing age. There were higher rates with increasing age among various complications including pseudomeningocele, urinary tract infection, pulmonary, procedure-related, and gastrointestinal.	It was concluded that older children with tethered cord syndrome tend to experience more complications, more extended hospital stays, non-routine discharges, and higher healthcare costs, strongly supporting the recommendation of surgery at a younger age for this condition
Sim, 2021[394] N = 82 Korea	Surgical detethering Transection of the filum was performed usually through hemilaminectomy at the level below the conus without foley insertion	**Bladder:** N/A **Neurological:** 79% showed symptom improvement. **Adverse events**: N/A	Transection of the filum is recommended as it results in excellent outcomes regarding preoperative syrinx and reveals interesting correlations between pathological findings and clinical features

Sofuoglu, 2017[395] N = 23 Turkey	Surgical detethering Patients are positioned in a prone orientation under general anesthesia with intraoperative neurophysiological monitoring, and a midline incision, guided by magnetic resonance imaging findings (e.g., extended from L4 to S1 for a conus medullaris at L5), is employed to access the spine; this process includes the dissection of muscles, and the surgical approach is adapted based on the spinal cord's extent, with an extension of laminectomy or laminotomy as needed, also an operative microscope is utilized to reveal nerve structures, including the filum terminale, and the mean follow-up period for patients was 75.6 ± 40.5 months	**Bladder:** Bladder and bowel functions improved **Neurological:** Improved leg and back pain, sensory disturbance, dysesthesias, motor weakness, and gait ataxia **Adverse events**: Cerebrospinal fluid leakage	Early surgery is recommended for symptomatic adult patients with tethered cord syndrome to prevent generally irreversible neurological deficits

Solmaz, 2011[396] N = 49 Turkey	Surgical detethering Patients are positioned prone under general anesthesia with supporting rolls on each side. The routine procedure is the L5 laminectomy, and additional partial or complete S1 laminectomy is added in order to expose the dura and then to identify FT. Laminotomy may also be selected for the exposure of the FT, especially in young children. In cases of spina bifida occulta, there is no need for laminectomy or laminotomy. Normally, the dural sac ends at the second sacral vertebra. In some circumstances, the spinal cord may continue until the S1 or S2 levels by giving some sacral rootlets, the laminectomy should be performed up to this level. The dura should be opened in the midline and tacked by four sutures bilaterally. Following the dural opening, FT, arachnoid bands, and rootlets should be first observed. Microsurgery with microinstruments should be used after the dural opening. FT is a fibrovascular tag containing a large vessel, which becomes smaller across its course in the lumbar subdural space. However, this vessel is not a reliable landmark FT because similar vessels can be found on the rootlets or no vessel may be seen on the FT. The most important issue at this time is the differentiation of the neural elements from extraneural structures. Rootlets and arachnoid bands are mostly confused by the surgeons. The rootlets at the sacral levels are directed to both sides and may be identified by their size and situation. The arachnoid bands are	**Bladder:** Urological disturbances improved in 2 (20%) of 10 patients **Neurological:** Neurological improvement was observed in 4 (44.4%) of 9 patients, while unchanged in the others **Adverse events**: No mortality or neurological deterioration was recorded	Spinal cord release with appropriate technique seems to be beneficial in maintaining neurological functioning in children with TCS

	attached to the dura and rootlets. Both of them are thin and white in color. The intraoperative electrophysiological monitoring may be useful for safe surgery, but in the absence of this assortment, good neuroanatomical knowledge is required to preserve the neural structures. The rootlets are retracted laterally by microdissector in order to cut the arachnoid adhesions by microscissors and to expose the FT. In most cases, FT is thicker than normal, violet in color and is attached to the dura posteriorly in the midline leaving barely no free subarachnoid space for cerebrospinal fluid (CSF) passage. FT is coagulated and cut after the identification. The practical way to assess the degree of tethering per-operatively is the immediate cranial movement of FT right after releasing. This sudden cranial movement of the superior-edge of FT resembles the movement of the string of a violin. In addition to sectioning the FT, all connective tissues attached to the caudal part of the spinal cord and CM should be released. FT and nerve roots must be free from the surrounding tissues. In cases of dermal sinus, the tracts may be attached to the FT or other fibrous bands, therefore, these structures should also be cut in order to release the spinal cord. Another useful measure of preventing re-tethering would be performing dura-plasty in order to create a potent space allowing passage of CSF between lumbosacral rootlets and dura matter. The only way to prevent a recurrence in a detethered cord is to be		

	certain that the neural elements remain free circumferentially with a patent CSF circulation.		
Son, 2019[397] N = 43 Korea	Surgical detethering All patients were diagnosed with tethered cord using magnetic resonance imaging and underwent subsequent untethering surgery by neurosurgeons at Severance Hospital in Seoul, South Korea; no other surgery details provided	**Bladder:** A total of 23.3% (10/43) of patients could perform normal voluntary self- voiding without medication. The proportion of patients taking alpha-adrenergic receptor antagonists for treatment of detrusor sphincter dyssynergia or poor bladder neck opening15 wa **Neurological:** N/A **Adverse events**: N/A	Enuresis is common in adult primary tethered cord syndrome without noticeable neurological symptoms, and bladder conditions vary based on symptom onset, emphasizing the need for early recognition and proper management due to the potential for misdiagnosis
Stavrinou, 2010[398] N = 20 Germany	Surgical detethering Surgery was performed under continuous intraoperative neurophysiological monitoring with somatosensory evoked potentials coupled with motor evoked potentials, as well as direct nerve root stimulation of the lower limb muscles and the anal sphincter	**Bladder:** 80% of patients presented with urological dysfunction **Neurological:** Caudal traction of the spinal cord results in an impairment of spinal cord blood flow, the degree and duration of which directly correlates with the severity and permanency of the neurological deficits; Neurological deficits that are encountered in patients with neural tube defects should be related to secondary damage, such as amnion fluid toxicity, contractions, labor, etc. **Adverse events**: N/A	Surgical intervention is recommended for patients with open spinal dysraphism, and closed spinal dysraphism after a thorough multidisciplinary evaluation and by an experienced neurosurgeon to improve pain, neurological function, and urodynamics

Stenimahitis, 2022[399] N = 17 US	Surgical detethering Patients were evaluated for tethered cord syndrome based on a detailed neurological examination and magnetic resonance imaging verification of spinal cord injury; surgery involved a posterior midline approach with laminectomy, untethering, expansion duraplasty, and tenting; in some cases, syringo-subarachnoid shunts or fenestration were considered; neurophysiological monitoring was applied in some cases; patients were discharged to a rehabilitation facility following surgery; follow-up included postoperative magnetic resonance imaging and clinical examinations; median follow-up time was 5.1 (0.7–13) years	**Bladder:** N/A **Neurological:** Surgical untethering showed satisfactory results for motor symptoms in 92% (11 of 12), sensory loss in 100% (9 of 9), spasticity in 100% (9 of 9), gait disturbance in 100% (4 of 4) and pain in 86% (6 of 7). In addition, paired testing showed that there was also a significant improvement in motor deficit (p = 0.031) and PS status (p = 0.004) following surgery. In total, 15 patients (88%) showed satisfactory results following untethering surgery, defined as improvement or halted progression of one or more of the presenting signs or symptoms. **Adverse events**: Four postoperative complications were reported, including three cases of cerebrospinal fluid leakage and one case of postoperative hematoma requiring acute surgery. Two patients had a negative surgical outcome. One of these was a patient with satisfactory radiological results but unchanged motor function and increased neck pain. The other was the patient who developed a postoperative hematoma requiring emergency surgery, resulting in increased left arm weakness.	Surgical treatment of PSCT resulted in improved neurological function or halted neurological deterioration in the vast majority of patients
Stolke, 1988[400] N = 26 Germany	Surgical detethering Resecting the thickened filum terminale, techniques like carbon dioxide laser and cavitron ultrasonic surgical aspirator are used for dissection and reduction, but radical excision is avoided to preserve essential neural elements	**Bladder:** In three cases, only the bladder and bowel impairment disappeared, while in two older children, subjective improvement in symptoms was reported **Neurological:** There was no postoperative neurological deterioration in any patient, and seven cases showed improvement, also preoperative muscle atrophies, disturbances of tendon reflexes, and foot deformities could not be improved **Adverse events**: There were no deaths, and there were no post-operative complications	Early surgical intervention is recommended as it can potentially prevent symptom-free patients from developing neurological deficits

Sun, 2018[401] N = 120 China	Surgical detethering N/A	**Bladder:** Primary detethering: Comparable improvement was obtained for paresthesia (24.4%), motor deficit (18.6%), bladder dysfunction (12.6%), and bowel dysfunction (21.2%). However, almost one-half (41.2%-47.4%) of the patients reported no improvement after untet **Neurological:** Primary detethering: Comparable improvement was obtained for paresthesia (24.4%), motor deficit (18.6%), bladder dysfunction (12.6%), and bowel dysfunction (21.2%). However, almost one-half (41.2%-47.4%) of the patients reported no improvement after untethering surgery. Moreover, 23.3%-40.2% of patients experienced deterioration, with motor deficit (40.2%) and bladder dysfunction (40.0%) the most frequent symptoms. Revision detethering: The results demonstrated that improvement could be acquired, with 13.3% improvement in pain, 18.8% in paresthesia, 11.8% in motor deficit, none in bladder dysfunction, and 5.9% in bowel dysfunction. Nonetheless, most patients (58.8%-70.6%) were no better off after the revision surgery. Moreover, the revision untethering was associated with risk of deterioration, with rates of deterioration of 31.3% for bladder dysfunction, 35.3% for bowel dysfunction, 20.0% for pain, 18.8% for paresthesia, and 17.7% for motor deficit. **Adverse events**: N/A	The untethering surgery for tethered cord syndrome should be approached cautiously, as its effectiveness varies for different symptoms, and recommends further exploration of indications and timing, considering conservative treatment and comprehensive care as an alternative for some patients, particularly those with recurrent symptoms.

Sysoev, 2016[402] N = 21 Russia	Surgical detethering The study included 21 tethered cord patients aged 1 to 14 years who underwent tethered cord release; the preoperative and postoperative data of clinical and neurophysiological examination, and high field magnetic resonance imaging tractography of the caudal spinal cord were compared	**Bladder:** N/A **Neurological:** Coarse neurological deficit during tract interruption, based on MRI tractography data, suggests irreversible structural damage of the spinal cord, including structures of the propriospinal system **Adverse events**: In patients with secondary spinal cord tethering caused by scar formation after lumbosacral myelomeningocele repair, a motor deficit was related to the interruption level of the spinal tracts	Using stretch release techniques may increase the likelihood of neurological deficit recovery and result in a favorable prognosis of treatment
Sysosev, 2017[403] N = 58 Russia	Surgical detethering The results of surgical treatment and the data of preoperative clinical and instrumental examinations, as well as those of intraoperative electrophysical diagnostics and morphometry, were compared with the dynamics of the tethered spinal cord clinical presentation with follow-up periods ranging from 6 months to 5 years	**Bladder:** N/A **Neurological:** Worsening of neurological symptoms was more frequent in children operated over the age of 10 ($p = 0.03$), when the TCS was manifested exclusively through the pelvic dysfunction ($p = 0.00004$), if the F-wave block is less than 30% ($p = 0.0045$) and the stimulation threshold during root mapping ranged from 1 to 5 mA (p = 0 **Adverse events**: N/A	Surgical untethering is recommended when structural changes are minimal but advises caution and considers the risks higher when severe structural changes are present, particularly if the spinal cord tracts remain intact

Tanaka, 2006[404] N = 8 US	Surgical detethering Patients underwent a one-level laminectomy to release the tethered spinal cord; the level, which varied among patients, was selected to provide access to the terminal filum just below the level of the conus medullaris	**Bladder:** After surgery, six patients (Cases 1–5 and 7) demonstrated improvement in their symptoms; in four patients, the symptoms of tethered spinal cord dramatically resolved. Of these patients, one experienced diminished spasticity 2 weeks postoperatively and su **Neurological:** After surgery, six patients (Cases 1–5 and 7) demonstrated improvement in their symptoms; in four patients, the symptoms of tethered spinal cord dramatically resolved. Of these patients, one experienced diminished spasticity 2 weeks postoperatively and suffered fewer UTIs (Case 2), one patient had complete resolution of pain and improved bladder pressure (Case 3), one started walking on postoperative Day 2 (Case 4), and one became continent (Case 5). The patient in Case 7 exhibited an increased level of activity and physical endurance, and the status of the patient in Case 8 remains unchanged 3 months postoperatively. The patient in Case 6 died of medical conditions unrelated to surgery **Adverse events**: NR	Following surgical detethering, patients experienced improvement
Tarcan, 2001[405] N = 25 US	Surgical detethering Analyzed the records of 25 of 204 newborns (12%) with myelodysplasia in whom neurourological evaluation was normal after surgical repair of the spinal defect; initial assessment included complete urodynamic study, renal ultrasound, urinalysis and urine culture	**Bladder:** All 8 patients with deterioration on urodynamics underwent spinal cord untethering within 3 months of when the change was detected. MRI confirmed a tethered spinal cord. After surgery 2 children (25%) regained normal function, whereas in 6 (75%) there was **Neurological:** Neurological abnormalities developed in the lower extremities in the first and second years of life in 2, consistent with an upper motor neuron lesion characterized by spasticity in the lower extremities. These two children regained normal neurological function after surgical correction. **Adverse events**: NR	Strong recommendation for timely surgical correction when needed to prevent progressive urinary tract deterioration

Tarcan, 2006[406] N = 56 Turkey	Surgical detethering Surgical untethering was performed at our neurosurgery department by a single surgeon. The procedure involved a laminectomy to expose fully the involved spinal cord segments and standard microdissection techniques to release adhesions of the spinal cord	**Bladder:** In the entire study group urodynamic evaluation at 6 months postoperatively demonstrated a significant increase in bladder capacity (125 to 170 ml, p 0.001, paired t test) and a significant decrease in DLPP measurements (69.1 to 47.5 cm H2O, p 0.002, pa **Neurological:** NR **Adverse events**: NR	Secondary untethering surgery may significantly improve urological outcome

Telfeian, 2017[407] N = 1 US	Surgical detethering For the minimally invasive untethering procedure, the patient underwent general anesthesia and was positioned prone on the Jackson table and Wilson frame. Intraoperative monitoring electrodes were placed for both stimulated and free-run electromyograms. Motor evoked potentials were planned for bilateral quadriceps, anterior tibialis, gastrocnemius, and external anal sphincters using needle electrodes to monitor lumbosacral nerve roots. Monitoring required intravenous anesthesia using propofol and remifentanil and only short-acting muscle relaxants. A 2 cm midline vertical incision was made over the L4–5 spinous interspace. A 7 mm endoscopic tubular retractor was advanced over sequential dilators down to the ligamentum flavum using intermittent fluoroscopic guidance (Figure 2B). The Joimax TESSYS endoscopic system was used for the procedure, and the lamina, ligamentum flavum and dura were visualized endoscopically. Under endoscopic visualization, a small Lumbar 5 laminotomy was performed with the endoscopic drill and the ligamentum flavum was opened with a kerrison rongeur. At this point the endoscopic tubular retractor was removed and an expandable minimally invasive retractor was advanced. Under microscopic visualization, the laminotomy was completed and dural tacking sutures were placed on either side of the midline. A 7 mm vertical incision was then	**Bladder:** He initially required urinary self-catheterization for elevated post-void residuals, but by one month after surgery, he was voiding normally **Neurological:** The patient's radicular pain resolved immediately after surgery, and he was discharged on the first postoperative day **Adverse events**: NR	Utilizing minimally invasive, endoscopic techniques for identifying and sectioning the filum terminale in tethered cord syndrome could be a valuable addition to the armamentarium of minimally invasive spine surgeons

	made in the dura. The endoscope was placed intradurally for visualizing the intrathecal contents. Figure 2C-E depicts the key portions of the endoscopic procedure to identify and section the filum terminale. An endoscopic grasper was used to gently pull the filum terminale out of the small dural opening. A vessel loop was then placed under it. EMG testing confirmed that there were no motor responses to stimulating the filum. Under microscopic visualization, the filum was coagulated with a bipolar electrocoagulator, then sectioned with a micro-scissor. A 3 mm piece of the filum was sent for histopathological confirmation (Figure 2F). The dura was closed under microscopic visualization with a single purse string non-resorbable suture in a water-tight fashion. The rest of the wound was closed in a standard fashion		
Thompson, 1957[408] N = 5 US	Surgical detethering N/A	**Bladder:** Improvement in bladder control in all patients **Neurological:** N/A **Adverse events**: N/A	Relieving traction in the tethered spinal cord through sacral exploration and scar lysis not only improved peripheral neurologic defects but also restored continence

Thompson, 2021[409] N = 26 UK	Surgical detethering When required, surgery comprised untethering of the spinal cord with total or near total excision of the lipoma. Surgery was carried out under total intravenous anesthesia with intraoperative neurophysiological monitoring and mapping via electrodes placed in the quadriceps (L4), tibialis anterior (L5), gastrocnemius (S1), abductor halluces (S2), and anal sphincter (S3, 4)	**Bladder:** Of the 17 patients who had not had surgery, all had achieved urinary continence confirmed clinically and by bladder function assessment. Of the 9 patients who had undergone untethering surgery, 8/9 were reliably continent by day, and 1 had minor symptoms **Neurological:** All patients were independently mobile at last follow-up. In those without surgical intervention (n=17), none had motor deficits. Of those who had untethering surgery (n=9), one patient, who had required surgery due to a progressive motor deficit, had persisting ankle weakness with deformity requiring control with an ankle orthosis **Adverse events**: NR	A selective approach to untethering surgery is recommended for patients in the conus region
Thuy, 2015[410] N = 61 Australia	Surgical detethering Sixty-three detethering procedures were performed, four of which were redo operations; the most common complications were wound infection and cerebrospinal fluid leak; eight detethering procedures (12.7%) were complicated by wound infection, three (4.8%) by cerebrospinal fluid leak and two (3.2%) by both wound infection and cerebrospinal fluid leak; six detethering procedures (9.5%) required at least one return to theatre for wound repair or cerebrospinal fluid diversion; the majority of wound infections (75%) were able to be managed conservatively without return to theatre, however the majority of cerebrospinal fluid leaks (67%) required return to theatre and all children with both wound infection and cerebrospinal fluid leak required return to theatre	**Bladder:** 3 children showed postoperative improvement in sphincteric disturbance (bladder or bowel dysfunction) **Neurological:** 26.7% who had preoperative neurological, orthopedic or sphincteric deficits were noted to improve post-operatively. Improvement in motor function or gait disturbance was documented at clinician follow up for four children (36.4% of those with symptoms), sphincteric disturbance for 27.3%, scoliosis for 12.5% and back or leg pain for 16.7%. **Adverse events**: The most common complications were wound infection and cerebrospinal fluid leak. Six children (9.8%) required reoperation for wound issues and two patients (3.3%) required subsequent reoperation for cord retethering during the study period.	in the early post-operative period, detethering surgery did not result in deaths or new neurological deficits

Tominey, 2020[411] N = 36 UK	Surgical detethering Children with spinal lipomas, confirmed both radiologically and intraoperatively, and who had undergone surgical untethering and resection of spinal lipomas; preoperative and postoperative magnetic resonance imaging scans were independently assessed; postoperative follow-up was recorded at 6 months or the next data entry point thereafter; baseline characteristics, inter-adjudicator agreement, coexisting anomalies and/or malformations, and postoperative outcomes and complications were analyzed; neurological function was assessed using the Necker-Enfants Malades score, which was not explained nor is there readily accessible information able to be located to explain this better, however, it seems higher scores are improved scores and that the Necker-Enfants Malades score assesses motory, sensory, bladder, and bowel function	**Bladder:** N/A **Neurological:** At a median follow-up of 9 months, the median postoperative NEM score was 18. Among 22 symptomatic patients, 9 had improved overall NEM scores after untethering, while the scores in the remaining 13 patients were unchanged. All preoperatively asymptomatic patients remained asymptomatic at follow-up. No deterioration was observed at the last follow-up. **Adverse events**: Seven patients (19%) developed postoperative complications, but all resolved spontaneously or through medical or surgical intervention. Type 1 Lipoma: One case experienced postsurgical complications (2 weeks of urinary retention). Median postoperative NEM score: 18. One case improved postresection (33%). Type 2 Lipoma: Five cases had postsurgical complications (including transient urinary retention and weakness). Median postoperative NEM score: 17. Two cases (25%) improved postresection. Type 3 Lipoma: One case experienced postsurgical complications (CSF leakage). Median postoperative NEM score: 14. Three cases (75%) improved postresection. Type 4 Lipoma: No postsurgical complications were observed. Median postoperative NEM score: 18. Three cases (43%) had improvement postoperatively.	Resection of lipomas is safe and beneficial in the short term for both symptomatic and asymptomatic patients

Totonelli, 2019[163] N = 33 Italy	Surgical detethering The two groups were compared for age at neurosurgery, post-operative complications, mean post-operative follow-up, pre- and post-operative functional outcome, and presence of cutaneous stigmata (i.e. dermal sinus, localized hypertrichosis, hyperpigmented lesion); bowel evaluation was performed by neonatal/pediatric surgeons in terms of fecal incontinence and constipation and bowel management was indicated in patients with soiling grade 2 or 3 and/or constipation grade 2 or 3, according to Krickenbeck score; urological evaluation was performed by pediatric neuro-urologists in terms of bladder urodynamic studies (calyceal ectasia, bladder wall thickening, post-void residual) pad test and diary, and urodynamic evaluation in selected cases after 2 years of age; neuro-motor function was assessed by neurosurgeons with physical examinations; intraoperative neurophysiological monitoring was performed using somatosensory evoked potentials, motor evoked potentials and bulbocavernosus reflex; neuro-motor deficits include back pain worsened by activity and relieved with rest, leg pain, leg numbness or tingling, changes in leg strength, leg and/or foot deformities, gait disorders, and scoliosis; in patients with tests both before and after neurosurgery, the evolution of bowel function, urinary function and neuromotor function was also studied	**Bladder:** A significantly higher number of patients in group A needed bowel management compared to group B (p=0.0035) **Neurological:** In particular, group A was associated with a less severe type of lipoma, the filum lipoma (p=0.057), with spinal lipoma only presenting in group B; most of the patients with isolated spinal dysraphism (87%) presented with cutaneous stigmata, compared to a minority (20%) in anorectal malformation-associated spinal dysraphism group (p=0.0004)l a significantly higher number of patients in group A needed bowel management and presented with neuro-motor deficits, compared to group B (p=0.0035 and p=0.04 respectively); group A showed a significant postoperative neuro-motor improvement as compared to group B (p=0.002); three patients in group B (2 lipomyelocele, 1 lipomyelomeningocele) and no patient in group A underwent redo-detethering surgery for residual lipoma (p=ns). **Adverse events**: Three patients in group A developed post-operative minor complications: one localized epidural subcutaneous infection treated with wound toilet and local disinfection, and two intermittent leg pain and leg tiredness resolved spontaneously within 12 months from the untethering surgery (p=ns).	Untethering surgery can help with neuromotor symptoms in some anorectal malformation patients but doesn't improve intestinal and urinary symptoms

Tseng, 2008[412] N = 31 UK	Surgical detethering Surgical untethering: for lipomyelomeningoceles, untethering procedures consist of dissecting and debulking the lipoma upon the lumbodorsal fascia, laminectomy on the lower lumbar spine according to the level involved, and opening the dura for exposing the intradural portion of the lipoma; the junction between the lipoma and the neural placode is dissected and divided for untethering; the lipoma is subtotally excised to allow the neural placode to move freely within the spinal canal, and any tethering arachnoidal adhesions are divided; after the subtotal resection of the lipoma, the pia is closed if possible and the filum terminale is divided to release any potential tethering; for lipomas of filum terminale, untethering is achieved simply by dividing the tight filum terminale	**Bladder:** NR **Neurological:** During the follow-up, all patients had either symptoms unchanged (14 patients, 45.2%) or improved (17 patients, 54.8%). In 14 patients (45.2%) symptoms totally resolved. The main symptoms that remained after untethering were leg weakness (12 patients, 38.7%) and orthopedic deformities (12 patients, 38.7%). **Adverse events**: N/A	Our study suggests that untethering should be performed immediately once the patient shows evidence of symptomatic lumbosacral cord tethering, irrespective of age. Benefits can be seen in all patients, but young children (before 2 years old) have a higher chance to gain favorable outcome.

Tubbs, 2006[413] N = 20 US	Surgical detethering In this intervention, intradural retention sutures are placed just posterior to the liberated spinal cord over the area of dysraphism, these sutures are used to prevent spinal cord tethering, horizontal mattress sutures connect each side of the suture to the inner layer of the dura mater; routine duraplasty is then performed using the patient's thoracolumbar fascia; patients are kept in a relatively flat position for 3 to 5 days postoperative to prevent postoperative tethering and scarring; the use of monofilament sutures is chosen to minimize scarring and adhesion to the spinal cord, thus preventing tethering, this technique aims to ensure the safety and efficacy of the procedure; the mean follow-up time for this cohort was 8 years	**Bladder:** N/A **Neurological:** N/A **Adverse events**: N/A	Surgical detethering had a positive impact on the conditions of the patients

Tuuha, 2004[164] N = 223 Canada	Surgical detethering NR	**Bladder:** Urinary and bowel incontinence present preoperatively did not improve with the mean follow-up of approximately 5 years. Similarly, 3 patients underwent prophylactic untethering of the cord. The decision to have prophylactic surgery was because of patient/ **Neurological:** Symptoms improved significantly in all patients who had surgery for neuro/motor deterioration. Specifically, the surgery was beneficial in reversing the damage that caused gait disturbances, muscle tone (weakness or rigidity), and delayed developmental milestones. Similarly, 3 patients underwent prophylactic untethering of the cord. The decision to have prophylactic surgery was because of patient/surgeon preference. All 3 patients had urinary and bowel symptoms, and these did not improve after the surgery with mean follow-up of 8.4 years. These patients, however, did not have neuro/motor symptoms. There were no complications. **Adverse events**: Urinary and bowel incontinence present preoperatively did not improve with the mean follow-up of approximately 5 years. There was no death associated with surgery; however, one patient's recovery was prolonged by a cerebrospinal-fluid (CSF) leak postoperatively	Surgery can lead to improvements in neuro/motor functions for symptomatic patients with tethered cord, but it may not significantly impact bowel and urinary functions; furthermore, prophylactic surgery appears to offer minimal benefit, while an expectant conservative approach seems safe for asymptomatic tethered cord patients

Uchida, 2007[414] N = 13 Japan	Surgical detethering Tethered spinal cord in all patients was detected on magnetic resonance imaging . Then, the patients underwent physical examination by neurosurgeons, and all subsequently underwent a surgical untethering procedure. All surgery was performed by the same neurosurgeon. Authors reviewed the relationship between patient characteristics and the incidence of spinal cord tethering in anorectal malformation, and evaluated the results of untethering surgery. Urological, bowel, and orthopedic function were evaluated preoperatively and postoperatively. Urological functional evaluation was performed by pediatric surgeons and included an interview on urination, renal US and cystourethrography. Bowel function was also followed up by pediatric surgeons with an interview on defecation, an imaging study, and a manometric study. Orthopedic function was evaluated by pediatricians and neurosurgeons with physical examinations.	**Bladder:** 10 out of the 13 patients were symptomatic prior to the operation. The patients were assessed before and after surgery on bowel, urological and orthopedic involvement. Overall, the patients experiences an overwhelming improvement in orthopedic involveme **Neurological:** N/A **Adverse events**: N/A; There were no cases of re-tethered cord.	In conclusion, the present study demonstrates that several symptoms caused by spinal cord tethering are progressive and that urological/ bowel dysfunction often remains a permanent problem after untethering surgery. Based on this study, we recommend routine magnetic resonance imaging examination in patients with anorectal malformation and early untethering surgery in cases associated with spinal cord tethering.
Udayakumaran, 2021[415] N = 208 India	Surgical detethering Evaluation of the correlation of intraoperative neuromonitoring data in surgery for tethered cord syndrome in children to the neurological outcome at 1-year follow-up.	**Bladder:** 82.3% (n=60/73) of patients who had bladder deficits showed an improvement, and 88.8% (n=46/54) with bowel deficits showed improvement. Two patients with motor deficit had shown worsening, of which one improved at one year follow up. Four patients with bl **Neurological:** At one year follow-up, 91% (n=54/59) of the patients who had motor deficits had improvement **Adverse events**: Three patients experienced bladder worsening and 1 patient experienced motor worsening. Clinical worsening corresponded to those who had a drop in amplitude of baseline TcMEP (n=4)	Intraoperative neuromonitoring enhances the accuracy of predicting immediate and long-term outcomes in tethered cord surgery

Utsuki, 2009[416] N = 1 Japan	Surgical detethering The patient was operated upon under electrophysiological monitoring for the tibialis anterior muscle, gastrocnemius, and anal sphincter on day 22 after birth. The structure continued from the spinal cord to the caudal appendage and was covered with fibroconnective tissue up to the dura of the spinal cord. The structure was amputated together with the caudal appendage as there was no electrophysiological reaction. The string-shaped tissue which extended from the bottom part of the conus medullaris (L5) to the vertebral canal caudalis was amputated because there was no electrophysiological reaction. However, the string-shaped tissue extended towards the side; muscular contraction of gastrocnemius and an anal sphincter were revealed electrophysiologically. These were untouched as well as the normal nerve. A dural closure and plastic reconstruction of the superficial layers were then performed. The caudal appendage consisted of tissue that was covered up to the skin and had connective tissue and a rich blood vessel supply up to the substratum. Furthermore, there was spinal cord-like tissue mass comprising gangliocyte-like and central canal-like structures in the deep layer. Spinal root-like tissue was in close contact with this mass. Myelomeningocele was suggested. The tethering tissue bulged in the center, and both of the sides were	**Bladder:** NR **Neurological:** Axial MR image on postoperative day 5 of 11 thoracic vertebrae levels demonstrated improvement in spinal cord deviation and syringomyelia. No postoperative neurological deficits have been observed and growth is progressing normally **Adverse events**: NR	Surgical intervention led to improvement in syringomyelia

	slim filamentous tissue. The slim filamentous tissue of the head part was spinal root-like tissue. The bulging part consisted of gangliocyte. The slim filamentous tissue of the caudal side was fibrous tissue with no nervous component. This tethering tissue was an aberrant nerve root		
Valentini, 2005[417] N = 66 Italy	Surgical detethering Surgical detethering with intraoperative multichannel electromyographic monitoring, electromyographic monitoring was performed using monopolar needle electrode couples inserted into both sides of the rectus femori, tibialis anterior, gastrocnemius lateralis (or abductor hallucis), and the anal sphincter	**Bladder:** The failure to diagnose initial sphincter deficits in infants led to the late discovery of advanced bladder dysfunction in another 10% of children **Neurological:** Approximately 30% of patients experienced complications after surgery. These complications were almost always minor and self-limiting. The most frequent complication was cerebrospinal fluid collection, which required another operation. This was observed more frequently in caudal lipomas associated with sacral agenesis. Temporary deterioration was observed in four patients submitted to intraoperative EMG monitoring. In these patients, all deficits regressed completely between 2 and 4 months after surgery. In contrast, permanent deterioration was observed in four patients, all of whom underwent operation without monitoring (6%). Three children experienced neurological deterioration, and one adult had increasing pain. Each patient who worsened had a surgically complex malformation (three conus lipomas and one recurrent lipoma), for which the risk of postsurgical deterioration was 7.4% **Adverse events**: N/A	Motor and sphincter function monitoring method positively impacts surgical outcomes,offering the dual advantage of limiting potential nerve root injuries and increasing surgeon confidence for achieving complete untethering

Valentini, 2009[418] N = 110 Italy	Surgical detethering Resection of the subcutaneous lipoma and of the dermal sinus, laminar exposure, extended at least one space cranially than the first non-schisic segment, laminotomy performed by high speed drill, exposition the intact dural sac, opening of the dura under optic magnification, separation of the intradurallipoma from the lateral and caudal dural adhesion and from neural tissue under electromyography monitoring control, near-complete lipoma removal, sectioning of the tight filum, suture of the placode, positioning of adural graft to prevent retethering and fibringlue to reduce cerebrofluid spinal leaks, and fixation of the laminotomic flap	**Bladder:** All the cases were operated soon after the urodynamic variation, with normalization of the bladder function **Neurological:** The global rate of neurological deterioration before surgery in this series was higher than 50% in the long pre-operative period; this may be assumed as the rate of deteri-oration of symptomatic lipoma in their ‘‘natural history’’. **Adverse events**: A CSF collection, deserving surgical revision, occurred in 18 cases and infection in 2 cases; none caused permanent morbidity.	The surgical results of this series of occult spina bifida seem better than the natural history registered in the long pre-operative period in terms of neurological deterioration
Van Calenbergh, 1999[166] N = 32 Belgium	Surgical detethering Surgical untethering was performed, and the mean follow-up period for the patients was 3.4 years	**Bladder:** Some patients experienced improvement in bladder functions, while others remained unchanged or saw a worsening of their condition **Neurological:** Some patients experienced improvement in sensory and motor functions, and pain, while others remained unchanged or saw a worsening of their condition **Adverse events**: A superficial infection involving the subcutaneous tissue, with cerebrospinal fluid leakage, urinary tract infection, and herpes zoster affecting the L2-L3 region, aseptic meningitis and a neurological deficits	Surgical intervention for tethered cord syndrome did not prevent the later development of new deficits, leading to the argument against prophylactic surgery in asymptomatic patients
van den Hondel, 2016[419] N = 3 Netherlands	Surgical detethering Untethering surgery was performed in 3 of the 10 patients with TSC	**Bladder:** N/A **Neurological:** Neurological symptoms resolved in the one patient presenting them **Adverse events**: N/A	Ultrasound screening is an effective method for tethered spinal cord screening in patients with Anorectal Malformations and suggests considering an MRI for symptomatic patients

van Leeuwen, 2001[420] N = 57 Netherlands	Surgical detethering The surgical untethering included complete untethering of the spinal cord, removal of tethering elements like bony spines in spinal cord malformations, and reduction of intramedullary lipomas with special attention given to creating a cerebrospinal fluid-filled sac around the freed conus medullaris to minimize the risk of re-tethering the spinal cord, while in many cases, cadaveric dura mater or a substitute material was used to reconstruct the thecal sac, and for more complex cases, closure of fascia and skin was managed by a plastic and reconstructive surgeon with 2 years at least of following up	**Bladder:** Bladder and bowel function improved in nine patients, remained unchanged in 48 patients, did not deteriorate in any of the patients **Neurological:** Improved or unchanged muscle strength for most patients, with a minority showing a decline, especially those who had rapid motor function loss before surgery, neurologically intact patients didn't experience deficits. Pain, gait, sensory, motor function, and varied, with improvements, stability, or deterioration observed **Adverse events**: Only a few (4 patients) had a minor decrease in muscle strength, and a smaller number (2 patients, or 3.5%) showed significant deterioration	Surgical untethering is a safe and effective procedure for adult patients with tethered cord syndrome, preferably undertaken before serious neurological dysfunction occurs
Vepakomma, 2019[421] N = 44 India	Surgical detethering Detethering by excision of tethering element (bony spur-/ lipoma-/ dermal sinus) and division of filum was accomplished with or without a laminectomy	**Bladder:** Overall, 8 infants and 8 older children had preoperative neurological deficits or bladder dysfunction diagnosed during evaluation. The two infants who were asymptomatic but demonstrated bladder changes on imaging, showed normal bladder emptying with nil p **Neurological:** Overall, 8 infants and 8 older children had preoperative neurological deficits or bladder dysfunction diagnosed during evaluation. Four infants (3 lipoMMC and one tight filum) and 1 older girl (low lying conus with fatty filum) demonstrated functional recovery. Of these 4 infants, one had selective recovery of the limb weakness. **Adverse events**: N/A	Early prophylactic detethering is safe, feasible and advisable

Vernet, 1996[422] N = 25 Canada	Surgical detethering When present, associated mass lesions such as residual lipoma were debulked, usually by means of the carbon dioxide laser, intraoperative nerve root stimulation was used when feasible; all patients with spinal tethering secondary to previous myelomeningocele repair underwent dural sac expansion with lyophilized dura; all patients underwent surgery via a microsurgical technique, at a mean follow-up time of 2 years	**Bladder:** Postoperatively, in Group 1, one patient with normal values on a preoperative urodynamic study showed a pathological finding 1 year after surgery with total, 30-below, and 20-below bladder capacities of 75%, 65%, and 30% respectively, of the minimal accep **Neurological:** Both groups improved from baseline **Adverse events**: Five patients displayed continued deterioration in their bladder function	Urodynamic studies are highly valuable in the management of tethered spinal cord, especially after prior myelomeningocele repair, as they enable early detection and prompt surgical correction to prevent permanent tethering injury
Veronesi, 2020[423] N = 4 Italy	Surgical detethering The surgery was performed under local anesthesia and possible temporary sedation, the patients were in a prone position, and the average duration was 25 min. The same surgeon (VV) performed all procedures. The previously described surgical technique was performed [6]. The only variation is that sacral X-ray fluoroscopy was not performed. This minimally invasive surgical technique involves the use of the operating microscope in the central phase. The FTE sectioning with a transhiatal approach under local anesthesia involves only minimal discomfort for the patient and minimizes the risks related to the skin incision only.	**Bladder:** The sphincter disorders, which were present in 3 cases, disappeared in cases 1 and 2; one of these presented at a different type of symptom, less severe, which is still under investigation. In case 3, the disturbances have improved but not disappeared **Neurological:** Sensory disturbance and fatigue disappeared **Adverse events**: N/A	Sectioning of the filum terminale externum can effectively relieve pain and sensory disturbance symptoms in occult tethered cord syndrome patients

von Koch, 2002[424] N = 25 US	Surgical detethering The surgical tethered release was performed to access the filum, located at the lumbar 4/5 or lumbar 5/sacral 1 level, the filum was carefully identified and transected after neurophysiological evaluation, including electrical stimulation and recording, and ventral nerve root thresholds were measured, and compared to thresholds of the filum terminale, with the filum requiring significantly higher voltage for activation, this 1:100 threshold ratio was useful in identifying the filum in over 70% of patients	**Bladder:** There was no significant worsening in bowel and bladder, and four patients showed significant improvement in bowel and bladder function **Neurological:** Nine patients experienced motor improvement, and four patients reported reduced pain **Adverse events**: Three patients developed urinary tract infections postoperatively	Intraoperative neurophysiological monitoring during tethered cord release in pediatric patients with a thickened filum and/or low-lying conus shows promising results with no significant worsening in clinical outcomes and improvements in bowel, bladder, motor function, and pain in some cases
Vora, 2021[167] N = 109 India	Surgical detethering Surgery included radically excise lipomas in children, involving detaching the lipoma from the dura, denuding the neural placode, and performing neurulation and dural closure using autologous or synthetic materials, with a mean follow-up of 62.5 months	**Bladder:** Most of patients experienced urological function improvement **Neurological:** Most of patients experienced neurological function improvement **Adverse events**: A few patients experienced a CSF leak, and some had unchanged conditions or neurological deterioration	Radical resection of lipomyelomeningocele appears to preserve neurological function in over 90% of children at long-term follow-up.

Warder, 1993[425] N = 13 US	Surgical detethering NR	**Bladder:** At follow-up, two patients (Patients 7 and 8) had normal control, one patient (Patient 12) had improved bladder control, although he did have intermittent stress incontinence; the patient presenting with a neurogenic bladder (Patient 10) had no change in **Neurological:** Seventy-five percent of the patients with lower extremity weakness improved with surgery. Of the four patients (Patients 5, 6, 11, and 12) who presented with spasticity and hyperreflexia, one patient's symptoms improved (Patient 12) and two patients had no change (Patients 5 and 6); one patient (Patient 11) presented with lower extremity spasticity and during 6 years of follow-up developed a progressive spastic quadriparesis of unknown origin, despite extensive evaluation. The three patients whose presentation included lower extremity hyporeflexia (Patients 8, 12, and 13) had no change in this symptom at the time of follow-up. The two patients whose presentation included low back pain (Patients 5 and 9) experienced improvement of this symptom. Of the two patients whose presentation included lower extremity radicular pain (Patients 5 and 9), one improved (Patient 9) and the other had no change in this complaint at the time of follow-up. The one patient whose presentation included lower extremity paresthesia (Patient 5) experienced improvement of this symptom **Adverse events**: NR	Surgical intervention, specifically the release of a tight filum, can lead to improvement or stabilization of neurological complaints in patients with signs and symptoms of tethered cord syndrome, even when the conus is at a "normal" level

Warder, 1994[426] N = 67 US	Surgical detethering NR	**Bladder:** NR **Neurological:** In each of the two groups, a majority of presenting symptoms were either improved or unchanged at the time of follow-up. There was one patient in the normally positioned group whose neurological status was worse at follow-up. This patient presented with lower extremity spasticity and, during 6 years of follow-up, developed a progressive spastic quadriparesis of unknown origin despite extensive evaluation (5). There were two patients in the low-lying group whose neurological status was worse at follow up; both were neurologically normal at presentation **Adverse events**: NR	The decision to recommend surgery in the group of patients with the conus in the normal position was always made when the patient had clear evidence of other associated anomalies, frequently with a progressive neurological deficit.
Wehby, 2004[427] N = 66 US	Surgical detethering Patients underwent spinal detethering surgery, including sectioning of the fulum terminale; patients were followed for more than 6 months (mean 13.9 months)	**Bladder:** Urinary urgency/frequency resolved or improved in all affectedchildren (58/58). Urinary incontinence/retention resolved or improved to varying degrees in 53/54 children. Urinary incontinence/retention showed complete resolution in 52% (28/54); marked impr **Neurological:** Weakness, when present preoperatively, resolved in 21/21 patients. Sensory abnormalities, consisting primarily of hyperesthesia or hypesthesia to pinprick in distal lower extremities and/or saddle distribution, resolved on postoperative examination in 9/9 patients. Back/leg pain/cramps reported were resolved in 30/30 patients. **Adverse events**: N/A	An aggressive approach to clinical diagnosis and treatment, including filum terminale sectioning is recommended for children with bladder instability and clinical features consistent with tethered cord syndrome, even if radiographic findings show a normal conus position.

Xia, 2023[428] N = 23 China	Surgical detethering Spinal cord detethering: spinal cord untethering was performed by the same experienced doctor; the spinal cord tethering was released by opening the laminae of the diseased segment using the double-opening/single-opening technique, and the laminae were repositioned and fixed with an absorbable internal fixation system after surgery to maintain the integrity of the posterior spinal column and the incision was closed layer by layer; changes in LSA in lateral spinal radiographs were measured and analyzed preoperatively, postoperatively, and at the last follow-up	**Bladder:** NR **Neurological:** The mean preoperative LSA was 70.30 ± 9.04°, the mean postoperative lumbosacral angle was 63.34 ± 5.60°, and the mean postoperative lumbosacral angle at the last follow-up was 61.61 ± 9.14°. The angles were significantly different (p=0.002; p=0.001) both postoperatively and at the last follow-up compared to preoperatively. There was no statistical difference between postoperative and final follow-up. **Adverse events**: NR	Spinal cord untethering can improve the inclination of the lumbosacral angle in children older than 5 years with tethered cord syndrome

Yaghi, 2021[429] N = 1 US	Surgical detethering Surgical exploration and spinal cord detethering due to progressive neurological deficits. Work-up for this indication included physical exam, electromyographies, nerve conduction study, computed tomographies, endoscopy, and a thoracic spine magenetic resonance imaging. Multiple neuroraditiologists reviewed these and indicated patient for detethering surgery and exploration.	**Bladder:** Patient reported upon presentation no significant bowel or bladder incontinence, nor saddle anesthesia. There was no family history of neuromuscular disorders or multiple sclerosis. **Neurological:** Patient reported upon presentation a history of chronic low back pain that was first evaluated in a neurology outpatient clinic. There was a three-and-a-half-week history of insidious onset bilateral lower extremity ascending numbness. Sensory deficit was bilaterally symmetric, constant, and did not change with activity or position. No family history of neuromuscular disorders or multiple sclerosis. His neurological examination was significant for complete loss of sensation to light touch and reduced vibration sense from the level of waist down bilaterally. He had intact deep pressure sensation and proprioception. His strength was full in all muscle groups. His patellar reflexes were 3+ bilaterally without clonus, Hoffman's sign, nor Babinski's sign. Diagnostic electromyography and a nerve conduction study showed absent sural and superficial peroneal nerve sensory responses suggestive of peripheral polyneuropathy that was length-dependent. The upper limb sensory responses were preserved, with mild bilateral carpal tunnel syndrome. Of note, he had had an electromyography of the bilateral lower extremities 2 years prior, which was normal. Extensive blood work was unrevealing. Cervical and lumbar spine magnetic resonance imaging were unremarkable. Chest, abdomen, and pelvis computed tomography revealed no obvious signs of malignancy. There was evidence of a thickened terminal ileum and rectum for which the patient had undergone an endoscopy with negative biopsies. Patient woke from anesthesia with significant improvement in his bilateral lower extremity	This case of a thoracic spinal cord lipoma not related to bony spinal dysraphism was challenging to identify on pre-operative imaging, and ultimately was treated uniquely with a minimally invasive tubular surgical approach. A rare unusual pattern of imaging findings associated with thoracic spinal lipoma are presented. Feasibility of surgical excision of such a spinal lipoma with untethering through a minimally invasive tubular approach is demonstrated and found to be effective.

		sensation. At 2-week follow up visit in clinic, patient reported bilateral lower extremity numbness had resolved completely. He also reported that his legs felt "hyper-sensitive." At a 3-month postoperative follow up, he reported the numbness in his legs, gait difficulty, and hypersensitivity had resolved. He reported no headaches. Post-operative magnetic resonance imaging revealed untethering of the spinal cord with a small, infra-fascial pseudomeningocele. No cerebrospinal fluid leak was noted at any time. The patient will follow up with 1-year surveillance magnetic resonance imaging. **Adverse events**: N/A	
Yang, 2018[430] N = 6 Taiwan	Surgical detethering In addition to the routine preparations that are needed for performing functional mapping and monitoring during surgery for spinal dysraphism and tethered cord, the patients had a 1 × 4 strip of electrodes placed rostral to the surgical field, where it was secured by a surgeon after opening the dura; with the patient under total intravenous anesthesia, the sensory nerves and conus medullaris were stimulated with a concentric bipolar electrode over the surgical field while somatosensory evoked potentials were recorded with the strip electrodes to identify any possible sensory roots with remaining function and the most inferior functional portion of the conus medullaris	**Bladder:** Both groups improved from baseline **Neurological:** Both groups improved from baseline **Adverse events**: N/A	Using subdural strip electrodes to obtain sensory evoked potential recordings during detethering surgery in young children with spinal dysraphism and/or tethered cord syndrome is a valuable and feasible technique for mapping the most inferior functional portion of the conus medullaris and preserving sacral sensory functions

Yang, 2022[431] N = 5 Korea	Surgical detethering Untethering surgery was performed after one-level laminotomy or hemilaminectomy followed by filum terminale sectioning.	**Bladder:** There were three patients who showed improvement after untethering surgery. One patient had no improvement or aggravation, and one patient showed temporary improvement followed by re-aggravation. The latter patient (patient 3) underwent augmentation cysto **Neurological:** N/A **Adverse events**: There were no acute complications after untethering surgery.	Surgical untethering is recommended for occult tethered cord syndrome when patients experience a sudden onset of urinary dysfunction or pain with progression and demonstrate detrusor sphincter dyssynergia confirmed by urodynamic studies, emphasizing the importance of timely surgery and ongoing postoperative care for optimal outcomes.
Yener, 2015[432] N = 40 Turkey	Surgical detethering Urodynamic studies were carried out using standard techniques with a urodynamics and biofeedback device; the parameters assessed included expected bladder volume, leak pressure, maximum detrusor pressure, post-voiding residue, and the untethering procedure was performed, with 12 months of following-up	**Bladder:** Patients who had no urodynamic symptoms before untethering surgery demonstrated greater improvement compared to those who had urodynamic symptoms **Neurological:** N/A **Adverse events**: N/A	Untethering surgery for patients with primary tethered cord syndrome leads to improvements in urologic symptoms and urodynamic parameters
Zhang, 2020[123] N = 1 China	Surgical detethering The child was diagnosed with tethered cord syndrome by the magnetic resonance imaging, and surgical de-tethering of the terminal filum was performed under general anesthesia, with a follow-up period of 6 months	**Bladder:** Urodynamic testing indicated that fatigable detrusor contraction and the maximum detrusor contractile pressure were approximately 39 cm H_2O at the onset of abdominal pressure **Neurological:** N/A **Adverse events**: Lower back pain complicated by increased lumbosacral angle for more than 20 days	Surgery is recommended when children present with low back pain and an increased lumbosacral angle

Zide, 1991[433] N = 70 US	Surgical detethering In this intervention, a vertical incision is made to access and transect a lipoma, exposing the lumbodorsal fascia and fascial defect; the lumbodorsal fascia and underlying muscle are incised longitudinally to expose the site of tethering; the fascial layers are mobilized and prepared for closure, and the fascia is closed with sutures to prevent cereberospinal fluid leakage, a drain is placed to monitor the closure's integrity, the skin is closed in two or three layers to ensure secure wound closure, and a custom-made pressure garment is applied to the lumbosacral region for added support, the drain is usually left in place for 2 to 4 days, and the pressure garment is used as needed to prevent complications; this approach is employed in surgeries to address spinal lipomas and ensure proper wound healing	**Bladder:** Sixty-five (93%) of the 70 patients operated on by the technique had no wound problems whatsoever. The complications in the other five consisted of the following. 1) Small early CSF collections in two patients were controlled immediately with external-pre **Neurological:** N/A **Adverse events**: Sixty-five (93%) of the 70 patients operated on by the technique had no wound problems whatsoever. The complications in the other five consisted of the following. 1) Small early CSF collections in two patients were controlled immediately with external-pressure garments and disappeared. 2) Very large pseudomeningoceles occurred in two patients early in the series; these did not leak, due to excellent skin coaptation. 3) Infection in one patient required wound opening and packing. This occurred as a result of fat necrosis after lipoma excision.	Proper fascial closure following tethered cord correction can effectively prevent pseudomeningocele formation and reduce the risk of cerebrospinal fluid leakage

Zingman, 2020[434] N = 84 US	Surgical detethering All surgeries were performed by one surgeon at two hospitals. With the patient prone, an S1 laminectomy was performed. The lamina was kept in cold saline for later replacement. A midline durotomy was performed. The arachnoid was opened and clipped to the edge of the dura. Microsurgical mapping of the cauda equina with sacral nerve electrophysiological stimulation was employed in every case to confirm the identification of the FT (Figure 1). This also enabled the identification of the sacral nerve fibers adherent to the filum, which could then be dissected free. The threshold of stimulation of the FT ranged from 3 mA to 7 mA - or approximately three times the threshold demonstrated for sensory nerves. A 1-cm portion of the FT was cauterized at low voltage, sectioned, and retained as a pathological specimen. The dura was closed with 6-0 Prolene sutures, and a Valsalva maneuver was performed to confirm watertight closure. A laminoplasty was performed by replacing the lamina with titanium miniplates (Depuy Synthes, Raynham, MA), 6 mm screws, and demineralized bone. The wound was closed in layers, and the patient was kept on strict bed rest for 48 hours, after which they were granted bathroom privileges. Patients were usually discharged on the third postoperative day	**Bladder:** N/A **Neurological:** Low back pain was significantly improved across the cohort (mean preoperative vs. postoperative VAS 8.2 ± 1.3, vs. 4.3 ± 2.6; $P < 0.001$; Figure 2). For 19 patients with both pre and postoperative data available, the distance they were able to walk also improved significantly (mean preoperative vs. postoperative distance 359 ± 438 feet, vs. 3743 ± 3607 feet; $P = 0.003$) **Adverse events**: One patient required surgical repair of a dural leak approximately one week after surgery but subsequently recovered well. The leak occurred when the patient hyper-flexed her lumbosacral junction one week after the surgery, causing a tear in the durotomy. Another patient underwent lumbar surgery (L4-5 fusion) 16 months after the tethered cord surgery, and one underwent a sacroiliac fusion five years later	It concluded that surgical release of the filum terminale for tethered cord syndrome in patients with hypermobile Ehlers-Danlos syndrome was safe and effective

Aldave, 2017[435] N = 7 US	Vertebral column shortening The shortening procedure was centered at the level of L-1 in all patients, with the exception of 2 patients. In most cases, we performed pedicle subtraction osteotomy (PSO) (6 patients) rather than vertebral column resection, as used by Hsieh et al.13 We hypothesized that, by introducing lordosis with a PSO, the spinal cord would migrate dorsally, away from the dorsum of the vertebral body, particularly in cases of exaggerated kyphosis. The PSO performed in a standard manner at L-1 is described briefly below. Laminectomies from T-12 to L-2 were performed. Pedicle screws were placed bilaterally at T-12 and L-2. The pedicles at L-1 were then isolated after resection of T12–L1 and L1–2 facet joints, articular processes, pars interarticularis, and transverse processes. Using a combination of a Leksell rongeur and a high-speed air-powered drill, the pedicle on one side was resected down to its confluence with the posterior cortex of the vertebral body. The rostral portion of the L-1 vertebral body was drilled away on one side, with a rod coupling the pedicle screws on the opposite side, which prevented closure of the 1.5 cm osteotomy gap. The bony superior endplate of L-1 was not violated. The anterior cortex of the vertebral body was thinned but preserved. The same steps were repeated on the other side with a rod assembled on the opposite side for resection of the remaining portion of the rostral portion of L-1. The	**Bladder:** Improvement in 2 patients; no change in 2 patients **Neurological:** Improvement in 1 patient; no change in 3 patients **Adverse events**: One patient experienced a catastrophic failure of her spinal instrumentation and proximal junctional kyphosis at 3 months after surgery, which necessitated revision surgery with extension of her spinal instrumentation and fusion	Spinal column shortening seems to represent a safe and efficacious alternative to traditional untethering of the spinal cord for tethered cord syndrome

	posterior cortex in front of the thecal sac and spinal cord/conus medullaris/cauda equina was thinned to the consistency of an eggshell, and it was removed piecemeal with a down pushing curette and Kerrison rongeurs, along with the posterior longitudinal ligament. The osteotomy defect, filled with a small dose of bone morphogenetic protein, was gradually closed by compression applied to the pedicle screws at T-12 and L-2 using the rods as guides to obtain bone-on-bone contact. Bone morphogenetic protein and morcellized local autograft and allograft were also placed over the exposed bony elements from T-12 to L-2 to complete the posterior fusion. Bone morphogenetic protein to facilitate arthrodesis was used in an "off-label" manner in this series of pediatric and adult patients. We recognize that use of bone morphogenetic protein in children is controversial. A full discussion of the merits and faults of recombinant human bone morphogenetic protein–2 use in children is beyond the scope of this study. However, we do cover this topic in a series of previously published studies. Furthermore, written informed consent was obtained from the patient or legal guardian for off label use of bone morphogenetic protein as described above.		
Chaseling, 1985[126] N = 23 Australia	Vertebral column shortening Laminectomy	**Bladder:** N/A **Neurological:** N/A **Adverse events**: There was no morbidity directly associated with surgery.	The tethered cord group presented with progressive neurological deterioration and changing patterns of somatosensory-evoked potentials; surgery was likely to be beneficial to such patients, although the clinical details of outcome are scanty.

Menezes, 2021[436] N = 24 US	Vertebral column shortening Operative procedure was performed with the patient in the prone position and the operating microscope was used in all cases; an osteoplastic laminectomy was made, if possible, except when there were bony abnormalities such as diastematomyelia, in which case a laminectomy was made over the site of the bone spur or the fibrous septum; an osteoplastic laminectomy was included at the level above or below	**Bladder:** Of 20 operative patients with preoperative bladder and bowel dysfunction, 12 had return of normal urological function, 3 had improvement of function, and 5 had no change from their preoperative status. **Neurological:** 20/24 patients had motor or sensory complaints preoperatively and 17 had resolution of their symptoms after surgery, 3 patients stated that they had no change in their postoperative neurological deficit. **Adverse events**: There were no complications postoperatively or on long-term follow-up. CSF leak was not encountered, nor were infection or worsening of existing neurological deficits.	Most adults with newly diagnosed TCS have unrecognized neurocutaneous abnormalities and neurological deficits. The triad of nondermatomal sacral or perineal pain, bladder dysfunction, and neurological deficit should not be confused with hip or degenerative lumbosacral disease. Addressing the primary pathology often leads to successful results.
Xu, 2022[437] N = 24 China	Vertebral column shortening N/A	**Bladder:** According to UDS, there were 20 patients with bladder detrusor weakness and 4 with reflex before operation. However, seven cases presented with bladder detrusor weakness, 10 with reflex, and 7 with normal reflex at the final follow-up (P<0.01). Twenty cas **Neurological:** Patients' neurological function was also recorded. Before operation, there were 11 (45.8%) patients who exhibited motion dysfunction of the low extremities and 3 (1.3%) patients with sensory dysfunction of the low extremities. However, at the final follow-up, five patients reported satisfactory neurological recovery and all three patients. **Adverse events**: One patient developed mild pain in the left lower extremity after operation. It was considered that over-compression during operation resulted in nerve root shrinkage or edema. However, the pain was relieved after taking nonsteroidal anti-inflammatory drugs for two weeks. All patients had no severe neurologic complications during the overall follow-up.	The homogeneous spinal-shortening axial decompression can significantly restore the bladder function in patients with long-term urinary incontinence.

Table F.4. KQ4 case series

Study: Author, Year; Study Size; Location	KQ4 Interventions	Outcome and Results Adverse Events	Author Conclusions
Bamba, 2011[172] N = 19 Japan	Other Laminectomy or laminotomy	**Bladder:** NR **Neurological:** NR **Adverse events**: CSF leakage	Utilizing a three-dimensional reconstruction method combined with image Overlay in the treatment of patients has resulted in a lack of neurological complications, improving the visual understanding of complex surgical situations and potentially enhancing surgical efficiency and outcomes
Barolat, 1991[438] N = 1 US	Other Laminectomy. Patient underwent surgical resection of a lipomyelomeningocele at L5-S1.	**Bladder:** N/A **Neurological:** Neurological examination at the time of the initial assessment showed marked bilateral weakness of the muscle groups in the L4-S1 distribution. The anal sphincter was flaccid. There was complete anesthesia in the perineal area, anesthesia in the right S-1 distribution, and hypesthesia in the left S-1 and bilateral L-S distribution. Straight-leg raising elicited severe diffuse pain in both lower extremities. After the operation, the patient noticed complete relief from the bilateral and lower-extremity pain. In the 2 months following the procedure, the patient noticed further improvement in the S-1 and L-5 dermatomes on the left side. Positive results persist at the 1-year follow-up. **Adverse events**: N/A	In conclusion, this case emphasizes the complexity of managing recurrent tethering of the spinal cord/nerve roots following surgery for lipomyelomeningocele. Despite complete untethering, severe traction on nerve roots persisted, leading to significant symptoms like pain. Individualized treatment decisions, including nerve root division, were crucial in preventing further damage. Understanding the mechanisms of tethering is essential for improving treatment strategies and patient outcomes.
Borgstedt-Bakke, 2020[176] N = 45 Denmark	Other N/A	**Bladder:** N/A **Neurological:** Short-term follow-up was on average 4.7 months (range 1.2–10.5 months) and long-term follow-up was on average 72.6 months (range 22.8–153.5 months). The number of patients who improved was halved between short- and long-term follow-up, whereas the number of patients who deteriorated increased more than 4 times. The percentage of patients who stabilized is approximately the same at short- and long-term follow-up.	Tethered cord release in myelomeningocele patients initially provides a short-term benefit, but this effect diminishes over time, leading to uncertainty about long-term effectiveness and potential complications

		Adverse events: Perioperative complications occurred in 1 of 47 operations (2%); this was a neurotmesis. Due to the poor preoperative neurological status of the patient, no major neurological worsening was observed. Postoperative complications occurred in 7 procedures (15%). Of these, 2 were CSF leakage, 2 were suspected meningitis (both treated before CSF was cultured), 1 was a wound infection, 1 was a fistula, and 1 was fecal incontinence. This results in a total complication rate of 17%. One procedure (2%) was discontinued prematurely due to high risk of neurological deterioration in a complete TCR procedure.	
Bowman, 2009[177] N = 163 US	Other After adequate shunt function is confirmed, the child is positioned prone on chest gel rolls to avoid pressure sores. Prior to positioning, a urinary catheter is placed. A prophylactic antibiotic is administered. Preoperative MR images assist in determining the location and extent of the surgical incision (Fig. 3). Most of the time, the entire previous myelomeningocele scar will need to be reopened. If the child originally underwent closure with a transverse incision, we create a longitudinal incision dorsal to the placode. The incision is started superiorly, dorsal to the last intact lamina, and carried deep to the fascial layer. The paraspinal musculature is dissected laterally, exposing the last intact lamina. The ligamentum flavum is released from the undersurface of the intact lamina utilizing periosteal elevators, thereby exposing the superior epidural plane. If adequate	**Bladder:** In 30 children (26%), worsened urological functioning was a clinical sign of tethering, as determined by our urologist based on cystometrography, voiding cystoureterography, and/or renal ultrasonography. Thirty-seven procedures (23%) were performed for deteriorating urological functioning, and in 10 cases this was the sole indication for intervention. One child is currently in the early postoperative period and therefore has not yet undergone postoperative studies. In the remaining 36 procedures, 64% resulted in improvement and 36% in stabilization of urological symptoms on the postoperative evaluation. Postoperatively, no child had worsened urologically. Interestingly, 9 children have undergone an untethering for reasons other than urologic decline but have experienced an improvement in urologic functioning postoperatively. One child, however, has developed a decrease in his bladder capacity that has gradually improved back to baseline as shown on serial cystometrograms **Neurological:** Forty-seven children (41%) received diagnoses of symptomatic tethered cords after their LE strength declined. Fifty-four TCRs (33%) were performed in these 47 children. In 6 procedures (11%), a change in the MMT was the only indication of neurological worsening. In these 54 release surgeries, 70% resulted in improvement in motor functioning as assessed by physical therapists on the postoperative MMT, and in 28% the patients remained in stable condition. One surgery (2%) led to further decline in the child's LE motor strength postoperatively. Thirty-seven TCRs (23%) were performed in 34 patients (30%) due to the development of LE contractures. In 1 patient, the development of contractures was the only symptom of tethering. As	Tethered cord release is beneficial in preserving neurological, urological, and orthopedic functioning in children born with a myelomeningocele

	normal dura mater is not present, then a small inferior laminectomy is completed with bone rongeurs. If there is significant fibrofatty tissue in the epidural plane, the CO2 laser is useful in identifying the dura distally. Prior to dural opening, the child is tipped gently into the Trendelenburg position to limit the amount of spinal fluid loss. The dura is subsequently opened superiorly and retracted laterally. At the time of the original closure, the placode is imbricated, and hence, the tether is usually along the dorsal, pial suture line. During the dissection, we continually work distally on either side of the cord, taking care to preserve all dorsal nerve roots. All intradural dissection is completed with operating loupes and a headlight. If the spinal cord is densely adherent to the dorsal dura, dissection is carried out laterally on either side of the adherent zone, eventually circumferentially untethering the cord, except for the dorsally adherent dura. At this point, usually by working gently in all directions, the small, adherent dorsal dura is able to be removed. At the conclusion of the untethering, the spinal cord relaxes into the anterior spinal canal. Our senior author (D.G.M.) has noted no difference in outcome when intraoperative neurophysiological	expected, 22% of the contractures were improved postoperatively as assessed clinically by an orthopedic surgeon, with 78% remaining in stable condition. Spasticity was the indicator of tethering that led to 75 TCR procedures (46%) completed in 54 patients (47%) and was the only indication in 11 cases. Evaluation by orthopedic and rehabilitation medicine specialists 3 months postoperatively in these patients revealed that spasticity was improved in 63% and remained stable in 37% of the cohort. A worsening in the child's gait was a clinical sign of symptomatic tethering in 29 patients (25%) who underwent 32 procedures (20%). Two release surgeries were performed in a patient with gait changes as the only indicator of tethered cord. At the 3-month postoperative visit, 79% of patients showed improvement in this symptom, and 19% remained stable, as determined by orthopedic surgery and rehabilitation medicine specialists. One child (3%), the same child who had a worsened MMT postoperatively, had a worse gait because of increased weakness in her quadriceps. **Adverse events**: 3.5% of patients were neurologically worse after untethering. All 4 patients declined by at least 1 motor level on the MMT. In 3 patients, this weakness arose after the first untethering, and in another patient after the second surgery. In 2 patients, there was an associated lesion consisting of a large, distal dermoid tumor in 1 child, and a diastematomyelia with a thickened, fatty filum in another. Other complications have consisted of CSF leak (4%) and wound dehiscence/infection (7%). No patient who required a dural patch developed a postoperative CSF leak. Of the patients with a postoperative CSF leakage, 4 required temporary CSF diversions and another underwent ventriculoperitoneal shunt revision. One patient required a wound revision and another improved after an extended period of flat bed rest. In the 2 children with wound dehiscence, intravenous antibiotic agents were used with dressing changes; a sample in 1 patient cultured positive for meningitis. All cases of superficial wound dehiscence healed with local wound care (wet to dry dressing changes).	

	monitoring is used. Consequently, these surgical procedures are completed without the use of monitoring, but with diligent preservation of all nervous tissue during the release, even if the spinal cord cannot be untethered completely. Once the spinal cord is completely untethered, the spinal column should be inspected for other pathological entities including dermoid tumors in the distal spinal cord, a fatty or thickened filum, or split cord malformation. If other pathologies are confirmed, they are resected or released. After confirming that no other lesion is present, the dura is closed in a watertight fashion. Synthetic and cadaveric dural substitutes were used in 9 patient (AlloDerm in 4; cadaver dural graft in 4; GoreTex in 1) to create a capacious, watertight dural closure. The deep layers are closed and the skin is secured with nonabsorbable suture. Postoperatively, the child is maintained on flat bed rest for 4 days and then slowly mobilized		
Etus, 2006[181] N = 6 Turkey	Other NR	**Bladder:** NR **Neurological:** Follow up examination of the five patients in whom intradural exploration and microsurgical untethering of the spinal cord were performed showed that they were neurologically stable. The patient treated with a simple subcutaneous resection of the sac without releasing the intradural tethering bands was admitted to our clinic with progressive scoliosis, spasticity of the lower extremities and worsening of hand function 16 months following the initial operation. MRI of the spine revealed traction of the spinal cord dorsally at the	We suggest that the surgical technique in these lesions should include careful intradural exploration and microsurgical release of the spinal cord by meticulous resection of all tethering bands. This enables postoperative neurological improvement and possible prevention of future neurological

		level of C7, and a prominent syrinx at C4–C7. The patient was re-operated. Using the operating microscope, a careful intradural exploration was carried out, and microsurgical release of the spinal cord was performed by meticulous resection of all tethering bands and fibrosis. Postoperatively, the neurological deficits gradually improved in this patient. Postoperative follow up MRI studies of the spine showed that the spinal cord was untethered and that the width of the syrinx cavity had diminished, which were consistent with the neurological improvement of the patient **Adverse events**: NR	deficits due to cord tethering
Finger, 2019[439] N = 58 Germany	Other All surgical procedures were performed under general anesthesia with the patient in a prone position; a small midline incision was used over the lumbosacral junction; an interlaminar fenestration or partial hemilaminotomy, a small durotomy, was performed; the filum terminale was identified and then transected; wound closure was two-layered including a watertight closure of the fascia	**Bladder:** At the time point of first postoperative outpatient visit, a total of 14 patients showed improvement of symptoms (63.7%), in 7 patients a deterioration of the symptoms could be stopped (31.8%). **Neurological:** At the time point of first postoperative outpatient visit, a total of 14 patients showed improvement of symptoms (63.7%), in 7 patients a deterioration of the symptoms could be stopped (31.8%). **Adverse events**: The retethering rate in the patient cohort was 5.2% (3/58). From the symptomatic patients, two developed a retethering (9.1%) in comparison to one patient from the initially asymptomatic patients (2.8%; p = 0.30). The overall complication rate was 1.7%.	Transection of the filum terminale is a safe and effective procedure, with 63.7% of symptomatic patients experiencing clinical improvement
Kobets, 2021[191] N = 9 US	Other Nine patients in the series underwent 12 surgeries total, with two having symptoms mild enough to not warrant surgery, five undergoing a single detethering procedure, one undergoing three surgeries, and one undergoing four successive surgeries due to a recurrent symptoms and supporting radiographic findings; all initial surgeries addressed the split cord and remote low-lying conus, when identified at that time, and subsequent surgeries addressed the tethered low-lying	**Bladder:** N/A **Neurological:** Motor recovery was delayed in patients with preoperative deficits but was back to baseline by 3-month follow-up. **Adverse events**: Two patients experienced wound dehiscences which were oversewn and corrected, and two patient experienced motor deterioration postoperatively that significantly improved back to baseline upon follow-up at 3 months. Of the two patients who had multiple detethering operations, both experienced a return of their leg pain and clinical symptomatology consistent with tethered cord syndrome with a follow-up MRI consistent with a low-lying conus, fatty filum, or a dural adhesion band prior to the decision to reoperate. One had transient motor decline after her second surgery, which was resolved by the first follow-up, and both experienced years of	Surgery is recommended for patients with concurrent split cord and tethered cord syndrome, as the majority of patients in the study improved with operative intervention; however, it is noted that conservative management may be successful for up to 25% of patients, and even after multiple operative interventions, some patients may experience symptom recurrence decades later, but reoperation can still provide years of relief and should be considered.

	conus; of the seven patients who underwent detethering procedures, two underwent duroplasty with an artificial graft as stated, all but one had intraoperative monitoring utilized, and all remained prone for 48 hours after surgery, followed by a day lying flat, after which the activity was liberated	improvement of their leg pain after each subsequent surgery after the first.	
LaMarca, 1997[193] N = 270 US	Other NR	**Bladder:** FFT patients: urinary symptoms improved in 3 of 8 cases after first operation; LCM patients: urinary symptoms improved in 6 after first operation, 4 of 18 cases of urinary symptoms improved after second operation **Neurological:** FFT patients: motor symptoms improved in all cases after first operation; LCM patients: muscle weakness in 26 cases after first operation, muscle symptoms in 19 of 26 cases after second operation **Adverse events**: NR	Spinal lipomas should be operated on as soon as possible on a prophylactic basis, and careful and constant follow-up should be carried out to permit prompt reintervention in cases with deterioration
Pierre-Kahn, 1997[440] N = 291 France	Other For the vast majority , the objectives have been to free and decompress the cord when necessary, while sparing functional nervous tissue and preventing retethering; to achieve these aims, the surgical goals have been to remove as much lipoma as possible, to divide adhesions, and enlarge the dural sac before closing; the technique used depended upon the type of lipoma	**Bladder:** Constipation was more frequent than diarrhea and sometimes so severe that digital evacuation of the rectum was necessary. Stool leakage was more often due to stercoral retention than to sphincter hypotonia, and all patients with such problems also had urinary disorders. More than 60% of the patients with such lipomas benefited from surgery, while around 30% of those with preoperative deficits deteriorated with time, as did 47% of those operated on in the absence of neurological deficit - the functional loss in these patients was severe, an average of 3.8 points in our functional score, where the bowel function was 0.4 points. 3 patients complained postoperatively of insensitive bladder, at least during the first few postoperative weeks. Permanent deterioration. Permanent deterioration occurred in 10 of the 253 patients (3.9%) operated on for lipoma of the conus. Sphincteral disturbances were more frequent than others, and were explained by bladder hyposensitivity rather than by bladder paralysis. Of 21 preoperatively asymptomatic patients, 20 (95.2%) remained asymptomatic. The 1 patient who developed symptoms showed only moderate deterioration, complaining of a slightly disabling dysuria related to a hyperactive bladder.	The lack of basic information remains a stumbling block to management of these patients. Until this is remedied, we are unable to recommend prophylactic surgery in patients with asymptomatic lipomas of the conus.

		Neurological: Preoperative neurological def- icits existed in 57% of the patients and were congenital in 22%. Clinical signs and symptoms recorded were pain in 13.3% of the patients and/or neurological deficits affecting sphincter (52%), motor (27.6%) and sensory (22.4%) functions. Of the 32 patients with no preoperative deficits, 17 were still symptom free (53.1%), but 15 had deficits (46.9%). Thus, of these patients, who were symptom free before surgery and operated on prophylactically, 93.6% were still neurologically normal 1 year after surgery. In our experience, apart from scoliosis or club foot, all other types of neurological deficits were improved by surgery. **Adverse events**: In 37 cases, the lipomatous filum was cut or removed as expected, but in 1 case (2.6%) this could not be achieved owing to the presence of lipomatous roots. Decompression and/or untethering of the nervous system were correctly achieved in 202 of these 253 cases, but in the remaining 51 patients (20%), surgery was stopped owing to the complexity of the malformations. 1 patient developed septicemia and 1, pulmonary embolism. Local complications affected almost 20% of our patients (meningocele, subcutaneous infection, CSF leak, wound non-union, meningitis, skin necrosis).	
Satar, 1997[205] N = 28 US	Other NR	**Bladder:** Early postoperative evaluation revealed that 8 patients (29%) had improvement after surgery, including 2 of the 15 who had an abnormal neurological examination and 6 of the 10 who had an abnormal urodynamic assessment. Conversely the condition of 9 patients (32%) worsened after surgery, including 4 of the 13 who were neurologically and 6 of the 18 who were urodynamically normal (including 1 with deterioration in both categories) Because these children were followed periodically after surgery with careful neurological and urodynamic examinations, several had changes with time. The condition of 7 patients (25%) continued to deteriorate, including 6 urodynamically and 5 neurologically with 4 in both categories. Two children had improvement (7%), 1 each neurologically and urodynamically. The remaining 19 cases (68%) maintained a stable neurological and urodynamic condition. Six of the 7 patients (21% of the total) with progressive deterioration underwent secondary spinal surgery for tethering at a mean age of 8.5 years (range 4 to 15). At the latest followup neurological and	Early surgical repair seems to provide a degree of protection against later spinal cord tethering, and subsequent neurological and/or urodynamic deterioration (25% of our patients versus a reported 80% of those followed expectantly)

		urodynamic states stabilized after this secondary spinal surgery in all children. **Neurological:** Early postoperative evaluation revealed that 8 patients (29%) had improvement after surgery, including 2 of the 15 who had an abnormal neurological examination and 6 of the 10 who had an abnormal urodynamic assessment. Conversely the condition of 9 patients (32%) worsened after surgery, including 4 of the 13 who were neurologically and 6 of the 18 who were urodynamically normal (including 1 with deterioration in both categories) Because these children were followed periodically after surgery with careful neurological and urodynamic examinations, several had changes with time. The condition of 7 patients (25%) continued to deteriorate, including 6 urodynamically and 5 neurologically with 4 in both categories. Two children had improvement (7%), 1 each neurologically and urodynamically. The remaining 19 cases (68%) maintained a stable neurological and urodynamic condition. Six of the 7 patients (21% of the total) with progressive deterioration underwent secondary spinal surgery for tethering at a mean age of 8.5 years (range 4 to 15). At the latest followup neurological and urodynamic states stabilized after this secondary spinal surgery in all children. **Adverse events**: NR	
Schoenmakers, 2003[207] N = 73 Netherlands	Other Surgical techniques for release of the tethered cord were: (1) removal of excessive lipomatous tissue, (2) resection of the midline bony or cartilaginous spur in cases of split cord malformation, (3) transection of the filum, and (4) a duroplasty. All untethering procedures were performed using standard microsurgical techniques. Intrinsic lipomas were debulked using a microscope-mounted CO2-laser. All initial surgical releases were performed by the same, experienced	**Bladder:** NR **Neurological:** In all patients, 6 weeks to 6 months after surgery, ambulation level remained stable compared with the preoperative situation. Late deterioration of the ambulatory status was seen in five patients; three of them had lipomyelomeningocele and two myelomeningocele with intradural lipomas. In 26 of the 44 patients ambulation remained stable during the entire follow-up period. Thirteen children were too young to ambulate at time of operation (<2 years 6 months). In the long-term, four of the patients became community ambulant: they all had lipomyelomeningocele. In two of these children, ambulation level was normal half a year after operation (at the age of 2 years 6 months), but it deteriorated in the long term and they became community ambulators. All other children younger than 2 years 6 months of age (n=9) at time of operation, developed normal walking abilities that remained stable during the entire follow-up. During long-term follow-up (ranging from 4 to 9 years)	After neurosurgical untethering, long-term stability in neurosegmental motor level and ambulatory status is observed in most patients

	pediatric neurosurgeon	44 children underwent a total of 57 untethering operations. Thirty-five children had a single untethering procedure. Revision of the initial tethered cord release was seen in nine of the 44 children. Five patients had lipomyelomeningocele, three had myelomeningocele, and one had filum terminale lipoma. In the patients with lipomyelomeningocele, two patients required three releases, and one patient underwent four releases. All these patients presented with recurrent acute back pain, combined with progressive foot deformities due to progressive neurological loss. The other six patients had two releases. The second release was carried out 1 year 6 months to 6 years to after the initial untethering. The presence of lipomas (17 of 44), and age at operation were not significantly associated with the occurrence of retethering **Adverse events**: NR	
Vassilyadi, 2012[146] N = 146 Canada	Other A low lumbar single or partial laminectomy was performed, followed by a linear durotomy to expose the cauda equina, the filum terminale was identified based on its thickness and pale color, approximately 1 cm of the filum terminale was exposed, coagulated at a low frequency with the bipolar instrument at either end, and sectioned after 0.5–2 mA stimulation with a hand-held battery-operated stimulator; in the majority of cases a specimen was submitted to Pathology; intraoperative neurophysiology monitoring was not used	**Bladder:** At primary presentation, 51.4% had bladder/bowel dysfunction. Patients with bladder/bowel dysfunction improved by 84%. **Neurological:** At primary presentation, 26.7% had neuroorthopedic symptoms. Patients with neuroorthopedic symptoms improved by 92%. **Adverse events**: Of the 146 patients at CHEO who underwent surgery, 7.5% retethered, with 36% being initially asymptomatic.	A more conservative approach is needed for initially asymptomatic children without tethered cord symptoms to avoid unnecessary surgery and the potential risk of symptomatic retethering in the future
Yong, 2011[217] N = 152 Canada	Other All patients underwent similar initial procedures to divide the filum terminale. After a single-level or partial laminectomy, a linear durotomy was performed to expose the cauda equina	**Bladder:** Patients with pain had improvement in their symptoms after surgery in 87% of cases. Neuro-orthopedic abnormalities improved in 73% of cases, bowel or bladder complaints in 72%, and scoliosis in 44%. Among retethers, all patients in both groups underwent a microsurgical lysis of adhesions with immediate improvement in symptoms. No further procedures were	The study highlights the risk of symptomatic retethering after a simple filum snip, recommending cautious long-term follow-up

	below the conus medullaris. The filum terminale was identified macroscopically and isolated. If there was any uncertainty, electrical stimulation of the suspected filum and obvious nerve roots was used to confirm what was the filum on the basis of the amplitude of the stimulation required to cause a muscle contraction. In the majority of cases, the filum was released by excising a section for histopathology. The dura was closed in a primary fashion with a braided polyglactin (Vicryl) suture in all cases. Repeat procedures for untethering varied depending on the pathology observed but in general included extension of the laminectomy, repeat division of the filum terminale, and a dorsolateral lysis of adhesions when necessary. Electrophysiological monitoring was used, and duraplasties were again avoided	required for late retethers, whereas 4 of 8 early retethers went on to have 1 to 4 additional procedures for recurrent scarring of neural elements to dura. Despite repeat surgery, 6 of the 8 early retethers developed recurrent symptoms **Neurological:** Patients with pain had improvement in their symptoms after surgery in 87% of cases. Neuro-orthopedic abnormalities improved in 73% of cases, bowel or bladder complaints in 72%, and scoliosis in 44%. Among retethers, all patients in both groups underwent a microsurgical lysis of adhesions with immediate improvement in symptoms. No further procedures were required for late retethers, whereas 4 of 8 early retethers went on to have 1 to 4 additional procedures for recurrent scarring of neural elements to dura. Despite repeat surgery, 6 of the 8 early retethers developed recurrent symptoms **Adverse events**: There were no deaths in the cohort related to surgery. Eighteen patients experienced 20 postoperative complications, yielding an overall complication rate of 12%. Major complications included bacterial meningitis in 1 patient and cerebrospinal fluid (CSF) leaks in 3. With regard to minor complications, pseudomeningoceles (8 patients) and superficial wound infections (7 patients) were the most common. One patient developed aseptic meningitis. Among the initial procedures performed on those who went on to be late retethers, only 1 of 5 had a complication (pseudomeningocele). In contrast, 3 of 8 patients in the early retethering group had complications after the initial procedure: 2 CSF leaks and 1 case of aseptic meningitis. Two patients who retethered late were initially operated on in the first year of life for prophylactic reasons, and all 5 patients with late retethering re-presented with urological dysfunction. In contrast, all patients who retethered early were initially symptomatic and re-presented with back and leg pain in addition to other symptoms.	
Acaroglu, 2017[218] N = 6 Turkey	Other surgery Patients underwent corrective surgery with instrumentation for congenital scoliosis associated with tethered cord (n=6), with five patients underwent corrective	**Bladder:** N/A **Neurological:** One patient's neurologic status gradually deteriorated to complete paraplegia in one week, this complication could not be attributed to specific pathology except very poor oxygenation of the cord because of respiratory problems following surgery that necessitated	Corrective surgery for severe congenital spinal deformities with a tethered cord can be challenging with a high complication rate, and in select cases, a staged anterior and

	surgery following a detethering operation, one patient with diastematomyelia did not have surgery for excision for the bony spur, and two of the patients had only posterior surgeries, while four had both anterior and posterior; one Harrington and one Texas Scottish Rite Hospital (TSRH) instrumentation was used for the cases with only posterior surgeries with extension of the instrumentation down to the pelvis in the latter patient; ISOLA brand instrumentation was used for the other four cases with anterior and posterior multiple osteotomies, and none had to be extended down to the pelvis; the osteotomies were performed as closing wedges of the convex side of the deformity so as not to elongate the spinal column and stretch the spinal cord, and did not coincide with the level of the diastematomyelia in any of the cases; use of sublaminar wires was avoided in most cases unless the spinal canal could be demonstrated to be normal in diameter during surgery; the follow-up period ranges from 1 to 10 years for the five patients with corrective surgery, and the sixth patient was not followed for the same follow-up time because they died in the third postoperative month because of respiratory problems (see adverse events)	continuous mechanical ventilation via a tracheostomy for one week **Adverse events**: Complications were seen in two patients. One patient had late deep infection of the instrumentation that necessitated hardware removal with mild loss of correction (from 45 degrees to 57 degrees). Another patient who had the most severe deformity in this group presented with a curve of 100 degrees and a forced vital lung capacity of 850 ccs. She had undergone sequential anterior-posterior surgery and demonstrated monoparesis of the left lower extremity after this intervention. Despite prompt removal of the instrumentation allowing collapse of the spinal column, her neurologic status gradually deteriorated to complete paraplegia in one week. This complication could not be attributed to specific pathology except very poor oxygenation of the cord because of respiratory problems following surgery that necessitated continuous mechanical ventilation via a tracheostomy for one week; she was weaned of the respirator in six weeks. This patient died three months after her discharge because of an acute upper respiratory tract infection.	posterior approach may be needed

Toshiaki, 2013[441] N = 69 Japan	Other surgery Lumbosacral laminectomy with electrophysiological monitoring: the dural incision was started at the normal proximal site; the presence of extensive arachnoidal adhesion required meticulous dissection using an operative microscope to ensure complete release of the spinal cord in a majority of the cases; at the time of dissection, any tethering bands were identified and divided, whereas any spinal roots were preserved unless these showed abnormal anatomical structure; the filum terminale was cut if it had not been cut during the previous operation; the surgical goal was to debulk and disconnect the fibrous tissue, or in lipoma cases, to remove residual lipomatous tissue that tethered the cord circumferentially; next, the pia was approximated by suturing with 8-0 nylon to reconstruct the neural placode; finally, reconstruction of the duralsac was performed; each patient was evaluated 4 weeks, 3 months, and 6 months postoperatively	**Bladder:** Urological symptoms subjectively improved in 4 of the 5 patients with urinary incontinence and in 1 of the 2 patients with residual urine, but neither of the symptoms completely resolved. **Neurological:** At the time of follow-up, back pain and leg pain/paresthesia improved in all patients. Sensory loss improved in 67% of patients. Progressive motor deficits that were present preoperatively all showed improvement postoperatively. Seven of 12 patients with motor deficits returned to their best status recorded, whereas 5 showed improvement, but did not achieve their best status recorded. In contrast, all leg/foot deformities or scoliosis remained unchanged. **Adverse events**: The most common complication was temporary lower leg paresthesia that recovered at follow-up. Aggravated dysuria was noted in 3 patients.	The study recommends early untethering operations for symptomatic relief in retethered cord syndrome, with emphasis on urodynamic study findings, particularly detrusor overactivity, as crucial indicators for early diagnosis
Chapman, 1995[442] N = 3 US	Repeat detethering The operation exposed extensive syringomyelia that reduced parts of the spinal cord to a translucent membrane, with a single cavity's fluid showing a protein content of 155 mg compared to CSF's 20 mg, leading to the	**Bladder:** N/A **Neurological:** Minor improvement in the sensor motor functions **Adverse events**: One case had stabilized condition with no improvement	Despite its simplicity, syringosubarachnoid shunting may require reoperation due to complexities like multiloculation, underscoring the importance of early treatment to minimize lasting neurological deficits

	insertion of a syringosubarachnoid shunt post-untethering the conus medullaris		
Colak,1998[443] N = 19 US	Repeat detethering First, an effort was made to delineate the lipoma extradurally and trace it to its insertion into the spinal cord. Second, the lipoma was debulked microsurgically, often using an ultrasonic aspirator or a laser, to permit the conus to move freely within the spinal canal, and tethering arachnoidal bands were divided. Third, the pia was approximated over the residual lipoma, if feasible, using 7-0 prolene sutues. Fourth, a capacious thecal sac was constructed with the inclusion of a dural graft, if necessary	**Bladder:** Three of 5 patients who presented with worsening bowel or bladder function had improvement (n = 2) or resolution (n = 1) of these problems postoperatively; 2 other patients failed to improve **Neurological:** Four of the 5 patients who presented with increasing leg weakness either regained function completely (n = 1), or improved significantly (n = 3) , and 1 patient had a stable residual deficit **Adverse events**: NR	To date, no type of graft material has been shown to entirely prevent this problem, and close long-term surveillance of such patients is required to allow detection and treatment of symptomatic retethering
Idriceanu, 2022[444] N = 209 France	Repeat detethering Removing a persistent lipoma, liberating the conus medullaris by precise dissection, attempting pia-to-pia closure, and conducting a duroplasty to create more space around the spinal cord; retethering occurred at the same site. with patients in a prone position, using the same skin incision, extended if necessary to reach nonfibrous tissues with careful dissection is performed, followed by removal of the subjacent vertebral lamina to expose the normal dura, also fibrous tissue and any remaining lipoma are carefully dissected and untethered, the pia mater is sutured for neural tube closure,	**Bladder:** One patient with bladder dysfunction showed improvement **Neurological:** 50% of the patients experienced an improvement in gait disturbances, but the rest of the patients retained their pre-surgical status **Adverse events**: Some patients experienced aggravation of scoliosis, worsening of preexisting condition, and back pain	When RTC is confirmed, the child should be referred to surgery as soon as possible, because the postoperative clinical outcome improved and surgery did not worsen patients' condition

	and a new, larger duroplasty is securely sutured to prevent cerebrospinal fluid leakage and pseudomeningocele, with 3 months to 13 years range of follow up		
Jackson, 2014[445] N = 6 US	Repeat detethering Fetal repair of the myelomeningocele followed by later surgical untethering performed by a single senior surgeon	**Bladder:** N/A **Neurological:** As some patients had weak, inconsistent signals that may not be consistent with normal function at some levels, the lowest level with consistent, reproducible neurophysiological responses across both modalities was noted as well. Five of the patients had functional signals definitively below the anatomical level. One patient had functional signals at or slightly below the anatomical level (L-3 in a patient with an L2–3 anatomical level). No patient demonstrated loss of signals above the anatomical level. **Adverse events**: N/A	The study shows improvement of neurological status with fetal repair for myelomeningocele, evident in enhanced lower-extremity function and neurophysiological monitoring signals below the anatomical level.
Maher, 2007[446] N = 22 US	Repeat detethering The surgical repeated untethering was to debulk and disconnect the fibrous tissue, or in some instances residual lipomatous tissue, that tethers the spinal cord to the thecal sac, with the primary goal being the complete circumferential untethering of the cord while also reconstructing the thecal sac to allow for proper cerebrospinal fluid bathing of the spinal cord and nerve roots, and whenever possible, reconstituting the neural tube to minimize potential contact between the cord and the dorsal and lateral dura mater, accompanied by the consistent use of electromyographic monitoring for anal sphincter and lower-extremity function assessment and the frequent application of the yttrium-aluminum-	**Bladder:** Patients experienced an improvement in urinary symptoms (53%) **Neurological:** Patients experienced an improvement in pain (81%), weakness (48%), and sensory function **Adverse events**: Postoperative cerebrospinal fluid leakage or pseudomeningocele, as well as new postoperative lower-extremity dysesthesia occurring in five cases (17%)	Cautioning that efficacy decreases and morbidity increases with each subsequent operation, and while the results represent an improvement over the natural history, the long-term outcomes remain uncertain

	garnet laser for both cutting fibrous bands and reducing residual lipomatous tissue		
Moens, 2010[447] N = 1 Belgium	Repeat detethering A spinal cord stimulator was surgically placed under epidural anesthesia, acatheter was inserted at L2 to L3 and the patient was injected with 0.5% ropivacaine with 0.5 micrograms/mL sulfenta with top-up doses of 4 mL 0.5% ropivacaine to reach a segmental sensory block; a Specify 565 electrode was inserted orthodromically at levels T9 to T10 and T11-T12; at higher levels of stimulation (T9 to T10), paresthesia was noted to her loins, abdominal wall and anterior part of the upper leg; paresthesias were achieved by stimulation at level T12, the electrode was centered at level T12 for definitive implantation	**Bladder:** N/A **Neurological:** A neurological examination revealed that our patient had no neurological problems besides the sensory deficit at her buttocks and leg and her hyper-reflexive neurogenic bladder problem. She scored 7 on the DN4 questionnaire for indicating neuropathic pain **Adverse events**: Repeat surgical interventions resulted in severe neuropathic pain in her lower back and right leg	Successfully achieving optimal results by implanting the epidural electrode in a more caudal position than usual and utilizing lower voltage, suggesting the potential efficacy of this intervention for neuropathic pain management in tethered cord syndrome
Ostling, 2012[448] N = 99 US	Repeat detethering One hundred consecutive patients were identified who had an operation at Cincinnati Children's Hospital Medical Center for division of a tight or fatty filum; one patient was excluded due to previous spinal surgery performed at an outside institution; the 99 consecutive study patients included 43 boys and 56 girls who ranged in age from 2 months to 19 years (mean 6.2 years) at the time of initial operation for division of a tight or fatty filum terminale; the decision to perform surgery was based on	**Bladder:** Both groups improved from baseline **Neurological:** Both groups improved from baseline **Adverse events**: 12 patients had at least one symptom or sign that had worsened; 5 children required a second operation for recurrent tethered cord syndrome; There were a total of 12 complications in 9 patients including 5 wound infections, 4 cerebrospinal leaks, 1 pseudomeningocele, 1 stitch abscess, and 1 transient headache	Most of the children who underwent division of a tight or fatty filum terminale, reported improvement or stability

	clinical symptoms and/or radiographic findings; radiographic findings included location of the conus, movement of the cord when positioned prone, and motion of the cord detected on cine imaging; patients were excluded if they were found to have a diagnosis of lipomyelomeningocele, myelomeningocele, dermal sinus tract, split cord malformation, or a spinal dysraphism other than an isolated tight or fatty filum; in all patients a similar operative procedure was performed; a single or partial lumbar laminectomy with a midsagittal durotomy was performed to expose the cauda equina below the conus medullaris, the filum terminale was identified; intraoperative electrodiagnostic stimulation was used in 58% of patients to confirm the identity of the filum; the filum terminale was coagulated and divided; the dura was closed primarily with a running suture; ninety-seven patients had clinical follow-up; mean follow-up for these patients was 33 months; eighty patients were followed for 6 months or more and 68 patients were followed for 12 months or more, two patients were lost to follow-up		
Finger, 2020[449] N = 32 Germany	Revision detethering All surgical procedures were performed under sterile conditions in the operating room with the patient under general anesthesia.	**Bladder:** Bladder dysfunction at 60.2% (95% CI, 41.6–78.7%) compared with the initial 79% **Neurological:** Paresthesia at 28.7% (95% CI, 12.6–44.8%) compared with 68%, weakness in the lower extremities at	Untethering surgery in adult patients is relatively safe and shows a reasonable likelihood of clinical improvement in pain, paresthesia, and

	The patient was operated via a midline incision in a prone position. Using microsurgical technique, the untethering of neural structures was achieved by its meticulous separation from mesenchymal tissue. Great emphasis was put on minimizing bleeding intradurally to prevent associated subarachnoiditis later on. Before the dura was finally closed, we irrigated the intradural space until the fluid was completely clear. Dura closure was done in a watertight fashion with a running suture with or without an additional duraplasty. To compensate for the loss of CSF due to the dura opening, we instilled irrigation fluid before finally putting the last stich. Based on our experience, we can hereby establish sufficient space of CSF flow around the neural structures and reconstruct the diameter of the dural sac to its maximal size. Subsequently, re-adaptation of the rectus spinal muscles and the watertight closure of the fascia was conducted. A two layered wound closure including topical skin adhesive finished the procedure	27.7% (95% CI, 11.1–44.4%) compared with 68% **Adverse events**: The incidence for immediate revision surgery for surgery-related complications was 7.9% (3/38). All three patients developed a CSF fistula with cerebrospinal fluid leakage. All revision surgeries were performed successfully without any long-term sequelae	weakness in the lower extremities, with the positive influence of intraoperative monitoring on preoperative paralysis improvement
Sakamoto, 1991[450] N = 4 Japan	Revision detethering Repeat untethering was performed in the standard manner (Fig. 3a and b). At two or three vertebral levels proximal to the bifid lamina, an osteotomy was performed with a chisel or a sagittal	**Bladder:** Two patients (cases 2 and 3) showed transient bladder dysfunction **Neurological:** In a series of 75 patients with surgically treated lipomyelomeningoceles, the neurological condition of six patients deteriorated 6 months to 14 years after the operation due to repeat tethering of the spinal cord **Adverse events**: NR	The study recommends the new surgical procedure as it can prevent dural adhesion and maintain cerebrospinal fluid (CSF) around the lumbosacral cord, providing a beneficial intervention for

	saw. Keeping the interconnected ligamentous structures, the laminar flap was turned upward and retracted. The rostral portion of the dura mater was opened. As the dural incision was extended caudally, the spinal cord was dissected from the dense scar tissue. A Malls bipolar coagulator and cutter system and a contact Nd:YAG (neodymium: yttrium-aluminum-garnet) laser, with a 50-microgram sapphire tip and 1 to 3 W in output power, were used for dissection of the neural tissue. Electrical stimulation was utilized for intraoperative monitoring of the contractions of the segmental muscle group and of the anal sphincter. This monitoring helped to identify the nerve roots involved in the lipomatous and scar tissue. Further removal of the residual lipomatous tissue involving the conus medullaris reduced the volume of the conus, while the pial layer was preserved for reconstruction of the conus medullaris. Then, the pial flaps were approximated for reconstruction of the conus medullaris. Thus, the spinal cord was completely released from the transdural adhesion. A new method was applied at this point. First, trans position of the spinal cord was carried out (Figs. 3c and 4A); the conus medullaris, dorsally		lipomyelomeningocele patients at a high risk of cord retethering after initial repair

	and/or laterally shifted in the dural sac even after untethering of the cord, was kept near the center of the dural sac so that it was not in contact with the dura mater. The dentate ligaments, if present, were divided close to the dura mater two or three vertebral levels rostral to the conus medullaris. The end of each spinal cut was sutured to the dura mater. A couple of stay sutures were also applied between the thick pial layer of the ventrolateral surface of the conus and the ventral dura mater. When, after untethering, the lumbosacral spinal cord was shifted to the right in the dural sac, stay sutures for transposition were applied mainly in the left ventrolateral surface of the conus medullaris. When the cord was shifted to the left, stay sutures were applied mainly in the right ventrolateral surface of the conus. For these stay sutures, 8-0 or 9-0 monofilament nylon thread was used. Thus, the conus that had been adherent to the surrounding dura mater was maintained around the center of the dural sac and kept away from the surrounding dura mater. After transposition of the spinal cord, the dural sac was reconstructed with a large patch graft of fascia lata and the dura mater was closed in watertight fashion. The laminar flap was brought back to its		

	anatomical position. A new technique was also employed in the extradural space of the bifid vertebral levels. Remnants of the bifid laminae on both sides were exposed at one to three vertebral levels, usually at levels L-4, L-5, and S-1. For laminoplasty, bone grafts of the rib or iliac bone were modified to resemble a lamina (Fig. 3d), and were then approximated to the exposed remnants of the laminae. The underlying dura mater, after repair with a graft, was sutured to the newly constructed posterior arches (Figs. 3e and 4B). These tenting sutures permitted sufficient CSF space to be preserved behind the conus medullaris which might otherwise readhere to the surrounding dura mater. Duration of follow-up period was 1 to 3 years.		
Hsieh, 2009[451] N = 2 US	Spine-shortening vertebral osteotomy After general anesthesia induction, the surgical procedure involved positioning the patient on a Jackson Spinal Table, employing neurophysiological monitoring through somatosensory evoked potentials, motor evoked potentials, and electromyography, making a midline incision to expose the spine from T-10 to L-2 with T-12 as the target for posterior vertebral column subtraction osteotomy, widely exposing the T-12 segment including posterior elements,	**Bladder:** Urodynamic studies showed enhanced urological function, notably increasing the functional bladder capacity to 250 ml, alongside normal bowel function **Neurological:** Improvement in the motor and sensory functions **Adverse events**: No complications	In recurrent Tethered Cord Syndrome cases, posterior vertebral column subtraction osteotomy offers a safer alternative to traditional detethering by reducing spinal cord tension, this technique, avoiding direct neural manipulation, minimizes complications but requires technical expertise.

	transverse processes, and proximal ribs bilaterally, and placing bilateral pedicle screw implants at T-10, T-11, L-1, and L-2 using a standard free-hand technique, all to provide a biomechanically stable construct with two levels of instrumentation both rostral and caudal to the posterior vertebral column subtraction osteotomy site.		
Steinberg, 2017[452] N = 1 US	Spine-shortening vertebral osteotomy A discectomy at T11/12 was completed, followed by partial corpectomy from the top of the T12 vertebral body down to the inferior aspect of the T12 pedicle. The ipsilateral pedicle was then removed. The patient was then turned to the prone position and a skin incision was made from T10-L2. Pedicle screws were placed at T10, T11, L1, and L2. A temporary rod was placed and laminectomy was completed at T12. This was followed by a partial laminectomy of T11 with facetectomy at T11/T12 to release the posterior elements in addition to the removal of the remaining T12 pedicle. Permanent rods were sequentially placed followed by the compression of the vertebral column. Neuromonitoring remained at baseline throughout the entirety of the procedure.	**Bladder:** Improved control of the bowel and bladder function although still required straight catheterization **Neurological:** Postoperative neurologic exam remained stable as compared to preoperative exam **Adverse events**: N/A	Spine shortening via vertebral osteotomy using a lateral retropleural approach is a viable treatment for the recurrence of tethered cord syndrome
Tanaka, 2023[453] N = 1 Japan	Spine-shortening vertebral osteotomy The patient underwent a spinal shortening procedure by 15 mm	**Bladder:** N/A **Neurological:** Neurological functions improvement	A new spinal shortening technique presents a promising option for relieving tension in cases of a

	for tethered cord syndrome involving an anterior discectomy with O-arm navigation and intravenous anesthesia, followed by a posterior osteotomy on the same day, where pedicle screws were placed from T11 to L3, Ponte osteotomy, and anulus resection was performed, and compression force was applied at each disc level, all under navigation guidance, with one year of following up	**Adverse events**: No complications postoperation	retethered spinal cord following initial untethering surgery.
Kacar, 2018[454] N = 26 Turkey	Surgical detethering As a surgical technique, in the primary TCS, release of the spinal cord was performed by cutting the fibrous bands and filum terminale and if there was a secondary TCS or accompanying malformation, surgical treatment was firstly performed for this malformation, following filum terminale was cut in the same session. All adhesions and fibrous bands around the rootlets and the surrounding neural tissues had been removed	**Bladder:** Pre-existing foot deformities, urinary incontinence and impotence remained unchanged **Neurological:** Pre-existing foot deformities, urinary incontinence and impotence remained unchanged **Adverse events**: Postoperatively 47% of the patients had back pain, in 17.8% had cerebrospinal fluid (CSF) fistula, in 5.9% CSF collection, numbness of the leg, impotence or urinary incontinence. But subsequently these complications were resolved. Only in 17.6% of the patients were asymptomatic after surgery	If surgery done earlier, the greater the likelihood of regression of the neurological deficit or stablization the deficits
Lee, 2022[455] N = 51 Korea	Surgical detethering N/A	**Bladder:** All patients experienced improved storage parameters in urodynamics and detrusor overactivity (DO) disappeared after 1 year's video urodynamic study (VUDS) and recurred in four (14.3%) patients who were not compliant in 5–6 times of CIC and medication. However, no further progression of DO and reduced compliance was seen as long as they were compliant to management. Preoperative detrusor sphincter dyssynergia (DSD) was changed into two kinds of sphincteric morphology. During the urodynamic filling phase, until 130% of age-adjusted estimated all patients experienced improved storage parameters in urodynamics and DO disappeared after	Re-untethering can effectively address urological problems at the cost of some neuro-orthopedic functions in some patients

		1 year's VUDS and recurred in four (14.3%) patients who were not compliant in 5–6 times of CIC and medication. However, no further progression of DO and reduced compliance was seen as long as they were compliant to management. Preoperative DSD was changed into two kinds of sphincteric morphology. During the urodynamic filling phase, until 130% of age-adjusted estimated **Neurological:** N/A **Adverse events**: N/A	
Maste, 2019[456] N = 9 India	Surgical detethering Surgical detethering: all post-operative outcomes were assessed between 1 and 2 months; the surgical procedure was optimized, individualized according to the etiology and specific pathology; the second surgery was aimed at dealing with the intradural pathology with detethering of cord and dysraphic elements with compulsory release of filum	**Bladder:** Statistically significant neurological improvement in bladder (P = 0.005) and bowel (P = 0.032) function was seen, but improvement in motor and sensory function was statistically insignificant because motor function and sensation was relatively less affected in comparison with bowel and bladder function at second presentation in our study. **Neurological:** At follow-up of 8–10 weeks, all patients had clinical improvement and significant neurological improvement with six patients being ambulatory (score of 5) on modified Hoffer ambulatory scale. **Adverse events**: One patient had cerebrospinal fluid leak which needed re-exploration and repair while the second patient had wound infection which was treated with antibiotics	Patients presenting with recurrent symptoms in an operated case of SD need to be investigated, cause of recurrence has to be identified, and if needed repeat surgery is recommended at the earliest
Scalia, 2021[457] N = 1 Italy	Surgical detethering At surgery, the posterior dysraphism was easily recognized along with the associated fibroadipose tissue; once a fibrous and hypertrophied dural sac was identified, the filum terminale was released under electrophysiological monitoring; instead of applying a dural substitute to expand the closure, a dural splitting technique (i.e., thickened, and fibrous dura on both sides was incised, split on the medial border, and reflected medially over the midline was used; next, a continuous non-	**Bladder:** The patient had a deficit of a neurogenic bladder, reported over 10 years after the initial repair of the lipomeningocele **Neurological:** The 16-year-old now presents with progressive low back pain and gait disturbances **Adverse events**: N/A	The dural splitting reconstruction technique for watertight dural closure of a tethered cord offered an alternative to performing a duroplasty

	adsorbable 4-0 Prolene suture allowed for closure of the respective flaps without tension, six months later, the lumbosacral magnetic resonance imaging showed no further dural adhesions or retethering		
Sun, 2018[401] N = 120 China	Surgical detethering N/A	**Bladder:** Primary detethering: Comparable improvement was obtained for paresthesia (24.4%), motor deficit (18.6%), bladder dysfunction (12.6%), and bowel dysfunction (21.2%). However, almost one-half (41.2%-47.4%) of the patients reported no improvement after untethering surgery. Moreover, 23.3%-40.2% of patients experienced deterioration, with motor deficit (40.2%) and bladder dysfunction (40.0%) the most frequent symptoms. Revision detethering: The results demonstrated that improvement could be acquired, with 13.3% improvement in pain, 18.8% in paresthesia, 11.8% in motor deficit, none in bladder dysfunction, and 5.9% in bowel dysfunction. Nonetheless, most patients (58.8%-70.6%) were no better off after the revision surgery. Moreover, the revision untethering was associated with risk of deterioration, with rates of deterioration of 31.3% for bladder dysfunction, 35.3% for bowel dysfunction, 20.0% for pain, 18.8% for paresthesia, and 17.7% for motor deficit **Neurological:** Primary detethering: Comparable improvement was obtained for paresthesia (24.4%), motor deficit (18.6%), bladder dysfunction (12.6%), and bowel dysfunction (21.2%). However, almost one-half (41.2%-47.4%) of the patients reported no improvement after untethering surgery. Moreover, 23.3%-40.2% of patients experienced deterioration, with motor deficit (40.2%) and bladder dysfunction (40.0%) the most frequent symptoms. Revision detethering: The results demonstrated that improvement could be acquired, with 13.3% improvement in pain, 18.8% in paresthesia, 11.8% in motor deficit, none in bladder dysfunction, and 5.9% in bowel dysfunction. Nonetheless, most patients (58.8%-70.6%) were no better off after the revision surgery. Moreover, the revision untethering was associated with risk of deterioration, with rates of	The untethering surgery for tethered cord syndrome should be approached cautiously, as its effectiveness varies for different symptoms, and recommends further exploration of indications and timing, considering conservative treatment and comprehensive care as an alternative for some patients, particularly those with recurrent symptoms.

		deterioration of 31.3% for bladder dysfunction, 35.3% for bowel dysfunction, 20.0% for pain, 18.8% for paresthesia, and 17.7% for motor deficit. **Adverse events**: N/A	
Thuy, 2015[410] N = 61 Australia	Surgical detethering Sixty-three detethering procedures were performed, four of which were redo operations; the most common complications were wound infection and cerebrospinal fluid leak; eight detethering procedures (12.7%) were complicated by wound infection, three (4.8%) by cerebrospinal fluid leak and two (3.2%) by both wound infection and cerebrospinal fluid leak; six detethering procedures (9.5%) required at least one return to theatre for wound repair or cerebrospinal fluid diversion; the majority of wound infections (75%) were able to be managed conservatively without return to theatre, however the majority of cerebrospinal fluid leaks (67%) required return to theatre and all children with both wound infection and cerebrospinal fluid leak required return to theatre	**Bladder:** 3 children showed postoperative improvement in sphincteric disturbance (bladder or bowel dysfunction) **Neurological:** 26.7% who had preoperative neurological, orthopedic or sphincteric deficits were noted to improve post-operatively. Improvement in motor function or gait disturbance was documented at clinician follow up for four children (36.4% of those with symptoms), sphincteric disturbance for 27.3%, scoliosis for 12.5% and back or leg pain for 16.7%. **Adverse events**: The most common complications were wound infection and cerebrospinal fluid leak. Six children (9.8%) required reoperation for wound issues and two patients (3.3%) required subsequent reoperation for cord retethering during the study period.	in the early post-operative period, detethering surgery did not result in deaths or new neurological deficits
Theodore, 2021[458] N = 20 US	Vertebral column shortening All posterior vertebral column subtraction osteotomy (PVCSO) procedures were performed at T12 or L1, with fixation one or more levels above and below the osteotomized vertebra, depending on bone quality and intraoperative evaluation.	**Bladder:** A total of 8 (50%) of the 16 patients who presented with urinary incontinence experienced symptomatic improvement (5/8) or resolution (3/8), while 6 (55%) of the 11 patients who presented with bowel incontinence experienced symptomatic improvement (4/6) or resolution (2/6) **Neurological:** Improvement in motor function was seen in 80% (8/10) of patients who presented with motor deficits. Of the 10 patients who presented with sensory abnormalities, 80% saw symptomatic improvement (6/10) or resolution (2/10)	Posterior vertebral column subtraction osteotomy was found to be an excellent extradural approach that may afford definitive treatment in this particularly challenging population

		Adverse events: One patient developed L1-level numbness, corresponding to the osteotomized vertebra	

Appendix G. PCORI Checklist

This systematic review adheres to the PCORI Methodology Standards (see table below).

Table G.1. PCORI Methodology Checklist

Standard Category	Abbrev.	Standard	Is This Standard Applicable to This SR?	List Sections and Pages of the SR Report Where You Address This Standard	If Applicable, Describe How and Why the SR Deviated From This Standard?
Standards for Formulating Research Questions	RQ-1	Identify gaps in evidence.	Yes	Report introduction	N/A
	RQ-2	Develop a formal study protocol.	Yes	AHRQ website	N/A
	RQ-3	Identify specific populations and health decision(s) affected by the research.	Yes	Introduction and methods section	N/A
	RQ-4	Identify and assess participant subgroups.	Yes	Methods section, KQ	N/A
	RQ-5	Select appropriate interventions and comparators.	Yes	Methods chapter	N/A
	RQ-6	Measure outcomes that people representing the population of interest notice and care about.	Yes	Method section	N/A
Standards Associated with Patient-Centeredness	PC-1	Engage people representing the population of interest and other relevant stakeholders in ways that are appropriate and necessary in a given research context.	Yes	KI, TEP	N/A
	PC-2	Identify, select, recruit, and retain study participants representative of the spectrum of the population of interest and ensure that data are collected thoroughly and systematically from all study participants.	Yes	KI and TEP info incorporated	N/A
	PC-3	Use patient-reported outcomes when patients or people at risk of a condition are the best source of information for outcomes of interest.	Yes	Methods section describes selection	N/A
	PC-4	Support dissemination and implementation of study results.	Yes	Early engagement of interest holders	N/A
Standards for Data Integrity and Rigorous Analyses	IR-1	A priori, specify plans for quantitative data analysis that correspond to major aims.	Yes	Protocol, PROSPERO	N/A
	IR-2	Assess data source adequacy.	Yes	Criteria in method section, results at beginning of result sections	N/A
	IR-3	Describe data linkage plans, if applicable.	Yes	SRDR	N/A

Standard Category	Abbrev.	Standard	Is This Standard Applicable to This SR?	List Sections and Pages of the SR Report Where You Address This Standard	If Applicable, Describe How and Why the SR Deviated From This Standard?
	IR-4	Document validated scales and tests.	Yes	Using published assessment methods	N/A
	IR-5	Provide sufficient information in reports to allow for assessments of the study's internal and external validity.	Yes	Evidence table appendix	N/A
	IR-6	Masking should be used when feasible.	No	N/A	The authors' qualifications and potential conflict of interest of included studies are important sources of information
	IR-7	In the study protocol, specify a data management plan that addresses, at a minimum, the following elements: collecting data, organizing data, handling data, describing data, preserving data, and sharing data.	Yes	Protocol on AHRQ website	N/A
Standards for Preventing and Handling Missing Data	MD-1	Describe methods to prevent and monitor missing data.	Yes	Methods (contacted authors)	N/A
	MD-2	Use valid statistical methods to deal with missing data that properly account for statistical uncertainty due to missingness.	Yes	SoE assessment	N/A
	MD-3	Record and report all reasons for dropout and missing data, and account for all patients in reports.	No	N/A	We depend on the reporting in primary studies.
	MD-4	Examine sensitivity of inferences to missing data methods and assumptions, and incorporate into interpretation.	No	N/A	There is no obvious way to do this in a systematic review.
Standards for Heterogeneity of Treatment Effect (HTE)	HT-1	State the goals of HTE analyses, including hypotheses and the supporting evidence base.	Yes	Methods section	N/A
	HT-2	For all HTE analyses, provide an analysis plan, including the use of appropriate statistical methods.	Yes	Methods section	N/A
	HT-3	Report all prespecified HTE analyses and, at minimum, the number of post-hoc HTE analyses, including all subgroups and outcomes analyzed.	Yes	Methods section	N/A

Standard Category	Abbrev.	Standard	Is This Standard Applicable to This SR?	List Sections and Pages of the SR Report Where You Address This Standard	If Applicable, Describe How and Why the SR Deviated From This Standard?
Standards for Systematic Reviews	SR-1	Adhere to National Academy of Medicine (NAM) standards for systematic reviews of comparative effectiveness research, as appropriate.	Yes	Methods section	No handsearching selected journals (lack of yield) or conference abstracts (insufficient detail for critical appraisal)

Appendix H. Appendix References

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