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Original Research

Characterization of Orthopaedic Indications Among Patients Undergoing Tethered Cord Release

Katia E. Valdez [1,*]; Cameron M. Arkin, BA[2]; Theresa Meyer, RN[3]; Jill E. Larson, MD[3]; Vineeta T. Swaroop, MD[3]

[1] Northwestern University Feinberg School of Medicine, Chicago, IL, USA
[2] The University of Utah School of Medicine, Salt Lake City, UT, USA
[3] Ann & Robert H. Lurie Children's Hospital of Chicago, Chicago, IL, USA

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ABSTRACT

Background: Tethered cord syndrome (TCS) can present with neurologic, urologic, and/or orthopaedic symptoms, but little research has focused on the orthopaedic conditions that result in tethered cord release (TCR). This study aims to categorize orthopaedic findings associated with TCS and identify which conditions require further surgical intervention post TCR.
Methods: This retrospective cohort study involved 247 patients from our tertiary referral center, all enrolled in the National Spina Bifida Patient Registry (NSBPR) and who underwent TCR between 2007 and 2017. Patients were grouped by tethered cord diagnosis: fatty filum (fatty filum, low-lying cord), lipoma [lipoma, meningocele, myelocystocele, diastematomyelia, meningocele manqué (MM)], and myelomeningocele (MMC). TCR indications were classified as orthopaedic or urologic "yellow" or "red" flags—yellow flags denoting the initial symptoms prompting a referral for tethered cord work-up and red flags representing physician-identified indicators for TCR. Red-flag surgical indicators were identified by an interdisciplinary team of orthopaedic surgeons, urologists, and neurosurgeons. Orthopaedic yellow and red flags included findings such as gait abnormalities or extremity deformities, while urologic flags included hydronephrosis or incontinence. Data on orthopaedic surgeries performed within 18 months post TCR were collected.
Results: Orthopaedic-only symptoms were found in 41 patients (yellow flags) and 51 patients (red flags). Both urologic and orthopaedic symptoms led to TCR in 29 patients (yellow) and 54 patients (red). The number of orthopaedic indicators for TCR was strongly correlated with the total number of orthopaedic surgeries performed within 18 months after TCR ($P < .00001$). Additionally, the number of orthopaedic yellow flags was significantly correlated with the number of TCRs a patient underwent ($P = .002$). Among those who went on to require orthopaedic intervention, the most common surgeries performed were foot, ankle, and knee contracture releases.
Conclusions: Formal orthopaedic evaluation is an essential component of the multidisciplinary assessment and treatment of TCS. Nearly half (47%) of TCR patients presented with preoperative orthopaedic indicators, which varied by tethered cord diagnosis. Despite undergoing TCR, 16% of patients required further surgical intervention for definitive management of their orthopaedic conditions.
Key Concepts:
(1) Orthopaedic symptoms and sequelae are common among patients with tethered cord syndrome (TCS)—many will go on to require surgery.
(2) Foot and ankle contractures are among the top presenting orthopaedic manifestations of TCS.
(3) Formal orthopaedic evaluation is an essential component of the multidisciplinary assessment and treatment of TCS.
(4) Our data suggest a relationship between orthopaedic presenting symptoms and the number of tethered cord release surgeries a patient eventually went on to receive.

Abbreviations: TCS, tethered cord syndrome; TCR, tethered cord release; NSBPR, National Spina Bifida Patient Registry; MM, meningocele manqué; MMC, myelomeningocele; CMG, cystometrogram; MMT, manual muscle testing.

* Corresponding author: Northwestern University Feinberg School of Medicine, 420 E. Superior St., Chicago, IL 60611, USA.
E-mail address: katia.valdez@northwestern.edu (K.E. Valdez).

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(5) Longitudinal orthopaedic monitoring is essential for the comprehensive care of patients with TCS.

Level of Evidence: Level III

Introduction

Tethered cord syndrome (TCS) can occur in patients with or without underlying associated medical conditions, such as lipomeningocele (herniation and attachment of overlying fatty tissue to the spinal cord) or myelomeningocele (herniation of the cord and meninges through a defect in the spine) [1]. Among those with TCS, there is a wide range of clinical manifestations, encompassing neurological, urological, and orthopaedic issues. The orthopaedic conditions associated with TCS can have debilitating consequences if not addressed in a timely manner, and as a result, a tethered cord release (TCR) is often performed shortly after birth or in early childhood to prevent further complications [2–4]. Some sequelae of TCS include difficulty ambulating, muscle atrophy, trouble controlling bowel and bladder movements, and difficulties performing activities of daily living [2].

Despite this complexity, there is a paucity of published research focusing specifically on the types of orthopaedic conditions associated with TCS that result in surgical intervention. This paper aims to systematically categorize the clinical orthopaedic findings associated with TCS and to identify which specific orthopaedic manifestations are associated with TCR. Furthermore, we investigated whether patients required additional orthopaedic intervention for their condition following the initial TCR surgery.

Materials and methods

Study design

This was a descriptive analysis of patients aged 23 years or younger undergoing work-up for TCS at a large, university-based, urban healthcare system. We performed a retrospective review of patients seen at our multidisciplinary clinic who underwent a TCR between 2007 and 2017 and were enrolled in either the National Spina Bifida Patient Registry (NSBPR) and/or our long-term follow-up study. Patients were grouped into three categories based on tethered cord diagnosis: fatty filum (fatty filum and low-lying cord), lipoma [lipoma, meningocele, myelocystocele, diastematomyelia, and meningocele manqué (MM)]), and myelomeningocele (MMC). We then recorded every indication for surgery found on each child's tethered cord work-up. At our institution, a tethered cord work-up includes urodynamics, manual muscle testing (MMT), and full consultation with our multidisciplinary team, including urology, neurosurgery, and orthopaedic surgery. A urodynamics work-up consists of tests assessing the function of the bladder or urethra such as a pressure flow study or measuring a postvoid residual of urine [5], while MMT is a scoring system designed to measure the strength of each isolated muscle on a scale from 0 (no palpable/observable muscle contraction) to 5 (the full range of motion against gravity and full resistance) [6]. A clinical diagnosis of TCS was made based on the consensus of the multidisciplinary team consisting of orthopaedic surgery, urology, and neurosurgery. Patients were excluded from the analysis if they had a diagnosis of occult tethered cord syndrome (patients with TCS without findings on magnetic resonance imaging) [7] or if there were insufficient data provided in their chart. All other participants were considered eligible.

Data collection

A total of 247 patients aged 0 to 23 years, having underwent a TCR between 2007 and 2017, and enrolled in the NSBPR at our tertiary referral center were included in our data set. Data were collected via the use of one-time surveys which collected information on the demographic background of the patients, their primary and secondary TCS diagnoses, primary and secondary urologic diagnoses, the number of TCR surgeries and repair surgeries, data on congenital and acquired orthopaedic diagnoses, and data on orthopaedic and urologic red- and yellow-flag symptoms. For the purpose of this study, yellow flags were defined as symptoms for which a patient was originally referred to the clinic for tethered cord work-up, such as a sacral dimple or a singular complaint, such as enuresis or excessive tripping. At the conclusion of the tethered-cord work-up, the red flags are defined as those findings which served as the indicators for TCR, such as urodynamic findings, change on MMT, or other orthopaedic findings.

Analysis and study outcomes

Measures of central tendency, Student's t-tests for nonparametric samples, one-way analysis of variance (ANOVA) tests, and Pearson correlation coefficients were calculated using R Studio v.4.2.3 (Shortstop Beagle). All data were imported into Excel Version 16.89.1 for the final table and figure presentation. The primary variables of interest were those pertaining to orthopaedic yellow and red flags and the number of TCRs. Student's t-tests and one-way ANOVA tests were used to

Table 1.
Frequency of patient characteristics of pediatric patients receiving a tethered cord release (TCR) between January 1, 2007, and December 31, 2017.

Patient characteristics	Total*
	N = 247
Age (in months)	46 [0, 276]
Sex	
Female	136 (55.06%)
Male	111 (44.94%)
Ethnicity	
Hispanic/Latino	75 (30.36%)
Not Hispanic/Latino	172 (69.64%)
Race	
White	197 (79.76%)
Black or African American	18 (7.29%)
Asian	16 (6.48%)
Multiracial	8 (3.24%)
Other	8 (3.24%)
Native Hawaiian or other Pacific Islander	0 (0%)
American Indian or Alaska Native	0 (0%)
Number of ortho surgeries	39 (15.79%)
1	1 (0.40%)
2	1 (0.40%)
0	206 (83.40%)
None	
TCR with initial resection/repair?	57 (23.08%)
Yes	184 (74.49%)
No	

Square brackets provide the range (ranging from ages 0-276), and the curved brackets are the percentage of the total (136 out of 247 patients is 55.06% of patients).

[*] Counts may be lower than the total due to missing data.

Table 2.
Primary and secondary diagnoses among pediatric patients receiving a tethered cord release (TCR) between January 1, 2007, and December 31, 2017.

Primary and secondary diagnoses	Total*
	N = 247
Primary diagnosis	
Fatty filum	95 (38.46%)
Myelomeningocele	68 (27.53%)
Lipoma	41 (16.60%)
Myelocystocele	16 (6.48%)
LLC	13 (5.26%)
Meningocele manqué	6 (2.43%)
Meningocele	4 (1.62%)
Dermal sinus tract	3 (1.21%)
Split cord malformation	1 (0.40%)
Secondary diagnosis	
Neurogenic bladder/bowel	113 (45.75%)
Chiari II	60 (24.29%)
Sacral dimple	58 (23.48%)
Hydronephrosis	28 (11.34%)
Scoliosis	26 (10.53%)
VUR	21 (8.50%)
Abnormal gluteal crease/cleft	22 (8.91%)
Hydromyelia	18 (7.29%)
Congenital clubfoot	14 (5.67%)
Hypotonia	13 (5.26%)
Hemangioma	13 (5.26%)
Vertebral anomaly	12 (4.86%)
VACTERL	9 (3.64%)
Acquired clubfoot	8 (3.24%)
Premature	7 (2.83%)
Hip dysplasia	6 (2.43%)
Pelvis syndrome	4 (1.62%)
Chiari I	4 (1.62%)
Calcaneovalgus foot deformity	1 (0.40%)

LLC: low lying cord; VUR: vesicoureteral reflux; VACTERL: a syndrome consisting of vertebral defects, anal atresia, cardiac defects, tracheo-esophageal fistula, renal anomalies, and limb anomalies.
* Counts may be lower than the total due to missing data.

Table 3.
Frequency of urologic yellow and red flags among pediatric patients receiving a tethered cord release (TCR) between January 1, 2007, and December 31, 2017.

Urologic flags	Total*
	N = 247
Urologic yellow flags	
None	178 (72.06%)
Other	36 (14.57%)
CMG change/abnormality	27 (10.93%)
Incontinence	21 (8.50%)
Hydronephrosis	10 (4.05%)
Increased bladder pressure	8 (3.24%)
Changes in neurogenic bladder	4 (1.62%)
Bladder spasticity	3 (1.21%)
Dyssynergy on bladder evaluation	0 (0%)
Larger bladder, long contraction	0 (0%)
Urologic red flags	
None	109 (44.13%)
CMG change/abnormality	108 (43.72%)
Other	39 (15.79%)
Incontinence	20 (8.10%)
Bladder spasticity	14 (5.67%)
Increased bladder pressure	14 (5.67%)
Hydronephrosis	10 (4.05%)
Changes in neurogenic bladder	5 (2.02%)
Dyssynergy on bladder evaluation	2 (0.81%)
Larger bladder, long contraction	0 (0%)

CMG, cystometrogram.
* Counts may be lower than the total due to missing data.

compare the mean number of orthopaedic yellow and red flags among patients receiving one, two, or three TCR surgeries; Pearson correlation coefficient test was used to assess the strength of the relationship between the number of orthopaedic yellow and red flags and the number of TCR surgeries patients underwent.

Results

The characteristics of the sample are summarized in Table 1. Among the total 247 participants, the average age at the first TCR surgery was 46 months, with a median age of 19 months and a range of 276 months. Table 2 outlines the tethered cord diagnoses of patients undergoing TCR, and the cohort was further categorized into three groups by diagnosis type: fatty filum, lipoma, and myelomeningocele. A minority of patients were in additional groups of those with a dermal sinus tract or split cord. A fatty filum categorization includes diagnoses of a fatty filum and low-lying cord. A lipoma categorization includes diagnoses of lipoma, meningocele, myelocystocele, diastematomyelia, and meningocele manqué. The MMC categorization encompasses those with a diagnosis of myelomeningocele. The results of the number of patients with varying yellow and red urologic flags is outlined in Table 3.

A total of 136 (55.06%) of the patients were female, and the remaining 111 were male. The largest number of patients (95, 38.46%) had a primary tethered cord diagnosis of fatty filum, and the least (1, 0.40%) had a diagnosis of split cord malformation. Many patients had secondary diagnoses (such as neurogenic bladder, scoliosis, Chiari I/II malformations, and an abnormal gluteal crease/cleft) as well. Most patients (206, 83.40%) did not undergo orthopaedic surgery after the initial TCR, while 41 (16.60%) underwent 1, 2, or 3 total orthopaedic surgeries. Across all tethered cord groups, 38.25% of MMC, 16.42% of lipoma, 3.70% of fatty filum patients underwent orthopaedic surgery after their TCR surgeries; 0% of split cord malformation and dermal sinus tract patients underwent orthopaedic surgery.

Overall, 70 (28.34%) patients endorsed any urologic yellow flag, and 147 (59.51%) were found to have any urologic red flag on physician workup. Yellow and red flags were symptoms such as cystometrogram (CMG) changes/abnormalities, bladder spasticity, or incontinence. Among TCS patients, 16.6% only had urologic yellow flags, 33.6% only had orthopaedic yellow flags, and 11.74% had both urologic and orthopaedic yellow flags; 37.65% only had urologic red flags, 20.65% only had orthopaedic red flags, and 21.86% had both urologic and orthopaedic red flags. The results of the number of patients with orthopaedic yellow and red flags by tethered cord characterization are summarized in Table 4.

Our cohort was also categorized by the number of TCRs undergone. Overall, 231 (93.5%) received only one surgery, while the remaining 16 (6.48%) underwent two or three total TCR surgeries. The correlation

Table 4.
Frequency of patients with orthopaedic yellow and red flags by the number of tethered cord releases (TCRs) performed between January 1, 2007, and December 31, 2017.

	Total = 247		
	1st release	2nd release	3rd release
	N = 247	N = 16	N = 1
*Yellow flags			
Any yellow flag	90 (36.44%)	10 (62.5%)	1 (100%)
Foot deformity	24 (9.72%)	3 (18.75%)	0 (0%)
Weakness in extremities	17 (6.88%)	0 (0%)	1 (100%)
Tone increase	14 (5.67%)	3 (18.75%)	1 (100%)
Back pain	13 (5.26%)	5 (31.25%)	0 (0%)
Gait deviation	12 (4.86%)	2 (12.5%)	0 (0%)
Increase in scoliosis	11 (4.45%)	0 (0%)	0 (0%)
Decrease on MMT	10 (4.05%)	1 (6.25%)	0 (0%)
Increase in contractures	9 (3.64%)	1 (6.25%)	0 (0%)
Calf atrophy	8 (3.24%)	0 (0%)	0 (0%)
LE pain	7 (2.83%)	3 (18.75%)	0 (0%)
Pain over MMC site	4 (1.62%)	0 (0%)	0 (0%)
Increased tripping/falling	4 (1.62%)	0 (0%)	0 (0%)
Decreased mobility	4 (1.62%)	0 (0%)	0 (0%)
Decrease in stamina	3 (1.21%)	0 (0%)	0 (0%)
Parasthesias	3 (1.21%)	0 (0%)	0 (0%)
Toe walking	2 (0.81%)	0 (0%)	0 (0%)
Tight heel cords	2 (0.81%)	0 (0%)	0 (0%)
Hip abnormality	2 (0.81%)	0 (0%)	0 (0%)
Hypotonia of the trunk	2 (0.81%)	0 (0%)	0 (0%)
Fixed deformity	2 (0.81%)	0 (0%)	0 (0%)
Atrophy of glutes and the lower extremity	1 (0.40%)	0 (0%)	0 (0%)
Pain with activity	1 (0.40%)	0 (0%)	0 (0%)
Neck pain	1 (0.40%)	0 (0%)	0 (0%)
Extremity deformity	1 (0.40%)	0 (0%)	0 (0%)
Hyperreflexia	1 (0.40%)	0 (0%)	0 (0%)
Leg-length discrepancy	1 (0.40%)	1 (6.25%)	0 (0%)
†Red Flags			
Any red flag	101 (40.89%)	9 (56.25%)	1 (100%)
Weakness in the extremities	31 (12.55%)	0 (0%)	1 (100%)
Foot deformity	29 (11.74%)	4 (25%)	0 (0%)
Decrease on MMT	20 (8.10%)	4 (25%)	1 (100%)
Tone increase	19 (7.69%)	3 (18.75%)	1 (100%)
Gait deviation	17 (6.88%)	2 (12.5%)	0 (0%)
Increase in scoliosis	15 (6.07%)	0 (0%)	0 (0%)
Back pain	15 (6.07%)	3 (18.75%)	0 (0%)
Increase in contractures	10 (4.05%)	1 (6.25%)	0 (0%)
LE pain	7 (2.83%)	2 (12.5%)	0 (0%)
Increased tripping/falling	6 (2.43%)	0 (0%)	0 (0%)
Pain over MMC site	4 (1.62%)	0 (0%)	0 (0%)
Calf atrophy	4 (1.62%)	0 (0%)	0 (0%)
Decreased mobility	4 (1.62%)	0 (0%)	0 (0%)
Toe walking	3 (1.21%)	0 (0%)	0 (0%)

Table 4. (*continued*)

	Total = 247		
	1st release	2nd release	3rd release
	N = 247	N = 16	N = 1
Tight heel cords	3 (1.21%)	0 (0%)	0 (0%)
Parasthesias	3 (1.21%)	0 (0%)	0 (0%)
Decrease in stamina	3 (1.21%)	0 (0%)	0 (0%)
Neck pain	2 (0.81%)	0 (0%)	0 (0%)
Hypotonia of the trunk	2 (0.81%)	0 (0%)	0 (0%)
Extremity deformity	1 (0.40%)	0 (0%)	0 (0%)
Hip abnormality	1 (0.40%)	0 (0%)	0 (0%)
Fixed deformity	1 (0.40%)	0 (0%)	0 (0%)
Pain with activity	1 (0.40%)	0 (0%)	0 (0%)
Hyperreflexia	1 (0.40%)	0 (0%)	0 (0%)
Pressure sores	0 (0%)	0 (0%)	0 (0%)
Leg-length discrepancy	0 (0%)	1 (6.25%)	0 (0%)

MMT, manual muscle testing; LE, lower extremity; MMC, myelomeningocele.
* Yellow flags describe symptoms for which a patient was originally referred for TCR repair.
† Red flags describe symptoms a patient was found to have upon workup by a physician.

coefficients between orthopaedic yellow and red flags and the total number of TCR surgeries undergone are summarized in Table 5. A significant relationship between the number of orthopaedic yellow flags and number of TCR surgeries was identified.

There was an average of 7.8 months from the initial TCR to the first orthopaedic surgery. Table 6 outlines the type and frequency of orthopaedic surgeries performed on patients after TCR. The most common surgeries performed were foot/ankle contracture (33 total surgeries) and knee contracture releases (16 total surgeries).

Table 7 summarizes the number of patients receiving 0, 1, 2, or 3 orthopaedic surgeries after the initial TCR repair at the children's hospital by the number of total TCR surgeries received.

In total, 41 patients went on to require and receive orthopaedic surgeries. A total of 192 (83.12%) of the patients undergoing one total TCR and 14 (87.50%) of those undergoing 2+ total TCRs had no orthopaedic surgeries. Thirty-nine (16.88%) of those with one total TCR and 2 (12.50%) of those with 2+ TCRs had any orthopaedic surgery. Lastly, the frequency of patients with orthopaedic yellow and red flags by the type of TCR-indicating diagnosis is summarized in Table 8.

Discussion

This study provides a descriptive overview of a large cohort of pediatric and young adult patients (n = 247) undergoing TCR for TCS at a large tertiary referral center. Our patient population consisted of predominantly non-Hispanic (69.64%), Caucasian (79.76%) females (55.06%), with the most common subgroup TCS diagnosis being fatty filum. A significant proportion of these patients had concurrent secondary conditions such as neurogenic bladder, scoliosis, and Chiari I/II malformations. On balance,

Table 5.
Correlation between the number of orthopaedic yellow and red flags before the first tethered cord release (TCR) and total number of TCRs performed between January 1, 2007, and December 31, 2017.

	Corr. (95% CI)	*P* value	t value
Yellow flags and total TCRs	0.195 (0.071, 0.312)	.002	3.104
Red flags and total TCRs	0.115 (-0.010, 0.236)	.071	1.813

Table 6.
Frequency of orthopaedic surgeries performed on patients undergoing 1, 2, or 3 total tethered cord release (TCR) surgeries between January 1, 2007, and December 31, 2017.

	Total = 247		
	1 TCR	2 TCRs	3 TCRs
	(N = 231)	(N = 15)	(N = 1)
Left			
Left foot or ankle contracture release	15 (6.5%)	2 (13.3%)	0 (0%)
Left knee contracture release	8 (3.5%)	0 (0%)	0 (0%)
Left hip contracture release	6 (2.6%)	0 (0%)	0 (0%)
Left foot deformity reconstruction	5 (2.2%)	0 (0%)	0 (0%)
Left tibia torsion correction	4 (1.7%)	0 (0%)	0 (0%)
Left femur torsion correction	3 (1.3%)	0 (0%)	0 (0%)
Left tibia epiphysiodesis	2 (0.9%)	0 (0%)	0 (0%)
Left hip bony surgery	1 (0.4%)	0 (0%)	0 (0%)
Left femur epiphysiodesis	0 (0%)	0 (0%)	0 (0%)
Right			
Right foot or ankle contracture release	16 (6.9%)	0 (0%)	0 (0%)
Right knee contracture release	8 (3.5%)	0 (0%)	0 (0%)
Right foot deformity reconstruction	6 (2.6%)	0 (0%)	0 (0%)
Right tibia torsion correction	3 (1.3%)	0 (0%)	0 (0%)
Right hip bony surgery	2 (0.9%)	0 (0%)	0 (0%)
Right hip contracture release	1 (0.4%)	0 (0%)	0 (0%)
Right femur torsion correction	0 (0%)	0 (0%)	0 (0%)
Right tibia epiphysiodesis	0 (0%)	0 (0%)	0 (0%)
Right femur epiphysiodesis	0 (0%)	0 (0%)	0 (0%)
Unspecified			
Spine fusion	3 (1.3%)	0 (0%)	0 (0%)
Fracture surgery	0 (0%)	0 (0%)	0 (0%)

Table 7.
Frequency of patients requiring orthopaedic repair after tethered cord release (TCR) between January 1, 2007, and December 31, 2017.

Number of orthopaedic surgeries	1 TCR	2+ TCRs
	N = 231	N = 16
0	192 (83.12%)	14 (87.5%)
1	37 (16.02%)	2 (12.5%)
2	1 (0.43%)	0 (0%)
3	1 (0.43%)	0 (0%)

our data suggest a relationship between orthopaedic-presenting symptoms (yellow flags) and the number of TCR surgeries a patient eventually went on to receive, suggesting an opportunity for early intervention and mitigation of future surgery with the early identification of these symptoms.

A majority of patients (83.4%) did not undergo orthopaedic procedures after their initial TCR, suggesting that primary surgical intervention may address many of the most pressing orthopaedic issues associated with TCS. It is also possible that, while still present, any remaining orthopaedic symptoms were manageable with nonsurgical treatment after the initial TCR. Among those requiring orthopaedic intervention, the most common TCS sequelae were foot and ankle contractures. Given that extremity weakness, tone increases, and gait deviation were among the top orthopaedic yellow flags, and foot deformity the most common orthopaedic red flag, thorough foot and ankle assessments remain crucial among all TCS patients. Patients received their first orthopaedic surgery on average nearly 8 months after the initial TCR. It is unclear whether this time frame represents a delay in care, a necessary pause to allow for recovery from TCR, an evolution of symptoms, or the discovery of initially missed or masked symptoms after TCR.

This ambiguity, along with the fact that some patients may go on to require multiple orthopaedic surgeries, underscores the importance of longitudinal monitoring of orthopaedic red flags, namely foot and ankle deformities, to provide timely, appropriate, and accessible orthopaedic intervention. Within this group receiving orthopaedic intervention, differences were noted between the TCS subgroups. Across all tethered cord groups, 38.25% of MMC, 16.42% of lipoma, and 3.70% of fatty filum patients underwent orthopaedic surgery after their TCR surgeries, in contrast to 0% of split cord malformation and dermal sinus tract patients. This suggests a difference in the clinical presentation and severity of orthopaedic indicators across different TCS subgroups, further underscoring the necessity of a systemic evaluation system for classification and intervention planning.

One study by Iborra et al. focused on the characterization of a subgroup of MMC TCS patients in Catalonia, Spain. This cross-sectional study conducted at a specialty Spina Bifida care unit elucidated a correlation between the neurological level of deformity and resulting orthopaedic manifestations, as assessed by ambulatory status, hip and spine angle measurements, and hip and spine flexion contractures [8]. Well-defined variables such as these are a critical component of a precise patient evaluation and categorization of symptoms. Our data highlight high rates of urologic yellow and red flags occurring concurrently with orthopaedic yellow and red flags. This, along with data highlighting the severity of urologic symptoms among this population, further supports the use of interdisciplinary clinical teams in the comprehensive evaluation of these groups [9–11]. These symptoms, along with orthopaedic and neurologic symptoms, pose a large threat to the quality of life for these patients.

The findings of this study should be interpreted considering some limitations. Namely, this was a retrospective chart review conducted at a

Table 8.
Frequency of patients with orthopaedic yellow and red flags during the first tethered cord release (TCR) by type of tethered cord syndrome, collected between January 1, 2007, and December 31, 2017.

	Total = 247				
	*Fatty filum	†Lipoma	‡MMC	Dermal sinus tract	Split cord malformation
	N = 108	N = 67	N = 68	N = 3	N = 1
Any yellow flag	23 (21.30%)	18 (26.87%)	47 (69.12%)	1 (33.33%)	1 (100%)
Any red flag	27 (25%)	24 (35.82%)	48 (70.59%)	1 (33.33%)	1 (100%)

* Fatty filum includes diagnoses of a fatty filum and low-lying cord.
† Lipoma includes diagnoses of lipoma, meningocele, myelocystocele, diastematomyelia, meningocele manqué.
‡ MMC includes a diagnosis of myelomeningocele.

large, well-funded, private healthcare center in a downtown urban setting. As a result, this patient population may not accurately represent the wide variety of patients presenting with TCS nationally. Furthermore, those with access to health centers such as these may have increased access to health information and perinatal care that may entirely prevent or mitigate the severity of neural tube defects such as TCS. This may, in turn, alter the manifestations of TCS in our patient population. As many of our patients were so young that they had not yet developed the ability to verbally describe their symptoms, incongruencies may exist between yellow (reported symptoms, often by a parent or caregiver) and red (clinically diagnosed symptoms) flags.

Looking forward, it is crucial for multidisciplinary teams, including orthopaedic surgeons, to create a standardized evaluation of patients with TCS and other related spinal cord anomalies. These evaluations may also provide significant relief to anxious patients and their families who are seeking definitive answers on functional prognosis [12]. While there are data published regarding the management and systemized treatment of orthopaedic ailments among this population [3,13–15], to our knowledge, no standardized orthopaedic criteria currently exist for patients with TCS and other related neurological deformities. Some have proposed such systematic evaluation, including strict physical exam criteria, gait analysis, assessment of functional capacity, and classification-based intervention [3,12–14,16]. Additional studies are warranted to continue the characterization of this population for the development of a formal orthopaedic evaluation guideline. Large-scale longitudinal studies may provide valuable information regarding the timing and appropriateness of specific interventions for different patient subgroups across a variety of care settings.

A more comprehensive understanding of the orthopaedic manifestations of TCS is essential in the improvement of multidisciplinary care, operative decision-making, and prevention of the progression of neurologic dysfunction and deformity. In addressing these gaps in knowledge, we hope to contribute to more effective treatment strategies and improved outcomes for patients with TCS.

Conclusion

A formal orthopaedic evaluation is an essential component of the multidisciplinary assessment and treatment of TCS. Nearly half (47%) of TCR patients in our cohort presented with preoperative orthopaedic indicators, which varied by subgroup diagnosis. Despite undergoing TCR, 16% of patients required further surgical intervention for definitive management of their orthopaedic conditions, and 6.48% underwent additional (two or three in total) TCR surgeries. As we grow in our understanding of the orthopaedic manifestations among this population, we may better address their conditions promptly or help those with delayed presentation in receiving the most effective care.

Additional links

- **AAOS Orthopaedic Video Theatre:** Tibia and Fibula Derotational Osteotomy for Internal Tibial Torsion in Patients With Spina Bifida
- **POSNAcademy:** Percutaneous Anterior Distal Femoral Hemiepiphysiodesis Using Simultaneous Biplanar Fluoroscopy
- **JPO:** Tethered Cord Syndrome: Neurologic and Orthopaedic Implications

Consent for publication

The author(s) declare that no patient consent was necessary as no images or identifying information are included in the article.

Author contributions

Katia E. Valdez: Writing – review & editing, Writing – original draft, Formal analysis, Data curation. **Cameron M. Arkin:** Data curation. **Theresa Meyer:** Writing – review & editing, Investigation, Data curation. **Jill E. Larson:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Conceptualization. **Vineeta T. Swaroop:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Data curation, Conceptualization.

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