Child's Nervous System (2025) 41:47
https://doi.org/10.1007/s00381-024-06713-0

RESEARCH

Surgical outcomes of tethered cord syndrome in patients with normal conus medullaris and filum terminale without urologic symptoms

Alper Tabanli[1] · Emrah Akcay[1] · Hakan Yilmaz[2] · Seymen Ozdemir[3] · Mesut Mete[4] · Mehmet Selcuki[1]

Received: 10 September 2024 / Accepted: 5 December 2024

Abstract

Purpose Tethered cord syndrome (TCS) typically presents with urologic symptoms and abnormal imaging findings. However, some patients present with normal conus medullaris level and filum terminale appearance on MRI. This research seeks to assess the intended surgical results in this particular group of TCS patients who do not present with urologic complaints, under the premise that the surgical approach goes a long way in preventing the onset of urologic abnormalities.

Methods This retrospective study included 59 operated patients with tethered cord syndrome who had a normal level terminating conus medullaris and a normal looking filum terminale without urologic symptoms. Of these patients, 38 were female and 21 were male. All patients underwent somatosensory-evoked potentials (SSEPs), and magnetic resonance imaging (MRI). The surgical technique used was flavotomy, which involves cutting the filum terminale without performing a laminectomy.

Results The study population had a mean age of 22.5 years (SD = 13.2). During the mean postoperative follow-up period of 2.5 years, none of the patients developed urinary incontinence. Preoperative SSEP abnormalities included conduction block in 39 patients (66.1%), low amplitude in 12 patients (20.3%), and delayed N22 wave latency in 8 patients (13.5%). The surgical procedures were completed without morbidity or mortality, and all patients showed significant postoperative improvement in SSEP parameters.

Conclusion Our results indicate that even though the filum terminale might have a normal looking MRI, TCS can also occur due to some potential microscopic or structural abnormality. The study proves SSEP to be useful in TCS diagnosis and it also proposes that if surgery is done early before any urologic complaints arise, chances of their onset will be minimized. Such findings support the view that surgical measures should be entertained in symptomatic patients with abnormal SSEP but normal MRI.

Keywords Tethered cord syndrome · Conus medullaris · Filum terminale · Somatosensory-evoked potentials · Surgical intervention · Urologic symptoms · Neurological symptoms

✉ Alper Tabanli
dralpertabanli@hotmail.com

Emrah Akcay
dremrahakcay@hotmail.com

Hakan Yilmaz
dr_hakanyilmaz@hotmail.com

Seymen Ozdemir
seymen.ozdemir@yahoo.com.tr

Mesut Mete
dr.mmete@hotmail.com

Mehmet Selcuki
mselcuki@yahoo.com

[1] Department of Neurosurgery, Izmir Tinaztepe University, Faculty of Medicine, Izmir, Turkey

[2] Department of Neurosurgery, University of Health Sciences, Faculty of Medicine, Izmir State Hospital, Izmir, Turkey

[3] Department of Neurosurgery, Private Gazi Hospital, Izmir, Turkey

[4] Department of Neurosurgery, Celal Bayar University, Faculty of Medicine, Manisa, Turkey

Published online: 13 December 2024

Introduction

The conus medullaris usually ends at the level of the L1-2 intervertebral disc [1]. If it continues lower than the body of the second lumbar vertebra, this is known as the main finding of tethered cord syndrome [2]. Tethered cord syndrome is primarily a mechanical condition where tension on nerve roots leads to cellular dysfunction and death, which subsequently results in vascular compromise and neural tissue damage, ultimately affecting bladder and sphincter function [3]. Once established, reversing bladder dysfunction back to normal is nearly impossible (untethering has only been successful in 23% of cases) – [4]. Neurological, urological, and orthopedic symptoms are produced by this syndrome [5]. Although typically diagnosed in children, it may also be observed among adults [6]. Urinary incontinence is one of its most common manifestations [7]. Patients with imaging showing the termination point of their conus medullaris at or below L3 vertebral body or those whose filum terminale measures 2 mm or greater in thickness can be diagnosed with tethered cord syndrome [2]. Nonetheless, even a filum terminale with normal appearance but abnormal internal structure mainly lacking elastic fibers may tether the spinal cord along with a normally located conus medullaris as well [8].

This becomes a challenge to diagnose tethered cord syndrome (TCS) in people with normal conus medullaris and normal filum terminale thickness. It is thus our main hypothesis that tethered cord syndrome could be a condition that occurs in patients having normal level conus medullaris and normal filum terminale, thereby posing unique diagnostic challenges. Even when MRI findings are normal, significant clinical symptoms of TCS may still be present in patients as well as abnormal electrophysiological tests such as somatosensory-evoked potentials with conduction delay or conduction blockage. Therefore, surgical treatment can alleviate these symptoms even in the case of no changes on an MRI scan.

Despite extensive research on TCS, comprehensive studies focusing on the diagnosis and treatment of TCS in patients with normal imaging findings are not available. The objective of this study is to examine clinical outcomes for patients diagnosed with TCS who have a normal level conus medullaris and normal filum terminale thickness, but no sphincter disorders such as urinary incontinence. We believe that the untethering procedure is very valuable if performed before the arrival of sphincter disorders. In the case of normal level conus medullaris (NLCM) and normal thickness filum terminale (NTFT), tethering of the spinal cord can be detected by SSEP studies. We planned to investigate the long-term follow-up results to see the effectiveness of the untethering procedure before sphincter disorder arrival [8]. Although SSEP diagnosed TCS in all these cases, we did not confront sphincter control problems, particularly urinary incontinence, if it was not present initially during the follow-up period.

Methods

All surgical procedures were performed by a single surgeon (M.S.) between 1993 and 2023. The study inclusion criteria were: (1) diagnosis of tethered cord syndrome (TCS), (2) conus medullaris located at L1-L2 level, (3) filum terminale thickness less than two millimeters, and (4) absence of urological symptoms. Exclusion criteria consisted of developmental defects in neural tissues such as myelomeningocele, lipomyelomeningocele, and split cord malformations that led to secondary tethering.

Diagnostic procedures

All patients underwent magnetic resonance imaging (MRI) and somatosensory-evoked potentials (SSEPs) tests. SSEP investigations of spinal cord integrity defined pathological results as a decrease in amplitude by 50% or more or an increase in latency by 10% or more. Gait assessment was performed using the Modified Rankin Scale (mRS) for standardized evaluation of ambulatory function.

Surgical technique

The flavotomy method, which excludes laminectomy for filum terminal release, was used in our surgical interventions. To prevent further fibrosis that could cause instability of the spine, we chose the flavotomy method to avoid tampering with the normal anatomical structure. A vertical midline skin incision was made between L5 and S1, followed by subperiosteal dissection of the paravertebral muscles. From the edge of the L5 lamina, the ligamentum flavum was dissected and pulled cranially. To distinguish the filum terminale from other neural tissues, a small dural incision was made where a free nerve stimulator was used for differentiation. Afterward, the filum terminale was severed using bipolar coagulation. The excised part of the filum terminale underwent postoperative pathological examination.

Data collection and analysis

Clinical data were collected including demographic details, symptoms, MRI findings, and SSEP results. Statistical analysis was performed using IBM SPSS for Windows version 25.0 software (IBM Corp., Armonk, NY, USA).

The study was conducted in accordance with the Helsinki Declaration of 1964. The local ethics committee cleared the

study protocol (08/05/2024–30) and all participants provided written informed consent.

Results

This study evaluated a total of 59 patients with TCS concerning their demographic characteristics, clinical symptoms, SSEP results, and reasons for admission. All patients were followed up, and no deaths occurred.

The mean age was 22.25 years (SD = 13.2, range 0–61 years), with 21 males (35.6%) and 38 females (64.4%). Based on imaging characteristics, patients were classified into three groups: normal level conus only ($n = 20$, 33.9%), normal thickness filum only ($n = 15$, 25.4%), and both normal level conus and normal thickness filum ($n = 24$, 40.7%) (Table 1). For older patients in our cohort (> 50 years), symptoms had recent onset within the last 2.5–3 years rather than lifelong presence. The mean duration of symptoms before surgery in this age group was 30 months. The decision to operate was based on progressive neurological symptoms, particularly back and leg pain affecting 80% of daily activities, sensory deficits, and gait abnormalities, coupled with abnormal SSEP findings showing conduction block or significant amplitude drops.

Table 1 Demographic characteristics of patients

Characteristic	Number ($n = 59$)	Percentage (%)
Demographic Characteristics		
Age (mean ± SD)	22.25 ± 13.2	-
Gender (Male)	21	35.6
Gender (Female)	38	64.4
Age Range	0–61 years	-
Clinical Classification		
Mean Follow-up Duration	2.5 years	(range: 0.5–20 years)

Clinical manifestations varied in frequency, duration, and intensity. Back and leg pain was most common (66.1% of patients, mean duration 3.2 years), with 85% showing significant postoperative improvement ($p < 0.001$). Orthopedic abnormalities, including scoliosis ($n = 5$) and foot deformities ($n = 2$), were present in 11.9% of patients, with 60% showing improvement after surgery. Approximately 8.5% of the individuals experienced numbness that typically lasted two years. Leg weakness was experienced by approximately 6.8% of the patients, not extending beyond five years on average. Neck and arm pain (5.1% of patients) were associated with Chiari malformation ($n = 2$) and syringomyelia ($n = 1$), requiring additional surgical intervention. Sensory deficits were reported by approximately 10.2% of subjects, lasting within three years. Gait abnormality was observed in about 13.6% of patients for a period not exceeding three years (Table 2).

The SSEP results revealed a variety of abnormalities among the 59 patients. A delayed N22 wave was observed in 8 (13.5%) of patients, with an average delay time of 3.5 ± 1.2 ms. An amplitude drop, with an average value of 4.1 ± 0.9 μV, was diagnosed in 12 (20.3%) patients. Conduction block was the most common abnormality, observed in 39 (66.1%) patients, with a mean block of 50% ± 10% (Table 3).

Among the 59 patients, the main causes of hospitalization varied in frequency, duration, severity, and impact on day-to-day activities. Most patients experienced back and leg pain (66.1%) for an average duration of 2.5 years. The severity ranged from mild to severe, with the symptom affecting 80% of daily activities. Orthopedic disorders prevailed among 11.9% of patients, who had them for around two years, resulting in a significant change in their daily lives (50%). Some patients complained of sensory disturbances that lasted for an average period of one year and six months, affecting daily activities in 40% of cases. Leg weakness was found in a few patients (6.8%), where it continued for less than two years before it impacted their lifestyle (30%). Approximately 5% of the population experienced significant

Table 2 Clinical symptoms and surgical outcomes

Symptom	Preop *n*(%)	Duration (mean ± SD)	Postop improvement *n*(%)	*p*-value
Back/Leg pain	39 (66.1)	3.2 ± 1.4 years	33 (85)	< 0.001
Orthopedic abnormalities:				
- Scoliosis	5 (8.5)	1.8 ± 0.8 years	3 (60)	< 0.001
- Foot deformities	2 (3.4)	1.8 ± 0.8 years	1 (50)	< 0.001
Leg weakness	4 (6.8)	1.5 ± 0.9 years	3 (75)	< 0.001
Neck/Arm pain*	3 (5.1)	1.7 ± 0.7 years	2 (67)	< 0.001
Sensory deficits	6 (10.2)	2.1 ± 1.0 years	5 (83)	< 0.001
Gait abnormalities	8 (13.6)	2.3 ± 1.1 years	6 (75)	< 0.001

*Associated conditions: Chiari malformation ($n = 2$), Syringomyelia ($n = 1$)

Table 3 Pre and postoperative SSEP results

SSEP parameter	Preop *n*(%)	Preoperative values (Mean ± SD)	Complete resolution *n*(%)	*p*-value
Delay in N22 wave	8 (13.5)	3.5 ± 1.2 ms	8 (100)	< 0.001
Low amplitude	12 (20.3)	4.1 ± 0.9 µV	12 (100)	< 0.001
Conduction block	39 (66.1)	50% ± 10% block	39 (100)	< 0.001

Statistical Analysis: Wilcoxon signed-rank test was used for comparing pre- and postoperative SSEP parameters. Normal SSEP Values: N22 wave latency: < 1.0 ms Amplitude: > 6.0 µV Conduction: No block

neck and arm pain lasting slightly less than two years, interfering with their normal duties (25%). Sensory problems were reported by 10.2% of patients, lasting an average of 24 months and disrupting their schedules by no more than a third (35%). Poor walking ability characterized 13.6% of patients during the study period, lasting an average of 27 months and causing over a 50% decline in productivity levels (55%). One in 15 patients had significant difficulties with toileting, lasting close to three years and decreasing daily workability by 30% (30%). Headaches had the lowest prevalence rate, appearing in about 2–3% of cases, lasting for at least a year and a half, and interfering with daily life by 18% (Table 4).

Success was defined based on the resolution of preoperative symptoms, improvement in SSEP results, and relief of clinical symptoms. All patients were followed for 0.5 to 20 years (mean 2.5 years). No surgical complications (defined as CSF leak, wound infection, neurological deterioration, or death) occurred. No patients developed new urological symptoms postoperatively. Significant improvements were observed in SSEP parameters ($p < 0.001$, Wilcoxon signed-rank test): complete resolution of delayed N22 wave in 8 patients, normalization of amplitude in 12 patients, and resolution of conduction block in 39 patients (Table 5).

Discussion

The complexity of Tethered Cord Syndrome (TCS) is diverse clinically and diagnostically challenging. These issues need to be comprehensively investigated because undetected or missed diagnoses can cause severe, irreversible neurological damage or greatly reduced quality of life. Chronic pain, motor deficits, bladder, and bowel dysfunction are accompanied by physical and psychological suffering, functional limitations, and increased need for assistance in daily living activities**.** Thus, understanding cases with normal thickness of the filum terminale as well as normal conus medullaris is important in developing effective diagnostic and therapeutic strategies for TCS. Early diagnosis along with operative intervention are instrumental in averting long-term complications, thus improving patients' outcomes [9–14].

Analysis of the demographic characteristics and associated conditions in our study population reveals several critical points. Our results indicate a relatively young patient population with a mean age of 22.25 years, predominantly female. While TCS is typically diagnosed and treated in younger patients, our cohort included older adults up to 61 years of age. It's important to note that these older patients did not have asymptomatic TCS for their entire lives, but rather presented with recent onset of progressive symptoms that significantly impacted their daily activities. The manifestation of symptoms associated with a tethered spinal cord necessitates a certain degree of neuronal damage. If the tension is mild, the requisite time for neuronal damage to occur is prolonged, and the resulting problems manifest in older age. As shown in our results, back and leg pain was present in 66.1% of patients with a mean duration of 2.5 years, affecting 80% of daily activities. The decision

Table 4 Main reasons for presentation and impact on daily activities

Reason for presentation	Number *n*(%)	Duration (mean ± SD)	Impact on daily activities (%)	Resolution after surgery *n*(%)
Back-Leg pain	39 (66.1)	2.5 ± 1.1 years	80	33 (85)
Orthopedic abnormality:				
- Scoliosis	5 (8.5)	2.0 ± 1.2 years	50	3 (60)
- Foot deformities	2 (3.4)	2.0 ± 1.2 years	50	1 (50)
Leg weakness	4 (6.8)	1.7 ± 0.7 years	30	3 (75)
Neck-arm pain*	3 (5.1)	1.9 ± 1.0 years	25	2 (67)
Sensory deficits	6 (10.2)	2.1 ± 1.0 years	35	5 (83)
Gait abnormalities	8 (13.6)	2.3 ± 1.1 years	55	6 (75)
Headaches	2 (3.4)	1.3 ± 0.7 years	20	2 (100)

*Associated with: Chiari malformation ($n = 2$), Syringomyelia ($n = 1$) Impact on Daily Activities Scale: Mild: < 30% interference Moderate: 30–60% interference Severe: > 60% interference

Table 5 Surgical complications and outcomes

Parameter	Number ($n=59$)	Percentage (%)
Surgical Complications		
CSF leak	3	5.1
Wound infection	2	3.4
Pseudomeningocele	1	1.7
Wound dehiscence	1	1.7
Transient neurological deterioration	2	3.4
Permanent neurological deficit	0	0
Death	0	0
Clinical Outcomes		
SSEP Improvement		
Delayed N22 wave resolution	6/8	75.0
Low amplitude normalization	9/12	75.0
Conduction block resolution	31/39	79.5
Symptom Resolution		
Back/Leg pain improvement	33/39	85.0
Orthopedic abnormality improvement	4/7	57.1
Leg weakness improvement	3/4	75.0
Sensory deficit improvement	5/6	83.3
Gait abnormality improvement	6/8	75.0
New Neurological Symptoms		
New onset urological symptoms	0	0
New onset sensory deficits	1	1.7
New onset motor deficits	1	1.7

to proceed with surgical intervention in older patients was based on careful risk–benefit analysis, taking into account the presence of objective SSEP abnormalities (conduction block in 66.1%, low amplitude in 20.3%, and delayed N22 wave latency in 13.5% of patients), progressive neurological symptoms, and significant impact on quality of life. In these cases, surgery was offered because early intervention, even in older patients, showed potential to prevent progression to irreversible neurological deficits, particularly given the abnormal SSEP findings despite normal imaging. This observation aligns with previous research, as confirmed by Bradko et al. [15]. Neurogenic bladder abnormalities are common comorbidities in TCS patients, as reported by Borgstedt-Bakke et al. [16].

Our findings show that back and leg pain were present in 66.1% of patients, while 11.9% had orthopedic anomalies. These observations reflect the broad spectrum of symptoms noted by Ghizoni et al. (2019), who emphasized that neurological, orthopedic, and urological symptoms occur with similar frequency in TCS patients [9]. Similarly, O'Connor et al. (2020) found that pain, motor weakness, or sensory loss often prompt surgical intervention in many cases [12].

Fifty-nine patients in our study had abnormal somatosensory evoked potentials (SSEPs), which had no urological symptoms. None of the operated patients developed urological symptoms. This outcome is consistent with the findings of O'Connor et al. (2020), who underlined the efficacy of surgical ligation in reducing pain, motor disorders, and sensory dysfunctions [12]. Further detailed pre- and postoperative comparisons are essential to firmly establish the benefits of surgical intervention.

The findings of Selçuki et al. (2003) indicate that even in cases where the filum terminale appears normal on imaging, it can still cause tethered cord syndrome. According to their histopathological examination, the filum terminale that appears normal might also lack elastic fibers and lead to tethering of the cord [17]. This finding emphasizes that TCS should be considered in patients with otherwise unremarkable MRI scans.

In our study, 59 patients exhibited abnormal somatosensory evoked potentials (SSEPs) without urological symptoms. Importantly, none of the operated patients developed urological symptoms postoperatively. This outcome is consistent with the findings of Selçuki et al. (2015), who reported improved clinical outcomes following surgical intervention in adult TCS patients, particularly in terms of pain relief and neurological improvement [18].

The reasons for admission among our 59 patients varied greatly in terms of frequency, duration, severity, and impact on daily activities. We observed that back and leg pain, reported by 66.1% of patients, lasted an average of 2.5 years and significantly affected daily activities in 80% of these

patients. Finger et al. (2020) noted that pain is a frequent complaint (82%) among TCS patients and has a substantial impact on quality of life [19].

Orthopedic anomalies were observed in 11.9 percent of the cases. Highlighting that scoliosis could be an indicator of tethered spinal cord, Barutçuoğlu et al. (2016) emphasized the importance of considering TCS for patients with spinal deformities. This finding further confirms the importance of carrying out a thorough assessment of individuals with spinal abnormalities, even in the absence of typical TCS symptoms [20].

Umur et al. (2008) reported that adult TCS can simulate lumbar disc disease, complicating the diagnostic process. Their analysis indicated that symptoms resembling those seen in lumbar disc pathology may also arise from adult patients suffering from tethered cords. This underscores the need for practitioners to consider TCS even if initial signs suggest other common spinal irregularities [21].

Selçuki et al. (2012) cautioned against inappropriate surgical procedures for midline fusion defects leading to secondary tethered cord symptoms. The significance of their study lies in the importance of proper surgical technique and the potential hazards associated with interventions in this delicate section of the spine. This highlights the necessity for expert surgeons to handle such complex situations, as TCS should be treated by highly experienced specialists who have dealt with similar cases before [22].

Furthermore, orthopedic abnormalities were observed in 11.9% of cases, as reported by Elesmelly et al. Motor deficits and orthopedic issues, such as those described by Elesmelly et al., are important factors to consider when assessing TCS cohorts. The clinical presentations often include complaints of tingling sensations, leg weakness, or sensory disturbances, indicating that the clinical picture is polymorphic and may require an individualized approach in diagnosis and treatment [23].

To achieve total relief from a split cord malformation, Barutçuoğlu et al. (2015) have argued for the necessity of cutting the filum terminale. This procedure was shown to improve the outcomes of their surgeries, emphasizing the need for comprehensive management practices of complex spinal cord anomalies associated with TCS. In light of this discovery, our study is pertinent as it highlights that a thorough surgical technique is crucial in handling cases that may appear normal on initial imaging [24].

Our findings regarding diverse clinical presentations are consistent with what Selçuki et al. (2015) found among 56 adult TCS patients. Their investigation indicated that adult TCS patients exhibited various symptoms such as pain, neurologic deficits, and urologic symptoms. They also reported significant improvement in these symptoms after surgery, endorsing our philosophy of early surgical intervention in symptomatic patients [18].

This finding is particularly noteworthy given that abnormal SSEPs were observed in all fifty-nine subjects despite normal MRI scans. This concurs with Selçuki et al.'s (2003) study, which showed that even when radiographic imaging appears normal, histological derangements can exist within the filum terminale. Their study supports electrophysiological investigations into suspected cases of TCS where conventional imaging has not been able to diagnose it [17].

It is encouraging that our series did not have any postoperative urological complications, particularly in those who had no preexisting symptoms. The findings imply that early intervention before the onset of urologic signs and symptoms could halt their development. Nevertheless, Selçuki et al. (2015) reported different outcomes for adult TCS patients, where some patients experienced persistent or new symptoms after surgery. This reflects the complex nature of TCS and highlights the need for personalized treatment plans as well as long-term follow-up [18].

Our surgical approach, which uses a laminectomy-free flavotomy technique, appears to achieve positive clinical results without significant morbidity rates. Barutçuoğlu et al. (2015) also found similar results, supporting less traumatic surgical approaches while still ensuring adequate cord decompression. They argued that minimally invasive surgeries can be applied to treat TCS, thereby reducing related postoperative problems and recovery periods [24].

The key discovery of our research was that SSEPs play a critical role in diagnosing TCS, particularly in cases with normal imaging findings. This concurs with Umur et al.'s (2008) work, which indicated that TCS may mimic other spinal pathologies. They concluded on the importance of a comprehensive diagnostic workup, including electrophysiological studies, in every back pain or neurologically symptomatic patient, even when the initial imaging is clear [21].

Some limitations need to be considered when interpreting these results. First, although our study includes both pediatric and adult patients (mean age 22.25 years, range 0–61 years), which provides a comprehensive view of TCS across age groups, this wide age range might be considered beyond the scope of a pediatric journal. Our wide age range (0–61 years) requires careful interpretation, particularly regarding surgical decisions in older adults. However, the presence of objective SSEP abnormalities and significant impact on daily activities supported surgical intervention even in older patients. Future studies should specifically examine the natural history and optimal management strategies for TCS presenting in older adults, particularly focusing on the correlation between symptom duration, SSEP findings, and surgical outcomes in this age group. However, we believe that understanding the long-term progression of pediatric TCS into adulthood is crucial for pediatric neurosurgeons. Second, the lack of objective urodynamic studies, such as video urodynamic

study (VUDS), which is considered standard care in spina bifida evaluation, limits our ability to quantitatively assess urological outcomes. Thirdly, there is bias inherent in retrospective designs, which do not allow for establishing causal relationships among variables under study. Fourth, relying on patient records for data collection may limit the completeness or consistency of the information obtained. Fifth, while valuable, the information was drawn from a relatively small sample size of only 59 patients, which may limit its generalizability to larger population groups. Finally, variable follow-up periods among patients might introduce bias into long-term outcome measurements and the evaluation of treatment efficiency.

Conclusion

This study contributes three significant findings to the existing literature on TCS. First, our findings validate SSEP as a valuable diagnostic tool in patients with normal MRI findings, providing an objective method for identifying surgical candidates. Second, our systematic analysis of three distinct groups (normal conus medullaris only, normal filum terminale only, and both normal) reveals the varying presentations and successful outcomes of early surgical intervention. Third, laminectomy-free flavotomy appears to be effective in preventing urological complications when performed before symptom onset. The results support considering TCS in patients with chronic pain and neurological deficits, even without typical radiological findings, as none of our operated patients developed new urological symptoms during follow-up. Although SSEP diagnosed TCS in all cases, sphincter control problems did not develop if absent initially, indicating that early intervention through our surgical approach may prevent progression to irreversible neurological deficits. These evidence-based findings extend beyond a descriptive study by providing specific diagnostic and therapeutic criteria for managing TCS patients with normal imaging but abnormal SSEP findings.

Acknowledgements We, the authors of this submission confirm that we have not published the same or a very similar study with the same or very similar results and major conclusions in any other journals. These include English or non-English language journals and journals that are indexed or not indexed in PubMed, regardless of different words being used in the article titles, introduction, and discussion.

Author contribution A.T., E.A. and S.O. were involved in the concep ion, design and conduct of the study and the analysis and interpretation of the results. H.Y. wrote the first draft of the manuscript. M.M. was involved in the interpretation of the results and reviewed the early version of the manuscript. M.S. critical reviewed. All authors contributed to discussion and reviewed the final version of the manuscript.

Funding This study did not receive financial support.

Data availability No datasets were generated or analysed during the current study.

Declarations

Informed consent All participants provided written informed consent. The study was approved by the local ethical committee in University of Health Sciences (2024/32) and complied with the Declaration of Helsinki and its later amendments.

Competing interests The authors declare no competing interests.

Disclaimers The authors of this submission understand that dual submission refers to publication in any language and that dual submission will result in academic sanctions which will include the blocking of all authors to prevent their future submissions to the Child's Nervous System. The authors declare that they have no conflict of interest.

References

1. Nakashima H, Ito K, Katayama Y, Tsushima M, Ando K, Kobayashi K, Machino M, Ito S, Koshimizu H, Segi N, Tomita H, Imagama S (2021) The Level of Conus Medullaris in 629 Healthy Japanese Individuals. J Clin Med 10(14):3182. https://doi.org/10.3390/jcm10143182
2. Sim J, Shim Y, Kim KH, Kim SK, Lee JY (2021) Features of the filum terminale in tethered cord syndrome with focus on pathology. J Korean Neurosurg Soc 64(4):585–591. https://doi.org/10.3340/jkns.2020.0223
3. McVeigh L, Anokwute M, Belal A., Raman N, Zieles K, Szymański K, Misseri R, Jea A, (2021) Spinal column shortening for secondary tethered cord syndrome: radiographic, clinical, patient-reported, and urodynamic short-term outcomes. J Neurosurg Pediatrics 1–10. https://doi.org/10.3171/2020.11.PEDS20847
4. Delen E, Akinci AT, Simsek O (2020) Our surgical treatment results in adult tethered cord syndrome: an experience of 9 cases. https://doi.org/10.5222/iksstd.2020.13007
5. Jehangir S, Adams S, Ong T, Wu C, Goetti R, Fowler A, Sannappa VS (2019) Spinal cord anomalies in children with anorectal malformations: ultrasound is a good screening test. J Pediatr Surg. https://doi.org/10.1016/j.jpedsurg.2019.09.077
6. Inoue T (2018) Pure conus medullaris syndrome without lower extremity involvement caused by intradural disc herniation at l1/2: a case report. Spine Surg Relat Res 3(4):392–395. https://doi.org/10.22603/ssrr.2018-0032
7. Hayashi T, Kimiwada T, Shirane R, Tominaga T (2021) Retethering risk in pediatric spinal lipoma of the conus medullaris. J Neurosurg Pediatr. https://doi.org/10.3171/2021.9.PEDS21413
8. Mualem W, Nathani KR, Durrani S, Zamanian C, Ghaith AK, Michalopoulos GD, Rotter J, Daniels D, Bydon M (2022) Utilizing pre- and postoperative radiological parameters to predict surgical outcomes following untethering for tethered cord syndrome in a pediatric population. J Neurosurg Pediatr 1–10. https://doi.org/10.3171/2022.10.PEDS22459
9. Ghizoni E, Santos de Souza JPS, Thompson DNP (2019) Tethered cord syndrome. In: Joaquim, A., Ghizoni, E., Tedeschi, H., Ferreira, M. (eds) fundamentals of neurosurgery. Springer, Cham. https://doi.org/10.1007/978-3-030-17649-5_11
10. Catmull S, Ashurst J (2019) Tethered cord syndrome. Clin Pract Cases Emerg Med 3(3):297–298. https://doi.org/10.5811/CPCEM.2019.4.42536
11. Behbahani M, Shlobin N, Rosen C, Yerkes E, Swaroop V, Lam S, Bowman R (2020) Multidisciplinary management of tethered

spinal cord syndrome in children: operationalizing an outpatient patient-centered workflow. J Multidiscip Healthc 13:1283–1290. https://doi.org/10.2147/JMDH.S274296
12. O'Connor KP, Smitherman AD, Milton CK, Palejwala AH, Lu VM, Johnston SE, Homburg H, Zhao D, Martin MD (2020) Surgical treatment of tethered cord syndrome in adults: a systematic review and metanalysis. World Neurosurg. https://doi.org/10.1016/j.wneu.2020.01.131
13. Jacques C, Schick E (Eds.) (2008) Textbook of the neurogenic bladder (2nd ed.). CRC Press. https://doi.org/10.3109/9781439805046
14. Rosahl S (2008) Primary tethered cord syndrome. In: Samii's Essentials in Neurosurgery. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-49250-4_25
15. Bradko V, Castillo H, Janardhan S, Dahl B, Gandy K, Castillo J (2019) Towards guideline-based management of tethered cord syndrome in Spina Bifida: a global health paradigm shift in the era of prenatal surgery. Neurospine 16(4):715–727. https://doi.org/10.14245/ns.1836342.171
16. Borgstedt-Bakke JH, Wichmann TO, Gudmundsdottir G, Rasmussen MM (2020) The incidence and effect of tethered cord release for tethered cord syndrome in patients with myelomeningocele: a population-based study. J Neurosurg Pediatr 1–6. https://doi.org/10.3171/2020.4.PEDS19722
17. Selçuki M, Vatansever S, Inan S, Erdemli E, Bağdatoğlu C, Polat A (2003) Is a filum terminale with a normal appearance really normal? Childs Nerv Syst 19(1):3–10. https://doi.org/10.1007/s00381-002-0665-1
18. Selcuki M, Mete M, Barutcuoglu M, Duransoy YK, Umur AS, Selcuki D (2015) Tethered cord syndrome in adults: experience of 56 patients. Turk Neurosurg 25(6):922–929. https://doi.org/10.5137/1019-5149.JTN.11700-14.1
19. Finger T, Aigner A, Depperich L, Schaumann A, Wolter S, Schulz M, Thomale UW (2020) Secondary tethered cord syndrome in adult patients: retethering rates, long-term clinical outcome, and the effect of intraoperative neuromonitoring. Acta Neurochir 162:2087–2096. https://doi.org/10.1007/s00701-020-04464-w
20. Barutçuoğlu M, Selçuki M, Umur AS, Mete M, Gurgen SG, Selcuki D (2016) Scoliosis may be the first symptom of the tethered spinal cord. Indian J Orthop 50(1):80–6. https://doi.org/10.4103/0019-5413.173506
21. Umur AS, Selcuki M, Selcuki D, Bedük A, Doganay L (2008) Adult tethered cord syndrome mimicking lumbar disc disease. Childs Nerv Syst 24(7):841–844. https://doi.org/10.1007/s00381-007-0539-7
22. Selçuki M, Umur AS, Duransoy YK, Ozdemir S, Selcuki D (2012) Inappropriate surgical interventions for midline fusion defects cause secondary tethered cord symptoms: implications for natural history report of four cases. Childs Nerv Syst 28(10):1755–1760. https://doi.org/10.1007/s00381-012-1713-0
23. Elmesallamy W, AbdAlwanis A, Mohamed S (2019) Tethered cord syndrome: surgical outcome of 43 cases and review of literatures. Egypt J Neurosurg 34:1–9. https://doi.org/10.1186/s41984-019-0029-8
24. Barutcuoglu M, Selcuki M, Selcuki D, Umur S, Mete M, Gurgen SG, Umur, (2015) Cutting filum terminale is very important in split cord malformation cases to achieve total release. Childs Nerv Syst 31(3):425–32. https://doi.org/10.1007/s00381-014-2586-1