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Case Series

Anaesthesia Section

Feasibility and Safety of Total Intravenous Anaesthesia and Target-Controlled Infusion for Detethering Surgery in Tethered Cord Syndrome: A Case Series

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ABSTRACT

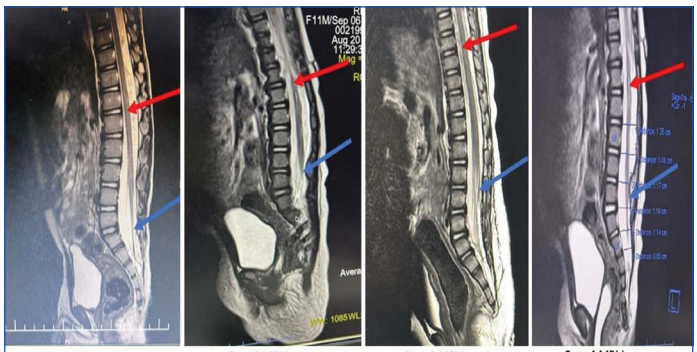
Tethered Cord Syndrome (TCS) is a critical congenital spinal dysraphism that necessitates surgical detethering to arrest progressive, irreversible neurological deterioration. These complicated neurosurgical procedures require robust Intraoperative Neuromonitoring (IONM) utilising multimodal Somatosensory Evoked Potential (SSEPs) and Motor Evoked Potentials (MEP) to protect neural tissue. Anaesthetic management is challenging because neurophysiological signals are vulnerable to anaesthetic-induced depression. Total Intravenous Anaesthesia (TIVA) with propofol and opioids is preferred over volatile drugs to reduce signal suppression, however manually controlled weight-based infusions can introduce intraoperative pharmacological fluctuation. Target-Controlled Infusion (TCI) titrate anaesthetic drugs to effect-site concentration using population-specific pharmacokinetic and pharmacodynamic models. TCI reduces false-positive neuromonitoring alerts, optimises spinal cord perfusion pressure, and facilitates predictable emergence for immediate postoperative neurological assessment. Incorporating TCI to neuroanaesthetic procedures provides a repeatable, stable neurophysiological substrate for accurate IONM interpretation and improved patient safety during complex spinal dysraphism repairs. This case series describes four paediatric patients with TCS who underwent detethering surgery using TIVA or TCI-guided propofol anaesthesia with entropy-guided depth monitoring. Reliable SSEPs and MEPs were successfully maintained throughout surgery in all patients without significant signal attenuation attributable to anaesthetic technique. Haemodynamic parameters remained stable with minimal requirement for vasoactive support, and no episodes of intraoperative awareness or major anaesthesia-related complications were observed. All patients had preserved postoperative neurological function with uneventful recovery. The uniqueness of this series lies in demonstrating the feasibility and effectiveness of TIVA and TCI-based anaesthesia in paediatric detethering surgeries requiring multimodal neuromonitoring.

Keywords: Bispectral index, Entropy, Evoked potentials, Intravenous anaesthesia, Propofol

CASE SERIES

Case 1

A 10-month-old ASA II infant presented with intermittent fever, vomiting, foul-smelling urine, and dull lower abdominal pain of gradual onset over 15 days. After treatment for urinary tract infection in the Paediatrics Department, the infant was referred to Neurosurgery for further evaluation. The infant was born preterm at 36 weeks due to foetal distress, and imperforate anus with anovestibular fistula was identified at birth; anterior sagittal anorectoplasty was performed at five months of age. General, cardiovascular, respiratory, and abdominal examinations were unremarkable. Neurological examination showed GCS E4V5M6, equal reactive pupils, normal tone and power in all limbs, intact sensation, and age-appropriate milestones. The infant weighed 7.4 kg, measured 72.5 cm, and had room-air oxygen saturation of 100%. Whole-spine MRI showed L5 sacralisation, spina bifida from S2, a low-lying cord ending at L2, and an intradural lipoma from L3 to S1, continuous with epidural and subcutaneous fat at S2-S3 [Table/Fig-1]. Abdominal ultrasonography showed a thickened, irregular bladder. Differential diagnoses included lipomyelomeningocele, isolated spinal lipoma, caudal regression syndrome, occult spinal dysraphism without tethering, and neurogenic bladder secondary to congenital spinal anomalies; these were excluded by neurological examination and MRI findings. The radiological findings confirmed TCS associated with occult spinal dysraphism. Fatty filum terminale detethering was performed under IONM and general anaesthesia.



[Table/Fig-1]: Depicts preoperative Magnetic Resonance Imaging (MRI) of the sagittal lumbosacral spine and spinal cord (red arrow) with low-lying tethered conus medullaris (blue arrow), consistent with Tethered Cord Syndrome (TCS).

Case 2

An 11-month-old ASA II infant was brought to the Department of Neurosurgery with a congenital depression over the back, without syndromic features or other comorbidities. The infant was haemodynamically stable, with a pulse rate of 120/min, blood pressure of 80/50 mmHg, and respiratory rate of 24/min. Systemic examination was unremarkable except for skin discoloration in the upper lumbar region. ECG showed sinus tachycardia of approximately 128 beats/min, and echocardiography revealed a structurally and functionally normal heart with good biventricular function, intact septa, and a normal left aortic arch. CT of the lumbar spine showed spina bifida occulta involving D11, L3, L4, L5, and the

entire sacral vertebrae, with posterior element fusion at L4 and L5. Differential diagnoses included myelomeningocele, spinal lipoma, dermal sinus tract, spinal arachnoid cyst, and caudal regression syndrome; these were excluded by the absence of an open neural tube defect, cerebrospinal fluid leak, midline sinus opening, and supportive clinical and MRI findings. MRI demonstrated dorsal levoscoliosis with the apex at D9, secondary cervicolumbar scoliosis, type II diastematomyelia from L2 to L5 with focal involvement at D7, and an interspinal sacral canal lipoma associated with dysplastic neural tissue extending through right-sided spina bifida into the subcutaneous tissue, along with multilevel lumbosacral and coccygeal spina bifida occulta [Table/Fig-1]. Based on these findings, diastematomyelia malformation was diagnosed, and the patient underwent split cord malformation repair with filum terminale detethering, dermal sinus tract excision, and dural repair.

Case 3

A 24-month-old child presented with an insidious, gradually progressive hard swelling over the lower back, from six months of age without ulceration or discharge, and had a history of crying while passing stools since one year. The child had previously undergone anterior sagittal anorectoplasty at 12 months of age, inguinal hernioplasty at four months of age, and had a brief neonatal intensive care unit stay after birth. On examination, the child was conscious, active, and haemodynamically stable, with a temperature of 98°F, heart rate of 120 beats/min, respiratory rate of 28 breaths/min, and blood pressure of 80/60 mmHg. There was no pallor, icterus, cyanosis, clubbing, lymphadenopathy, or pedal oedema. Cardiovascular, respiratory, and abdominal examinations were normal. Neurological examination showed GCS E4V5M6, equal reactive pupils, normal tone and power in all four limbs, intact sensation, and age-appropriate developmental milestones. Local examination revealed lumbar scoliosis with an external swelling, without lower-limb motor weakness, muscle wasting, or sensory loss. Although overt neurological deficits were absent, painful defecation and congenital vertebral anomalies suggested occult spinal dysraphism. Whole-spine CT showed mild lumbar dextroscoliosis, an L3 hemivertebra, and spina bifida occulta at S3-S5.

Differential diagnoses included lipomyelomeningocele, isolated spinal lipoma, caudal regression syndrome, occult spinal dysraphism without tethering, and neurogenic bladder secondary to congenital spinal anomalies. These were excluded by neurological examination and CT findings, which showed a low-lying tethered cord with an intradural lipoma, spina bifida, and L5 sacralisation, without sacral agenesis, presacral mass, or meningeal herniation. The radiological findings confirmed TCS associated with occult spinal dysraphism, and the child underwent L4-L5 laminectomy with cord detethering under IONM.

Case 4

A 36-month-old child presented with a congenital dorsal depression and a lower-back hair tuft present since birth. The child was unable to sit upright or cross-legged and had bowel and bladder incontinence, along with a two-year history of autism spectrum disorder. General and systemic examinations were otherwise normal, apart from skin discoloration in the upper lumbar region; no syndromic features were noted, and cardiac evaluation was normal. MRI of the lumbar spine demonstrated sagittal division of the spinal cord into two hemicords by a ventral septum extending from the upper border of L3 to S1, with a low-lying conus at the upper border of L5 and a thickened filum terminale. These findings supported a diagnosis of type II split cord malformation with tethered cord. Differential diagnoses included lipomyelomeningocele, dermal sinus tract, spinal lipoma, myelomeningocele, caudal regression syndrome, and TCS associated with occult spinal dysraphism; however, these were excluded by clinical examination and MRI findings, including the absence of an open neural tube defect, dermal sinus, meningeal herniation, lipomatous mass, or sacral agenesis [Table/Fig-1]. The child subsequently underwent excision of the lipomeningocele with sectioning of the fatty filum terminale under IONM.

Anaesthetic management: Given the lesion's size and location, high-risk informed consent was obtained from the parents, covering potential airway obstruction, ventilation difficulties, emergency airway interventions, and postoperative ventilatory support. Standard ASA monitoring was applied, and invasive arterial pressure monitoring was established via left radial artery cannulation (22-gauge) due to anticipated respiratory and haemodynamic challenges.

General anaesthesia was induced with fentanyl (2 mcg/kg), propofol (2-3mg/kg), Sevoflurane (MAC 0.5-0.7) and atracurium (0.5 mg/kg), followed by endotracheal intubation while muscle relaxants were avoided to preserve EMG monitoring. Maintenance was achieved with propofol manual infusion in case 1 and 2 with 5-10 mg/kg for 1st 10 min followed by 5 mg.kg for 30-90 minutes. Maintenance in case 3 and 4 was achieved with propofol paedfusor model plasma concentration (Cp) of 3-4 mcg/mL. Maintenance of propofol dose was titrated using Entropy monitoring (target 40-60) to optimise dosing, minimise anaesthetic exposure, and enable rapid recovery. Intraoperative monitoring included invasive arterial access for systolic and diastolic and mean artery blood pressure along with heart rate and saturation. Peak airway pressures and end tidal co2 along with entropy was used for monitoring, SSEP and MEP were monitored. One episode of hypotension was observed in case 1 and treated with phenyl ephrine 20 mcg bolus. Intraoperative course remained uneventful. All the children were extubated in the operating room with stable haemodynamics and intact neurological status.

DISCUSSION

This case series describes our experience with TCI-based anaesthetic management during detethering surgery for TCS and evaluates its feasibility, haemodynamic profile, and impact on IONM.

The TCS, a form of spinal dysraphism caused by abnormal fixation of the spinal cord, can lead to progressive neurological deficits if untreated. Surgical detethering is the definitive treatment aimed at preventing further neurological deterioration while preserving existing function [1]. IONM, including SSEP and MEP, plays a crucial role during detethering procedures, making the choice of anaesthetic technique particularly important [2]. IONM like bispectral index or entropy assist in stabilising and adjusting dose [3].

The TIVA using propofol and opioids is commonly preferred because of its minimal interference with evoked potentials compared to volatile anaesthetics [4] . However, manually controlled TIVA may result in fluctuations in anaesthetic depth due to interpatient pharmacokinetic variability, potentially affecting neuromonitoring reliability.

The TCI is an advanced intravenous drug delivery system that uses pharmacokinetic models to maintain predefined plasma or effect-site drug concentrations [5]. TCI may provide greater haemodynamic stability, improved titration of anaesthetic depth, and more consistent IONM signals [6]. Despite these potential advantages, evidence regarding its use in paediatric neurosurgical procedures remains limited.

The TIVA has been established in adult practice since 1982, with TCI introduced in 1989. In contrast, paediatric use remains limited- only about 10% of paediatric patients were receiving TCI/TIVA for maintenance of anaesthesia [7]. Anaesthetic management in infants and children requires careful attention to neurological status, positioning, and perioperative haemodynamic stability [8]. Successful anaesthetic management of TCS requires a comprehensive understanding of disease pathophysiology, careful anaesthetic technique selection, and close collaboration between anaesthesiologists, surgeons, and neurophysiology teams [9]. TIVA/TCI-based anaesthesia, vigilant haemodynamic control, and judicious use of neuromuscular blocking agents significantly contribute to improved perioperative neurological outcomes [6].

Author (year)	Study design	Patient characteristics	Anaesthetic/monitoring technique	Key findings	Outcome
Suryavanshi K and Panse N (2023) [12]	Case report	Child with Tethered Cord Syndrome (TCS) undergoing detethering surgery	Total Intravenous Anaesthesia (TIVA) (propofol-based TIVA) with Intraoperative Neuromonitoring (IONM) (MEP/SSEP)	Demonstrated feasibility of maintaining stable neuromonitoring signals using TIVA while avoiding inhalational agents and neuromuscular blockade	Successful detethering without neurological deterioration
Gadhvi MA et al., (2023) [14]	Prospective observational study (26 patients)	Patients aged 1-56 years undergoing detethering procedures	Multimodal IONM using triggered EMG, free-running EMG and TcMEP	Multimodal Intraoperative Neuromonitoring (IONM) may be beneficial in minimising postoperative morbidity. The utilisation of multimodal Intraoperative Neuromonitoring (IONM) during tethered cord surgery should be advocated to prevent occurrence of postoperative impairments.	No new postoperative neurological deficits reported
Guo J et al., (2024) [15]	Paediatric observational study	Children undergoing tethered cord release	Intraoperative neurophysiological monitoring during detethering surgery	The application of Intraoperative Neuromonitoring (IONM) during cord release surgery in patients with Tethered Cord Syndrome (TCS) improves long-term outcomes; however, it does not yield improvements in short-term treatment outcomes in children, nor does it minimise short-term new neurological impairment following surgery for TCS.	Demonstrated utility of routine neuromonitoring in paediatric tethered cord surgery
Zheng L et al., (2024) [16]	Case Report and Literature Review	18-year-old male with Tethered Cord Syndrome (TCS) associated with holocord syringomyelia	Surgical detethering following radiological diagnosis	Highlighted rare association of extensive syringomyelia secondary to Tethered Cord Syndrome (TCS) and emphasised importance of early recognition	Neurological improvement following treatment and review of similar cases presented
Mittimanj K et al., [17]	Case report	A two-year-old, child with Tethered Cord Syndrome (TCS) undergoing BCR facilitation.	Total Intravenous Anaesthesia (TIVA) (propofol-based TIVA) with Intraoperative Neuromonitoring (IONM) (MEP/SSEP)	Successful attainment of Bulbocavernous Reflex (BCR)	BCR monitoring was done in a two-year-old child was used to assess sacral reflex integrity, which is essential for bladder and bowel function.

[Table/Fig-2]: Recent studies and case reports on Tethered Cord Syndrome (TCS) and Intraoperative Neuromonitoring (IONM).
Abbreviations: EMG: Electromyography; IONM: Intraoperative neuromonitoring; MEP: Motor Evoked potential; SSEP: Somatosensory evoked potential; TcMEP: Transcranial motor evoked potential; TIVA: Total intravenous anaesthesia

Despite challenges such as pharmacokinetic variability and concerns over Propofol Infusion Syndrome (PrIS), TCI offers clear advantages. In specific anaesthetic or surgical contexts, it may outperform volatile agents and is essential when inhalational techniques are contraindicated [4].

Anaesthetic management in TCS requires a careful balance between maintaining adequate depth of anaesthesia and preserving neuromonitoring signals. Volatile anaesthetics cause dose-dependent suppression of SSEPs and MEPs, while neuromuscular blockers abolish motor responses, markedly reducing the utility of IONM during spinal cord surgery [4]. Therefore, propofol-based TIVA/TCI is the preferred anaesthetic approach in these cases. Propofol preserves evoked potential integrity better than inhalational anaesthetics, thereby supporting effective IONM [4]. TCI further stabilises plasma drug concentrations, helping maintain haemodynamic stability and consistent monitoring signals, which is particularly important in infants [10].

Recent randomised controlled trials have demonstrated that BIS-guided TIVA in children improves the proportion of time spent within the optimal anaesthetic range (BIS 40-60), thereby reducing episodes of light or deep anaesthesia without prolonging recovery times [3,11]. BIS or Entropy monitoring has been shown to reduce propofol requirements and improve perioperative stability, with studies confirming its feasibility in paediatric populations [3].

Suryavanshi K and Panse N also used TIVA with propofol 100 mcg/kg/min (12 mL/hr) and dexmedetomidine 0.2 mcg/kg/hr. Their study reported two episodes of tachycardia and increased airway pressures, possibly related to fluctuations in plasma propofol concentrations [12]. In contrast, in the present case series, TCI with entropy monitoring maintained a stable plasma propofol concentration of 3-4 mcg/mL and was not associated with intraoperative tachycardia.

Prone positioning during detethering surgery introduces additional challenges, including reduced venous return, pressure injuries, and airway-related complications. In the study, by Bhimani AD et al., the postoperative readmission rate was 5.9%, the reoperation rate was 2.7%, and the surgical site infection rate was 2.1%; in contrast, our case series had no readmissions, reoperations, or surgical site infections [13]. The advancement of IONM has been particularly significant. Multiple studies show that IONM enables early detection of spinal cord compromise and timely surgical intervention, thereby reducing the risk of permanent neurological deficits [10]. Gadhvi MA et al., reported that multimodal IONM may be beneficial in minimising postoperative morbidity [14]. Similarly, we used multimodal IONM techniques like SSEP and MEP. The utilisation of multimodal IONM during tethered cord surgery was recommended to prevent occurrence of postoperative neurologic impairments. In contrast Guo J et al., stated that application of IONM doesn't improve short term outcomes but there are improvements in long-term outcomes. Guo J et al., also stated that application of IONM must be individualised, taking into consideration the clinical expertise and judgment of physicians, while also thoroughly evaluating MRI data, patient symptoms, and additional criteria [15]. Similar cases are given in [Table/Fig-2].

Advances in paediatric TCI models, such as Paedfusor, and adjuncts including remifentanil and dexmedetomidine are enhancing precision and safety. TCS, despite its rarity, can be the sole cause of extensive syringomyelia. For these patients, the completion of untethering surgery can result in a satisfactory clinical prognosis and the complete resolution of the syrinx [16]. Mittimanj K et al., also reported the successful use of TIVA to assess sacral reflex integrity by facilitating the bulbocavernosus reflex in a two-year-old child [17]. Ongoing pharmacokinetic research in neonates, obese children, and critically ill patients is expected to further refine dosing strategies.

CONCLUSION(S)

This case series demonstrates that entropy-guided TCI with propofol-based TIVA stabilises haemodynamics and provides reliable neuromonitoring during paediatric tethered cord and split cord deformity procedures. TCI permitted precise anaesthetic depth titration while retaining SSEP and MEP signals for safe detethering. Entropy monitoring maintained adequate hypnotic depth, avoided anaesthetic fluctuations, and allowed smooth emergence with early

postoperative neurological assessment. Neuromonitoring improves with neuromuscular inhibition and less volatile anaesthetic exposure. For paediatric neuro-anaesthesia with IONM, entropy-guided TCI appears to be safe and feasible.

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