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Surgical outcomes of tethered cord syndrome in adults versus pediatric patients: A comparative study

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ABSTRACT

Background: Tethered cord syndrome (TCS) is a neurological disorder caused by the abnormal attachment of the spinal cord, which limits movement and leads to progressive neurological deficits. This study compares the surgical outcomes of TCS in pediatric and adult patients following detethering surgery at Maharani Laxmi Bai Medical College, Jhansi, Uttar Pradesh, between August 2015 and August 2024. **Aims and Objectives:** The aim of the study was to assess and compare the surgical outcomes, complication rates, and long-term prognosis in pediatric and adult TCS patients, with a focus on neurological improvement, post-operative complications, and quality of life. **Materials and Methods:** A retrospective cohort study was conducted, including 120 patients (60 pediatric and 60 adult) who underwent surgical detethering. Data were collected on patient demographics, presenting symptoms, surgical details, and post-operative outcomes. The primary outcomes were neurological improvement and functional independence. Secondary outcomes included complication rates and quality of life, assessed over a 2–5-year follow-up period. **Results:** Pediatric patients had significantly better neurological recovery (improvement in 70% vs. 45% of adults, $P=0.014$) and fewer complications (15% vs. 32%, $P=0.045$) compared to adults. Pediatric patients had lower re-tethering rates (10% vs. 18%, $P=0.132$) and higher functional independence (Glasgow outcome scale ≥ 4: 90% vs. 60%, $P<0.001$). Quality of life scores were significantly higher in pediatric patients (SF-36 score: 85.2 ± 10.6 vs. 72.3 ± 12.8, $P=0.021$). **Conclusion:** Pediatric patients exhibit better surgical outcomes, including higher rates of neurological improvement and fewer complications. Early diagnosis and timely surgical intervention are critical for optimizing outcomes, especially in pediatric patients.

Key words: Tethered cord syndrome; Pediatric; Adult; Neurological recovery; Surgical outcomes; Detethering; Post-operative complications; Quality of life

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INTRODUCTION

Tethered cord syndrome (TCS) is a neurological disorder characterized by the pathological fixation of the spinal cord, often leading to progressive stretching of neural elements during growth or movement. This condition may arise due to congenital anomalies, such as spina bifida, or acquired factors, such as post-surgical scarring or trauma. The clinical presentation varies significantly, ranging from motor and sensory deficits to urinary dysfunction and orthopedic deformities.[1,2]

The pathophysiology of TCS is rooted in abnormal tension applied to the spinal cord, which can impair neural function and result in irreversible damage over time. TCS is commonly classified into congenital and acquired forms,

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with congenital cases typically presenting during childhood and acquired cases more frequently observed in adults. The severity of symptoms and outcomes often depend on the extent and duration of neural compromise before intervention.[3]

The clinical manifestations and surgical outcomes of TCS differ significantly between pediatric and adult populations. Pediatric patients often present with early symptoms, including developmental delays, gait abnormalities, and incontinence, which are closely associated with congenital etiologies. In contrast, adult patients may exhibit progressive neurological decline, pain, or other symptoms linked to the acquired nature of their condition.[4,5] These differences necessitate tailored diagnostic and management approaches.

Surgical intervention remains the cornerstone of TCS management, aimed at releasing the tethering to alleviate symptoms and prevent further neurological deterioration. While the goals of surgery are consistent across age groups, the timing, technical approach, and potential complications may vary between children and adults due to differences in spinal anatomy, comorbidities, and neural plasticity.[6,7]

Despite advances in surgical techniques, comparative data on outcomes in pediatric and adult populations with TCS are limited. Understanding these differences is crucial to optimizing treatment strategies and improving prognosis.[8]

Aims and objectives

This study objectives are to assess and compare the surgical outcomes, complication rates, and long-term prognosis in pediatric and adult TCS patients, with a focus on neurological improvement and post-operative complications.

MATERIALS AND METHODS

Study design and location

This retrospective cohort study was conducted over a 9-year period from August 2015 to August 2024 at Maharani Laxmi Bai Medical College, Jhansi, Uttar Pradesh. A total of 120 patients were diagnosed with TCS-60 pediatric patients (under 18 years of age) and 60 adult patients (18 years and older) – who underwent surgical detethering.

Inclusion criteria

- Symptomatic TCS diagnosed by magnetic resonance imaging
- Patients with motor, sensory, or bladder dysfunction who required surgical detethering
- Surgery performed between August 2015 and August 2024.

Exclusion criteria

- Asymptomatic patients or those lost to follow-up
- Patients with incomplete medical records.

Methods

Patient data were collected from hospital records, including demographics, presenting symptoms, surgical details, and immediate post-operative outcomes. Follow-up data were gathered over a 2–5-year period to assess long-term neurological function, complications, and quality of life.

Neurological improvement criteria

The neurological improvement criteria were based on pre-operative and post-operative assessments of motor, sensory, and bladder function.

Clinical Improvement Categories and Their Definitions

Improvement category	Definition
Motor improvement	Increase in muscle strength by at least one grade on the MRC scale.
Sensory improvement	Improvement in sensory perception, including reduced numbness or tingling.
Bladder function improvement	Decrease in urinary incontinence or improved bladder control post-surgery.
Back pain reduction	Significant reduction in the severity or frequency of back pain.
Functional independence (GOS≥4)	Achievement of functional independence in daily activities.

GOS: Glasgow outcome scale

Outcome measures

- The primary outcome of the study focuses on neurological improvement, which is assessed through measurable changes in motor, sensory, and bladder function. These parameters are evaluated using the established neurological improvement criteria, ensuring a standardized approach to quantify recovery. This outcome serves as a critical indicator of the intervention's efficacy in restoring neurological function and enhancing the quality of life for patients
- The secondary outcomes include several important measures to comprehensively evaluate the intervention's effectiveness and long-term impact. Post-operative complications, such as rates of cerebrospinal fluid (CSF) leaks, wound infections, and re-tethering, are monitored to assess immediate surgical risks. Long-term quality of life is measured using the SF-36 Health Survey at 2–5-year follow-ups, providing insights into the sustained well-being of patients. Functional independence is evaluated with the Glasgow Outcome Scale (GOS), where a score of 4 or higher signifies a return to independent functionality. Together, these

outcomes offer a holistic view of both short- and long-term benefits and potential risks of the procedure.

Plan for data analysis

The statistical analysis will involve descriptive statistics to summarize demographic and clinical data, with continuous variables presented as mean±SD and categorical variables as frequencies and percentages. Comparative analyses between pediatric and adult groups will use independent t-tests or Mann–Whitney U tests for continuous variables and chi-square or Fisher's exact tests for categorical variables. Logistic regression will identify predictors of complications, while linear regression will assess the impact of clinical variables on quality of life (SF-36 scores). Kaplan-Meier survival analysis with log-rank tests will evaluate re-tethering rates over time. Correlation analyses (Pearson or Spearman) will examine relationships between key variables and paired t-tests or Wilcoxon signed-rank tests will compare pre-operative and post-operative outcomes within groups. All analyses will use a significance threshold of $P \leq 0.05$, with Bonferroni corrections for multiple comparisons, and results will be presented using clear tables and graphs generated through SPSS.

Ethical considerations

The study received approval from the Institutional Review Board of Maharani Laxmi Bai Medical College, Jhansi. Informed consent was obtained from all patients meeting the inclusion criteria before their enrollment in the study.

RESULTS

Pediatric patients presented at a younger mean age (8.5±3.1 years vs. 38.2±10.4 years, P<0.001) with shorter symptom durations (18.3±6.2 months vs. 48.7±12.5 months, P=0.015) and a predominance of congenital causes (80% vs. 30%, P<0.001), whereas adults exhibited more acquired etiologies (70% vs. 20%, P<0.001) (Table 1). A higher overall complication rate in adults (32% vs. 15%, P=0.045), including increased CSF leaks (18% vs. 7%, P=0.043) and re-tethering rates (15% vs. 5%, P=0.012) (Table 2). Adults had a much higher chance of complications than children, mainly due to their age (over 18 years) and longer duration of symptoms before surgery. Patients who had symptoms for more than two years were more likely to experience problems after the procedure. Additionally, those with pre-existing bladder issues or neurological deficits before surgery were at greater risk. These findings emphasize the importance of diagnosing and treating the condition early, as children tend to recover better with fewer complications (Table 3). Pediatric patients had superior immediate post-operative outcomes, including higher rates of neurological improvement (70% vs. 45%, P=0.014) and bladder function improvement (65% vs. 30%, P<0.001), along with shorter hospital stays (5.2±1.3 days vs. 7.1±2.4 days, P=0.023) (Table 4). Long-term outcomes for pediatric patients, including higher rates of functional independence (90% vs. 60%, P<0.001), lower recurrence of

Table 1: Patient demographics and pre-operative characteristics

Variable	Pediatric patients (n=60)	Adult patients (n=60)	P-value
Age (mean±SD)	8.5±3.1 years	38.2±10.4 years	<0.001
Male/Female ratio	35/25	34/26	0.824
Duration of symptoms (months)	18.3±6.2	48.7±12.5	0.015
Primary cause of TCS (%)			
Congenital	80	30	<0.001
Acquired (e.g., trauma)	20	70	<0.001
Pre-operative neurological deficit (%)	85	90	0.543
Pre-operative bladder dysfunction (%)	45	35	0.21
Pre-operative back pain (%)	25	65	<0.001
Spinal deformity (e.g., scoliosis) (%)	60	40	0.102

TCS: Tethered cord syndrome

Table 2: Complication rates and predictive factors

Complication (%)	Pediatric patients (n=60) (%)	Adult patients (n=60) (%)	P-value
Total complication rate	15 (9 patients)	32 (19 patients)	0.045
Cerebrospinal fluid leak	7 (4 patients)	18 (11 patients)	0.043
Wound infection	3 (2 patients)	10 (6 patients)	0.082
Neurological deterioration	5 (3 patients)	12 (7 patients)	0.064
Hematoma formation	2 (1 patient)	8 (5 patients)	0.092
Re-tethering	5 (3 patients)	15 (9 patients)	0.012
Pseudomeningocele formation	2 (1 patient)	5 (3 patients)	0.23
Sepsis	0 (0 patients)	2 (1 patient)	0.32
Persistent bladder dysfunction	3 (2 patients)	10 (6 patients)	0.082

bladder dysfunction (12% vs. 30%, P=0.014), and superior quality of life (SF-36 scores: 85.2±10.6 vs. 72.3±12.8, P=0.021) (Table 5). These findings emphasize the benefits of early intervention and the challenges of managing adult cases.

DISCUSSION

This study evaluated the surgical outcomes of pediatric and adult patients with TCS at Maharani Laxmi Bai Medical College over a 2–5-year follow-up period. The results indicate that pediatric patients had significantly better outcomes than adults in terms of neurological recovery, post-operative complications, and long-term functional outcomes.

Neurological improvement

Pediatric patients had a higher rate of immediate neurological improvement (70%) compared to adults (45%). Over the long term, 80% of pediatric patients achieved neurological stabilization versus 55% of adults. These findings are consistent with previous research, suggesting that younger patients benefit from early intervention due to the plasticity of their developing nervous systems.[9,10] Pediatric patients are more likely to recover motor, sensory, and bladder functions post-surgery, whereas adults often present with chronic, irreversible damage due to a longer duration of symptoms. Early intervention can, therefore, prevent the progressive deterioration seen in adults, highlighting the need for prompt diagnosis and treatment in pediatric cases.

Table 3: Predictive factors for complications

Predictive factors for complications	Pediatric patients (n=60)	Adult patients (n=60)	P-value
Age (>18 years)	-	+	<0.001
Duration of symptoms (>2 years)	+	+	<0.001
Pre-operative bladder dysfunction	+	+	0.012
Pre-operative neurological deficits	+	+	0.036

Complication rates

Adults had a significantly higher overall complication rate (32%) compared to pediatric patients (15%). Intraoperative and post-operative complications such as CSF leaks, wound infections, and re-tethering were more common in adult patients. The higher rate of complications in adults may be due to the chronicity of TCS at the time of surgery, as well as the more extensive scarring and fibrosis encountered during surgery, making detethering technically more difficult.[1,11] These factors likely explain the prolonged recovery times and poorer long-term outcomes in adult patients. For pediatric patients, fewer complications may be due to the relatively easier surgical access and faster postoperative healing.

Bladder dysfunction

Bladder dysfunction improved in 65% of pediatric patients compared to only 30% of adults. Pediatric patients who undergo early detethering are less likely to have permanent bladder dysfunction due to less cumulative damage to

Table 4: Surgical and immediate post-operative outcomes

Outcome (%)	Pediatric patients (n=60) (%)	Adult patients (n=60) (%)	P-value
Mean surgery time (hours)	2.4±0.5	3.1±0.7	0.028
Intraoperative complications	5 (3 patients)	10 (6 patients)	0.256
Post-operative CSF leak	7 (4 patients)	15 (9 patients)	0.12
Post-operative infection	3 (2 patients)	12 (7 patients)	0.048
Neurological improvement (immediate,)	70 (42 patients)	45 (27 patients)	0.014
Bladder function improvement	65 (39 patients)	30 (18 patients)	< 0.001
Post-operative back pain reduction	60 (36 patients)	35 (21 patients)	0.008
Length of hospital stay (days)	5.2±1.3	7.1±2.4	0.023

CSF: Cerebrospinal fluid

Table 5: Long-term outcomes (2–5 years follow-up)

Outcome (%)	Pediatric patients (n=60) (%)	Adult patients (n=60) (%)	P-value (%)
Neurological function stabilization	80 (48 patients)	55 (33 patients)	0.005
Re-tethering rates	10 (6 patients)	18 (11 patients)	0.132
Need for repeat surgery	8 (5 patients)	22 (13 patients)	0.039
Recurrence of bladder dysfunction	12 (7 patients)	30 (18 patients)	0.014
Recurrence of back pain	15 (9 patients)	40 (24 patients)	0.003
Functional independence (GOS ≥4)	90 (54 patients)	60 (36 patients)	<0.001
Quality of life (SF-36 Score, mean)	85.2±10.6	72.3±12.8	0.021

GOS: Glasgow outcome scale

the neural pathways controlling the bladder. In contrast, adults with prolonged symptoms are more likely to have irreversible damage to these pathways, making recovery less likely.[12,13] In addition, bladder dysfunction in adults is often more severe at the time of surgery, which may explain the lower rates of post-operative improvement in this group.

Long-term outcomes

At the 2–5-year follow-up, pediatric patients had better long-term outcomes, including fewer recurrences of bladder dysfunction and back pain, and a higher rate of functional independence (90% vs. 60%). Pediatric patients also reported better quality of life as measured by the SF-36 Health Survey. This aligns with other studies that emphasize the importance of early intervention in improving functional outcomes and quality of life.[14,15]

Adults, on the other hand, often continue to experience residual symptoms despite surgery. The higher rate of re-tethering and the need for repeat surgeries in adults (22% vs. 8% in pediatric patients) suggest that the long-term prognosis in adults is less favorable. These patients may require ongoing monitoring and management to address recurrent symptoms or complications.[16,17]

Clinical implications and challenges in adult TCS

The significantly poorer outcomes in adult patients point to the challenges of managing TCS in this population. Adult TCS is often underdiagnosed or diagnosed late, which exacerbates the severity of symptoms at the time of surgery.[1] In addition, adults tend to have more acquired forms of TCS, which are often secondary to trauma, surgery, or spinal conditions, and this complicates the surgical approach.[11]

For adult patients, surgical detethering is often more about halting the progression of symptoms rather than reversing the damage that has already occurred. This underscores the importance of early diagnosis, even in adult populations, to improve surgical outcomes. While surgery may alleviate symptoms and prevent further deterioration, the long-term results are less predictable in adults, and they are more likely to experience chronic symptoms that affect their quality of life.[12,18]

Future directions

Future research should focus on identifying ways to optimize outcomes for adult patients with TCS, including the development of enhanced surgical techniques or post-operative care protocols that reduce complications like re-tethering. Understanding the molecular and cellular mechanisms underlying fibrosis and scarring in adult TCS could also lead to new therapeutic approaches that minimize these challenges.

For pediatric patients, the focus should remain on early detection and timely intervention to maximize recovery. Public health strategies to improve the early diagnosis of TCS in children could have a significant impact on reducing the long-term disability associated with the condition.

Limitations of the study

This was a single-centered study.

CONCLUSION

The study underscores the significant differences in surgical outcomes between pediatric and adult patients with TCS, highlighting the advantages of early intervention. Pediatric patients exhibited superior neurological recovery, fewer post-operative complications, and better long-term functional outcomes compared to adults. The findings reveal that early diagnosis and timely surgical detethering in pediatric cases optimize recovery due to greater neural plasticity and reduced cumulative damage. Conversely, adult patients face higher complication rates and limited recovery potential, attributed to prolonged symptom duration and acquired etiologies, emphasizing the challenges of managing chronic cases. Notably, pediatric patients achieved higher rates of functional independence, with a GOS score of ≥4 observed in 90% of cases versus 60% in adults, and reported better quality of life as measured by the SF-36 Health Survey. While surgery effectively alleviates symptoms and prevents progression in both groups, the outcomes in adults are less predictable, requiring tailored management strategies to address chronicity and recurrent issues such as re-tethering. The study reinforces the critical role of early intervention in pediatric TCS and calls for enhanced diagnostic protocols to improve outcomes. For adult cases, the focus should be on halting disease progression, with future research exploring advanced surgical techniques and post-operative care strategies to mitigate complications. Ultimately, the comparative analysis provides valuable insights into the clinical and prognostic implications of surgical intervention in TCS, underscoring the necessity for age-specific approaches to optimize treatment efficacy and patient outcomes.

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