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Surgical treatment of tethered cord syndrome showed promising outcome in young children with short duration

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Abstract. – OBJECTIVE: Aside from the severity, surgical interventions for the treatment of neurological dysfunctions remain controversial. This study aimed to find factors predicting the benefits of tethered cord syndrome (TCS) surgery.

PATIENTS AND METHODS: 80 children with TCS were included and followed up for pre- and post-operative factors along with neurophysiological analysis. Outcomes were assessed by univariate and multivariate analysis.

RESULTS: Surgical treatment not only improved preoperative signs and symptoms in 79% of TCS patients but it showed to be an efficient procedure for the occurrence of future neurological defects. Univariate analysis also revealed that surgical intervention in TCS children (age <1 year) can modulate filar lipoma location and cutaneous abnormalities three months after surgery. Neurophysiological assessment revealed only 5.0% of surgical complications in TCS patients. Two patients had cerebrospinal fluid leakage, and two cases of CNS infection were detected.

CONCLUSIONS: Surgical intervention is highly recommended for the prevention of neurological deficits in children with TCS. Electrophysiological monitoring revealed rare complications following the surgery.

Key Words:
TCS, Neurophysiological monitoring, surgery, Neurological symptoms.

Introduction

Having a progressive identity, tethered cord syndrome (TCS) is a neurological disorder caused by spinal cord stretching or by its congenital abnormalities[1]. TCS is often observed as a low spinal cord cone, a shortened and thickened intradural filum terminale, and lipoma adhesions around the filum terminale, leading to a limitation of the activity of the spinal cord[2]. Radiology observations including thickened filum terminale, low-lying conus, and/or lipomatous infiltration within the filum have been previously reported[3]. TCS typically manifests as back pain, leg weakness or abnormal gait, hyporeflexia, bladder or bowel dysfunctions, and cutaneous abnormalities over the lumbosacral region in childhood[3].

Surgical detachment of the spinal cord is documented to be effective in reducing the potential lifelong disabilities and in TCS patients[4]. Untethering procedures are recommended for TCS patients with minimal structural changes in the spinal cord to reduce neurological impairments caused by tractions[5]. Monitoring of neurophysiological symptoms during the operation could be an effective way of reducing post-surgery complications and the recovery period[2]. Surgery, on the other hand, may not be an effective strategy in all cases and might even result in excessive deterioration. Consequently, more research is needed to approve its advantages for TCS treatment[6]. This study aimed to investigate the promising outcomes of surgical interventions in TCS patients.

Patients and Methods

Study Population

This study was conducted on 80 children with TCS who were hospitalized at Wuhan Children's Hospital between July 2017 and November 2021.

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The inclusion criteria were 1) TCS patients who were clinically and radiologically (MRI) confirmed; 2) patients who underwent neurophysiological monitoring during surgery. Patients with previous lumbar surgery, tumor, trauma, and other neurological diseases were excluded. This study was performed in accordance with the Helsinki declaration and approved by the ethical committee of Wuhan Children's Hospital.

Surgical Procedure

All children underwent general anesthesia in the prone position, in order to prevent excessive loss of cerebrospinal fluid due to the gravity. The 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.

The 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 lipomatous infiltrations, filar lipoma is relatively simple to remove. For the lipomyelocele type, a cavitron ultrasonic surgical aspirator (CUSA) 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.

Evaluation and Postsurgical Follow-up

The medical history and demographic data of patients were collected from the hospital. SBNS (Spina Bifida Neurological Scale) score was adopted for evaluation of clinical observations pre- and post-surgery[7]. The recovery of neurological symptoms was evaluated according to the Hoffman classification[8]. Normal functions of the bladder and bowel and muscle strength normal sensation were considered as cure criteria. To be considered as improved, enhancement of urination, defecation, and neuropathy were taken into account. The stationary term was assigned to unchanged factors, while the deteriorated term was assigned to newly developed or worsened symptoms.

In children without pre-surgery neurological symptoms, the occurrence of urination or defecation dysfunctions, without affecting daily life, was defined as a "mild progression. Severe progression in the postsurgical follow-up was defined as the occurrence of the above dysfunctions affecting daily life. For at least two years, all children with TCS were followed up on at the clinic or by phone.

Statistical Analysis

Chi-squared test or Fisher's exact test was used for data analysis. Beneficial post-surgery factors were identified and test by univariate and multivariate analysis respectively. All statistical analysis was performed using SPSS Software Version 25.0 (IBM Corp., Armonk, NY, USA) and p-value < 0.05 was considered as significant.

Results

Clinical Characteristics

Among the 80 children with TCS, 43 were male and 37 were female. Cutaneous abnormalities were the most common signs and ladder dysfunction was the most common symptom before surgery. The median duration of preoperative symptoms was 3 months (range: 1 to 156 months). The median SBNS score of all children was 13.2 (range: 8.0 to 15.0). Lipoma was frequently observed in children, and lipoma with thickened filum terminale was accounted for 52.5% of pathological types. The transitional lipoma location was more frequently observed than other locations (Table I).

Surgical Outcomes

In 79% of children with preoperative symptoms, the surgical treatment led to the cure or improvement (Figure 1A). Table II shows the detailed cases of cure/improvement and station/deterioration among each symptom. In 74% of children with asymptomatic TCS, neurological deficits can be prevented by surgery (Figure 1B). Table III depicts the detailed types of progressive symptoms in the follow-up. Figure 1C displays that SBNS score is significantly increased after surgery. Due to the neurophysiological monitoring, surgical complications were rarely observed in 4 children (5.0%). Of them, two showed cere-

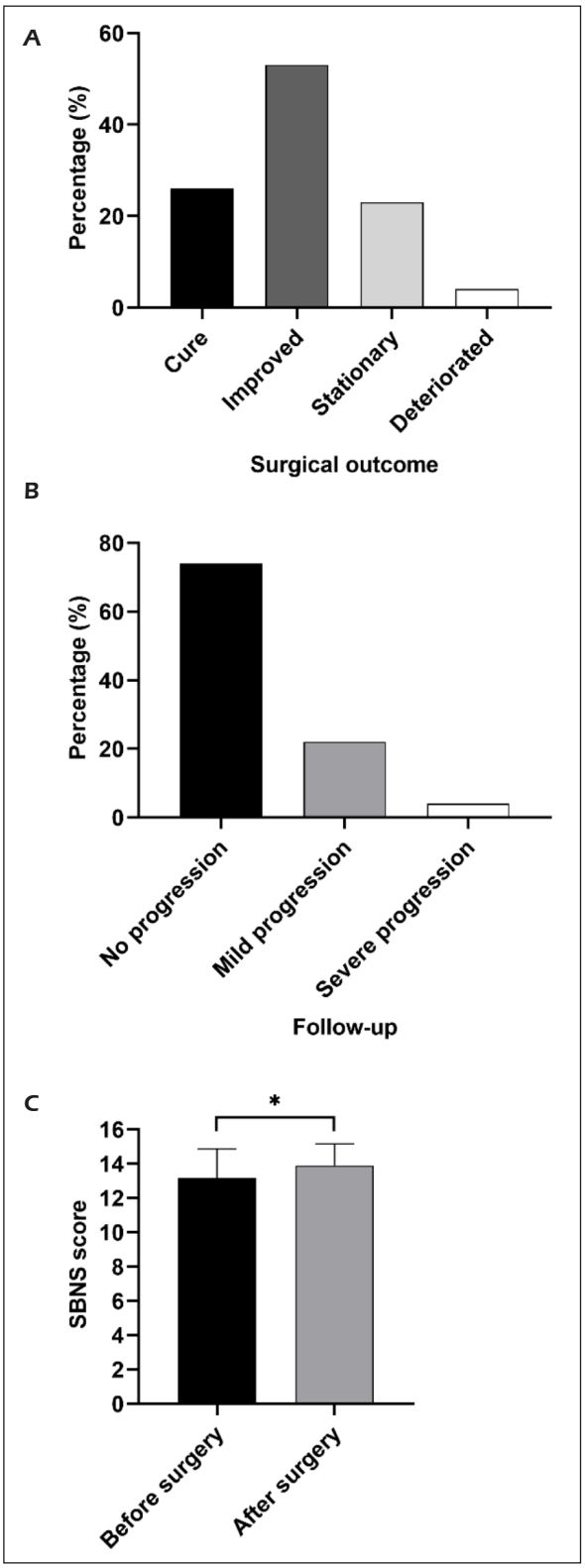

Figure 1. A, The outcome of surgical treatment in children with preoperative symptoms and signs and (**B**) surgical treatment can prevent the development of future neurological impairments in asymptomatic children and (**C**) Spina bifida neurological scale score before and after surgery.

brospinal fluid leakage and two cases with central nervous system infection were observed.

Factors Which Benefit from Surgical Intervention

Univariate analysis showed that patients of less than one year of age received significant surgical intervention benefits, including normal lipoma location and elimination of cutaneous abnormalities after a period of 3 months. Multivariate analysis considered age and duration as independent protective factors (Table IV).

Discussion

TCS is an important health issue for the pediatric population. Since the length of the spine grows with age, tethering leads to ischemia as a result of

Table I. Clinical characteristics.

Characteristics	No. (%) n=80
Sex	
Male	43 (53.8)
Female	37 (46.2)
Age	
< 1 years	34 (42.5)
1-5 years	37 (46.2)
> 5 years	9 (11.3)
Post-term birth	13 (16.2)
Symptoms and signs	
Cutaneous abnormalities	58 (72.5)
Bladder dysfunction	35 (43.8)
Bowel dysfunction	24 (30.0)
Leg weakness	25 (31.3)
Abnormal gait	10 (12.5)
Hyperreflexia	9 (11.3)
Back pain	3 (3.8)
Pathological type	
Lipoma	36 (45.0)
Thickened filum terminale	2 (2.5)
Mixed type	42 (52.5)
Lipoma location	
Transitional lipoma	16 (20.0)
Dorsal lipoma	9 (11.3)
Filar lipoma	9 (11.3)
Caudal lipoma	8 (10.0)
Radiographic sign	
Low-lying conus	63 (78.8)
Lipomatous infiltration	35 (43.8)
Thickened filum terminale	2 (2.5)
M (min-max)	7 (0-43)

SBNS: Spina Bifida Neurological Scale.

Table II. Surgical outcomes of patients with neurological dysfunctions.

Characteristics	Cure/Improved No. (%)	Stationary/Deteriorated No. (%)
Bladder dysfunction	20 (57.1)	15 (42.9)
Bowel dysfunction	13 (54.2)	11 (45.8)
Leg weakness	12 (48.0)	13 (52.0)
Cutaneous abnormalities	58 (100.0)	0 (0)
Back pain	3 (100.0)	0 (0)
Abnormal gait	5 (50.0)	5 (50.0)
Hyperreflexia	6 (66.7)	3 (33.3)

Table III. Follow-up of patients with asymptomatic TCS.

Characteristics	Clinical progression (%) n=7
Bladder dysfunction	4
Bowel dysfunction	2
Leg weakness	1
Cutaneous abnormalities	0
Back pain	0
Abnormal gait	0
Hyperreflexia	0

spinal cord stretching[9]. The persistent tension on the spinal cord can cause an irreversible neurological injury, which manifests as neurological dysfunctions[10]. Early surgical intervention to release or remove tethering has a pivotal role in improving the symptoms of neurological impairment, preventing the emergence of new symptoms, and alleviating the further progression of symptoms[11]. This study showed that surgical intervention decreases TCS complications in children below than 1 year of age and neurophysiological findings reported rare side effects.

TCS children are typically operated on shortly after birth; however, there is insufficient experience with infants born with TCS, particularly asymptomatic infants with a tethered cord[12]. Several studies[12] have found that untreated TCS increases the risk of progressive neurological impairments. In addition, patients with the risk of developing progressive neurological impairments are considered for surgical interventions[13] and according to electrophysiological facts, TCS complications have meaningfully decreased after surgery[14].

In most TCS cases, early surgical intervention leads to stabilization or improvement of neurological dysfunctions[15]. Surgical treatment may significantly prevent the irreversible neurological impairments in children with TCS if at early ages[16]. Our study was conducted on children with the age of ≤3 months and results documented the benefit of surgical intervention since a normal spinal is essential for normal neurological function.

Spinal lipoma accounts for 70% of tethering cases[17]. Symptoms in TCS children with lipomyelocele were relatively severe because dissociating and completely removing the fat surrounding filum terminale was difficult and was also accompanied by subsidiary-injury risks and a poor prognosis for improvement in TCS patients[18]. The location of filar lipoma was independently associated with improved neurosurgical symptoms when treated with surgery in this study, indicating that the filum terminale was relatively easy to dissociate and completely remove in filar lipoma type.

Prophylactic surgery for TCS children is also controversial. The rate of shift from asymptomatic to symptomatic TCS is reported to be 3%-4% per year, with a hazard ratio of 40% in 10 years[19]. Based on previous research[20], neurological manifestations in asymptomatic TCS can be disappeared for 7 years after the initial surgery, suggesting that in terms of asymptomatic TCS, prophylactic surgery would be effective in a certain period. In this study, 74% of asymptomatic TCS children who took the surgery were free of neurological symptoms in the follow up, indicat-

Table IV. Univariate and Multivariate Analysis of Factors Associated with surgical efficiency.

Characteristics	Univariable OR (95% CI)	*p*-value	Multivariable OR (95% CI)	*p*-value
Age < 1 year	4.25 (3.15-7.16)	< 0.001	3.06 (1.85-5.53)	0.035
Duration ≤ 3 months	5.33 (1.92-8.85)	0.001	4.79 (1.02-6.98)	0.048
Filar lipoma	2.35 (1.07-9.38)	0.044	6.80 (0.52-8.31)	0.143
Cutaneous abnormalities	1.68 (0.99-2.85)	0.047	1.13 (0.02-8.69)	0.074

OR: odds ratio, CI: confidence interval.

ing the prophylactic surgery advantage. Nevertheless, a regular follow-up is essential since the identity of TCS is poorly understood.

Thanks to technological advances for monitoring of neurophysiological symptoms even during the operation, not only safety and efficacy of TCS surgery are increased [21], but also preoperative and long-term progression are markedly reduced (from 9.4 to 2.9%, $p<0.001$) in TCS patients (88.7%, $p=0.033$)[22]. In this study, applying neurophysiological monitoring decreased surgical complication to about 5.0%. Therefore, with the guide of neurophysiological monitoring, surgical detethering of the spinal cord can be safe and acquire satisfactory postoperative results.

Limitations

Nonetheless, our study had also some limitations. Aside from surgical skills, neurophysiological instruments and infection prevention strategies were required for a reconsideration. Moreover, we were not able to extend the time and sample size of our study, which is an important issue when speaking about the advantages of surgical intervention. On the other hand, we hadn't access to homogenous samples from TCS cases for a more detailed study while for valid results this is a must-do. Consequently, more randomized trial studies are required with larger samples in future's studies.

Conclusions

This study showed that surgical intervention is remarkably efficient for decreasing the rate of TCS cases. Moreover, electrophysiological monitoring is documented as an effective approach to decreasing the rate of spinal damage and to having a safe and well-oriented surgery. This study also concluded that such a surgical intervention would be extremely effective at early ages and decrease the likelihood of future CNS-related disorders in TCS patients. These were independent protective factors for surgical intervention.

Conflict of Interest

The Authors declare that they have no conflict of interests.

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Informed Consent

The guardians of the study participants gave written informed consent for their respective minors to participate in the study.

Ethics Approval

This research complied with the guidelines for human studies and was conducted ethically in accordance with the World Medical Association Declaration of Helsinki. The study was approved by the Medical Ethics Committee of Wuhan Children's Hospital, Tongji Medical College, Huazhong University of Science and Technology (approval No. 2022R109-E01), which is equivalent to an IRB committee.

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Availability of Data and Material

All data generated or analyzed during this study are included in this published article.

Authors' Contributions

H.D. and W.Y.D. designed the research and wrote the manuscript; M.Y.L. collected and analyzed the data; Y.Y.L, Y.Z.H. and L.Y.H. contributed to the analysis of the study; Y.Y.L and Y.Z.H. supervised the study and contributed to the writing of the manuscript.

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References

1) Wang H, Li X, Wang Y, Sun J, Wang Y, Xu X, Zhang B, Shi J. Assessing Spinal Cord Injury Area in Patients with Tethered Cord Syndrome by Diffusion Tensor Imaging. World Neurosurg 2019; 127: e542-e547.
2) Jiang J, Zhang S, Dai C, Jiang X, Niu X, Chen X, Tang F. Clinical observations on the release of tethered spinal cord in children with intra-operative neurophysiological monitoring: A retrospective study. J Clin Neurosci 2020; 71: 205-212.
3) Michael MM, Garton ALA, Kuzan-Fischer CM, Uribe-Cardenas R, Greenfield JP. A critical analysis of surgery for occult tethered cord syndrome. Childs Nerv Syst 2021; 37: 3003-3011.
4) Geyik M, Alptekin M, Erkutlu I, Geyik S, Erbas C, Pusat S, Kural C. Tethered cord syndrome in chil-

dren: a single-center experience with 162 patients. Childs Nerv Syst 2015; 31: 1559-1563.

5) Sysoev K, Tadevosyan A, Samochernykh K, Khachatryan W. Prognosis of surgical treatment of the tethered cord syndrome in children. Childs Nerv Syst 2018; 34: 305-310.
6) Tu A, Steinbok P. Occult tethered cord syndrome: a review. Childs Nerv Syst 2013; 29: 1635-1640.
7) Oi S, Matsumoto S. A proposed grading and scoring system for spina bifida: Spina Bifida Neurological Scale (SBNS). Childs Nerv Syst 1992; 8: 337-342.
8) Hoffman HJ, Taecholarn C, Hendrick EB, Humphreys RP. Management of lipomyelomeningoceles. Experience at the Hospital for Sick Children, Toronto. J Neurosurg 1985; 62: 1-8.
9) Howells M, Hamby T, Honeycutt J, Donahue DJ. Detethering of MRI-Demonstrated Tethered Cord Syndrome. Pediatr Neurosurg 2022; 57: 85-92.
10) Hertzler DA 2nd, DePowell JJ, Stevenson CB, Mangano FT. Tethered cord syndrome: a review of the literature from embryology to adult presentation. Neurosurg Focus 2010; 29: E1.
11) Fukui J, Ohotsuka K, Asagai Y. Improved symptoms and lifestyle more than 20 years after untethering surgery for primary tethered cord syndrome. Neurourol Urodyn 2011; 30: 1333-1337.
12) Udayakumaran S, Nair NS, George M. Intraoperative Neuromonitoring for Tethered Cord Surgery in Infants: Challenges and Outcome. Pediatr Neurosurg 2021; 56: 501-510.
13) Manoranjan B, Pozdnyakov A, Ajani O. Neurosurgical management of conus lipoma in Canada: a multi-center survey. Childs Nerv Syst 2020; 36: 3041-3045.
14) Yi YG, Kim K, Shin HI, Bang MS, Kim HS, Choi J, Wang KC, Kim SK, Lee JY, Phi JH, Seo HG. Feasibility of intraoperative monitoring of motor evoked potentials obtained through transcranial electrical stimulation in infants younger than 3 months. J Neurosurg Pediatr 2019; 23: 758-766.
15) Kushel' IuV, Zemlianskiĭ MIu, Khit' MA. Tethered cord syndrome in different types of spina bifida in children. Zh Vopr Neirokhir Im N N Burdenko 2010; 2: 19-23.
16) Ailawadhi P, Kale SS, Agrawal D, Mahapatra AK, Kumar R. Primary tethered cord syndrome--clinical and urological manifestations, diagnosis and management: a prospective study. Pediatr Neurosurg 2012; 48: 210-215.
17) Islak C, Kandemirli SG, Kizilkilic O, Kocer N, Tuzgen S, Hanci MM. Combined Spinal Arteriovenous Malformation and Spinal Dysraphism. World Neurosurg 2018; 110: 407-413.
18) Gao J, Kong X, Li Z, Wang T, Li Y. Surgical treatments on adult tethered cord syndrome: A retrospective study. Medicine (Baltimore) 2016; 95: e5454.
19) Wykes V, Desai D, Thompson DN. Asymptomatic lumbosacral lipomas--a natural history study. Childs Nerv Syst 2012; 28: 1731-1739.
20) Seki T, Hida K, Yano S, Houkin K. Surgical Outcomes of Pediatric Patients with Asymptomatic Tethered Cord Syndrome. Asian Spine J 2018; 12: 551-555.
21) Bidkar PU, Thakkar A, Manohar N, Rao KS. Intraoperative neurophysiological monitoring in paediatric neurosurgery. Int J Clin Pract 2021; 75: e14160.
22) 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; 35: 979-984.