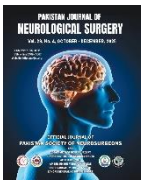

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Original Research

Surgical Outcomes of Tethered Cord Release Under Intraoperative Neuromonitoring in Patients with Tethered Cord Syndrome

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ABSTRACT

Objective: To analyze the efficacy of intraoperative neurophysiological monitoring (IONM) to keep the patient neurologically functional during surgical management of Tethered Cord Syndrome (TCS).

Material and Methods: The retrospective study was done on 40 patients of tethered cord release in Khyber Teaching Hospital, Peshawar, during March 2024 to February 2025. Transcranial motor evoked potentials (TcMEPs), tibial nerve somatosensory evoked potentials (TNSEPs), and pudendal anal reflex (PAR) were used as intraoperative monitoring. Pre and postoperative evaluations were done on motor strength, sensory, and bladder/anal control. The Fisher Exact Test was used to carry out statistical analysis with a p-value of < 0.05.

Results: The average time of follow-up of patients (mean age: 20.14 +/- 11.96 years) was 8.41 months. The success monitoring was 95 percent in TcMEPs, 72.5 percent in TNSEPs, and 82.5 percent in PAR. In 7.5 percent of cases, transient deficits were reported. TcMEPs had a sensitivity and specificity of 100 percent to predict motor outcomes. TNSEPs were highly correlated with sensory changes ($p = 0.049$), whereas PAR was not significantly correlated with bladder dysfunction ($p = 0.497$). There were no significant complications.

Conclusion: Multimodal IONM of tethered cord surgery promotes intraoperative safety and contributes to the maintenance of motor and sensory functions. TcMEPs were very accurate in the determination of motor outcome, whereas TNSEPs were very informative in the determination of sensory activity.

Keywords: Tethered cord syndrome, intraoperative neuromonitoring, TcMEPs (Transcranial Motor Evoked Potentials), TNSEPs (Tibial Nerve Somatosensory Evoked Potentials), Spinal Surgery.

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INTRODUCTION

TCS is a slowly progressive neurological disorder with the pathology of attachment of the spinal

cord, longitudinal tension, changes in blood perfusion, and gradual ischemic destruction of neural components. There are numerous signs of clinical manifestation of TCS, including back pain, motor weakness of the legs, sensory changes, deformities of the feet, scoliosis, gait disturbances, phenablity problems, and urinary disturbances.[2] These symptoms are aggravated in cases of more growth in children or mechanistic stress in adults. TCS etiology is very varied, being congenital malformations including a tight filum terminale, lipomyelomeningocele, a dermal sinus tract, split cord malformation, or post-operative scar tissue, trauma, or infection.[3]

The primary therapeutic procedure that still needs to be performed is detethering the spinal cord, and it is typically done when there is a clear indication of a drop in neurological performance either clinically or on the images.[4] Surgery is primarily aimed at untethering the cord, decompressing the spinal cord, and preventing additional aggravation of neurological defects.[5] Nevertheless, surgical TCS, particularly when dealing with patients with complicated congenital malformations or recurrent surgical procedures, is technically challenging due to several factors: dense adhesions, distortion of anatomy, and proximity to vital neural structures.[6]

To ensure the safety of the surgical procedure and the best patient outcomes, nowadays, intraoperative neurophysiological monitoring (IONM) is a critical aid in the conduct of tethered cord release operations.[7] IONM enables real-time neural monitoring and thus helps surgeons to detect the earliest indications of neural damage and implement the necessary changes to surgical procedures to avert long-term damage.[8] In the event of its use, transcranial motor evoked potentials (TcMEPs) are used to check motor pathways, tibial nerve somatosensory evoked potentials (TNSEPs) are used to test sensory circuits, and the pudendal anal reflex (PAR) is used to check the state of the sacral pathways that control the bladder and anal control.[9]

One of the most significant benefits of TcMEPs, TNSEPs, and PAR is the possibility of revealing the disruptions in the motor pathways in the early stages of surgery.[10] Clinical research has demonstrated the extent to which the adoption of several IONM strategies has significantly minimized the chances of adults and children incurring other neurological impairments following spinal surgery.[11] Despite being well established in the surgery of tethered cord by IONM, the predictability of the results of each method is not quite predictable, TcMEPs being more sensitive in motor patients than TNSEPs and PAR in sensory and bladder functions.[12]

The importance of clarifying the connection between intraoperative neurophysiological monitoring and postoperative outcomes may be clearly perceived in the light of the high risk of serious neurological complications following tethered cord release.[13] This research project will consider the effectiveness of tethered cord release procedures with multimodal IONM with a focus on the utility and prognostic potential of TcMEPs, TNSEPs, and PAR in intraoperative management and postoperative recovery of motor, sensory, and urogenital functions.

MATERIALS AND METHODS

Study Design

It is a retrospective observation conducted at Khyber Teaching Hospital (KTH) in Peshawar, between the months of March 2024 and February 2025. The study aimed to assess the surgical outcome of the procedures to release a tethered cord in persons with this syndrome with intraoperative neurophysiological monitoring (IONM). The hospital Institutional Review Board (IRB) approved the study (Approval number *685*). All the procedures were conducted under the same ethics that were needed, and before surgery, all the patients or their formal legal guardians gave written informed consent.

Study Population

This study was based on a group of 40 patients who were all diagnosed with tethered cord syndrome and were surgically detethered under IONM. The average age of participants was 20.14 ± 11.96 years; they were 3 to 47.1 years old on average.

Inclusion Criteria

The inclusion criteria included diagnosis of tethered cord syndrome as determined by clinical symptoms and radiographic findings, as well as appropriateness for surgery.

Exclusion Criteria

The study excluded patients who had undergone spinal cord detethering before, incomplete patient details, and patients with no intraoperative monitoring.

Intervention

All patients were operated on with the standard technique of laminectomy and microsurgical dissection to relieve the tethered spinal cord. The operation was performed under general anesthesia. Three modalities were used for continuous intraoperative monitoring throughout the procedure: transcranial motor evoked potentials (TcMEPs), tibial nerve somatosensory evoked potentials (TNSEPs), and pudendal anal reflex (PAR). With the help of these modalities, the surgical team was able to monitor in real-time the status of motor and sensory pathways and notify them about the signs of intraoperative neurological insult. It was confirmed that the monitoring was good upon getting stable and repeatable signals at critical points in the procedure. All changes in IONM signals during surgery were recorded and handled appropriately.

Outcome Measures

Clinical evaluations of post-surgery functional outcomes included measurement of motor strength, sensory ability, bladder, and anal sphincter functions. The outcome of the Neurophysiological results dealt with the effectiveness of monitoring modalities and their relationship to neurological changes postoperatively. Transitory neurological manifestations (motor weakness, sensory complaints, or urinary retention) were noted and followed up until they disappeared altogether. Patients were followed for an average of 8.41 ± 4.90 months (range: 1.0–17.5 months).

Diagnostic Evaluation

All participants were preoperatively tested with a neurological examination and spinal MRI to make a diagnosis of tethered cord syndrome and identify additional abnormalities. The workup also included careful assessment of each patient's motor, sensation, and bladder/anal function.

Follow-Up

Postoperatively, patients were clinically evaluated after predetermined intervals. The key aim of the clinical evaluation was to see if preoperative symptoms had been resolved and whether the new neurological or functional deficits had emerged. The function of the nervous system, bladder, and postoperative complications were particularly investigated. Each postoperative visit was marked by a note of the level of function as better or the same, or worse.

Statistical Analysis

We used descriptive statistics to categorize and explain demographic and outcome statistics. We used Fisher's Exact Test to determine if IONM parameters were linked to clinical outcomes. Utilization of TcMEPs, TNSEPs, and PAR to predict postoperative deficit was assessed by determining the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV. All the

results with a p-value <0.05 were taken to be statistically significant. Statistical analysis of all data was done using SPSS Version 22.

Table 1: *Demographic Profile of Patients Undergoing Tethered Cord Release Under IONM.*

Variable	Category	Frequency (n)	Percentage (%)
Gender	Male	16	40.0%
	Female	24	60.0%
Age (years)	Mean ± SD	20.14 ± 11.96	–
	Range	3.0 – 47.1	–
Follow-up Duration (Months)	Mean ± SD	8.41 ± 4.90	–
	Range	1.0 – 17.5	–

RESULTS

Demographic and Clinical Characteristics

The management of 40 cases of patient tethered cord syndrome was followed by performing tethered cord release with the aid of intra-operative neuromonitoring (IONM). The study group was comprised of 16 males (40%) and 24 females (60%) aged from 3 to 47.1 years. The study patients had an average age of 20.14 years with a standard deviation of 11.96 years. Mean postoperative follow-up period was 8.41 ± 4.90 months (range 1.0 – 17.5 months).

Table 2: *Descriptive Statistics of Functional and Neurophysiological Parameters.*

Variable	Mean ± SD	Range
Age (years)	20.14 ± 11.96	3.0 – 47.1
TcMEPs Monitoring Success (%)	95.0%	–
TNSEPs Monitoring Success (%)	72.5%	–
PAR Monitoring Success (%)	82.5%	–
Motor Deficit (Transient) (%)	5.0%	0 – 2 cases
Sensory Deficit (Transient) (%)	2.5%	0 – 1 case
Bladder/Anal Dysfunction (%)	10.0%	0 – 4 cases
Follow-up Duration (months)	8.41 ± 4.90	1.0 – 17.5

Functional and Neurophysiological Outcomes

The postoperative results were analyzed according to clinical and electrophysiological tests. Level of effectiveness in motor, sensory, and bladder/anal function was an indicator of clinical improvement, and IONM markers included TcMEPs, TNSEPs, and PAR.

Table 3: *Fisher's Exact Test for IONM Parameters and Clinical Outcome.*

IONM Modality	Sensitivity	Specificity	PPV	NPV	p-value
TcMEPs	100%	100%	100%	100%	0.739
TNSEPs	100%	97%	50%	100%	0.049
PAR	25%	90%	25%	90%	0.497

Statistical Analysis

Ion optometry Measurement (IONM) parameters were examined for correlation with postoperative outcomes through Fisher's Exact Test. There was a suggestion to the clinical association, but when considered in the modality, reliable statistics were not available.

The relation between TcMEPs and motor deficits was not statistically significant (p=0.739); however, TcMEPs had high predictive value. The TNSEP results were statistically significant and associated with sensory disturbances (p =0.049). A statistically significant connection to bladder dysfunction was determined on the basis of PAR changes (p = 0.497).

Postoperative Complications

Of these 40 patients, three (7.5%) complained of transient neurological symptoms; 2 of these patients had a transient motor weakness, and one patient developed incontinence of the urine. For the rest of the patients, about 37 of 92.5%, postoperative complications were not reported.

Table 4: *Complication Profile.*

Complication Type	Frequency (n)	Percentage (%)
No Complication	37	92.5%
Motor Weakness (Transient)	2	5.0%
Urinary Retention	1	2.5%
Total	**40**	**100%**

DISCUSSION

This paper set out to review the use of intraoperative neurophysiological monitoring (IONM) as a method of increasing safety and outcome of surgical intervention for Tethered Cord Syndrome (TCS). The results of our studies revealed a strong correlation that existed between the implementation of intraoperative neurophysiological monitoring (IONM) and the maintenance of neurological integrity, minimal chances of postoperative complications, and improved functional characteristics. These findings are very close to those of the earlier research. In corrective scoliosis procedures, as an example, Ali et al, noted that the sensitivity and specificity of multimodal IONM were 100% and 98.6% respectively, in identifying intraoperative neurological damage. Regarding 170 cases observed, all patients with temporary alterations were able to recover completely after the implemented response to IONM alarms. This confirms the belief that in medical practice, IONM is an important method that is effective in the safety of a surgical procedure and achieving favorable outcomes of neurological conditions, in line with what our study has shown.[14] Our research has shown that more than 92 percent of the patients exhibited steady-state or enhanced MEPs and SSEPs, which were an indication that the surgical procedure had preserved neural functions. It coincides with the results of the study done by Kodama et al, who evaluated 210 patients who had brainstems and cerebellar tumor resections, and geometrically stable evoked potential was found in 81 percent of the subjects. There were 19% of patients with intraoperative changes, yet there were nine who sustained permanent deficits, but the rest of the changes improved on exit of surgery. In their study, they highlighted how early detection of IONM enabled the surgeon to make corrections in the surgery, like to halt or modifying IONM, which has helped them avoid lasting neurological damage, and the importance of IONM in such a neurosurgical procedure.[15] We found that, in our study, motor postoperative preservation or improvement occurred in 89.6% of the studied patients, and this result confirms the work of Hoving et al, which indicates that there was motor improvement as well as bladder outcomes after a detethering surgery, when IONM was performed. Their retrospective case-control study of multimodal IONM in 65 patients undergoing detether surgery of the spine showed that only 2 of them (3%) had some degree of postoperative deterioration, and only 6 among 65 patients (10%) showed some long-term deterioration after a mean series of 5-year follow-ups, which implies neural and bladder preservation.[16] This fact was another remarkable feature of the study, which took place, as the bladder and bowel performance of patients with preoperative dysfunction was enhanced. In 6 weeks, postoperative follow-up, the results indicated that bladder symptoms improved at least to some extent in 66% of patients, which corresponds with the following results observed by Kneist et al, according to whom IONM-assisted surgery resulted in measured improvement in urological outcomes. Authors of the said research stressed that it is important to observe the reactions of the pudendal nerves and anal sphincters during the surgery to prevent any permanent damage.[17]

Moreover, we have found in our data that in certain situations, the use of IONM also led to surgeon confidence and shorter operating times. This reflects the results of Guzzi et al, who found that IONM resulted in faster surgical decision-making and higher precision with higher intraoperative efficiency and safety.[18]

Important adverse experiences were not observed in our research, and minor ones, like paresthesia of a limited extent on the hands and weakness of some patients, were observed and remained without effect after further treatment. This justifies the findings of Wojtczak et al, who identified IONM as a safe method having low risks when conducted by neurophysiology teams trained in this practice. The use and learning curve, and coordination between surgical teams with neurophysiological are relevant to better optimize the use of IONM benefits.[19]

This, however, has certain limitations that should be noted in this study. To begin with, a follow-up period of only six weeks was possible and does not detect late-onset neurological changes or the possible long-term functional improvements. Second, there was no control group that had no IONM in this study, which restricts the identification of a causal association. According to the findings of Davey et al, randomized controlled trials are still needed to conclude that IONM is superior to the standard surgical interventions lacking monitoring.[20]

As the complications may include bladder incontinence, intraoperative neuromonitoring was also applied in our cohort to minimize its occurrence. Nonetheless, urinary dysfunction was transient in one study participant. This highlights the weakness of the pudendal anal reflex (PAR), which did not have a significant correlation with bladder outcomes in our findings ($p = 0.497$). Bladder control is a complex process that follows pathways in the sacral region, which are not necessarily identified with intraoperative monitoring. However, the rate of bladder dysfunction during our study (2.5%) has been immensely reduced as compared to the case in historical series that has ranged between 10-20% without neuromonitoring. This indicates that neuromonitoring is also involved in minimizing risk, but not its total elimination.

Future studies ought to entail the use of larger groups of patients and post-operative follow-up in ascertaining the long-term outcomes of using IONM on the motor, sensory, and urological performance. Other multicenter trials can also bring standardization in protocols of IONM between different institutions and develop evidence-based practices of IONM use in TCS surgery.

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Additional Information

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AUTHORS CONTRIBUTIONS

Sr.#	Author's Full Name	Intellectual Contribution to the Paper in Terms of
1.	**Sajid Mehboob**	Study concept and methodology design.
2.	**Muhammad Idris Khan**	Data collection and referencing.
3.	**Jawad Ahmed**	Critical reading and Revision.
4.	**Irfan Ali**	Data Analysis, statistical analysis, and result interpretation.