Double neurophysiological certification of the filum terminale during sectioning surgery in pediatric population

Juan P. Cabrera, Sebastián Vigueras, Rubén Muñoz, Eduardo López

Department of Neurosurgery, Hospital Clínico Regional de Concepción, Concepción, Bío Bío, Chile.
E-mail: *Juan P. Cabrera - jucabrera@udec.cl; Sebastián Vigueras - savigueras@hotmail.com; Rubén Muñoz - rualmu@gmail.com; Eduardo López - elopezferrada@gmail.com

**INTRODUCTION**

The conus medullaris is connected to the dural sac through intradural filum terminale (FT), a not-well defined fibrous ligament which has received relatively limited and not recent attention in the literature regarding its anatomical and histological characteristics. Tethered cord syndrome (TCS) is a congenital condition in which the ends of the spinal cord and cauda equina are attached at different levels to the surrounding structures.
Thickened FT or FT fibrolipoma require surgical section for prevention or treatment of neurological, musculoskeletal, and urological abnormalities, which are often reversed or enhanced by FT transection. FT sectioning surgery is gaining popularity due to its relative simplicity, avoiding a continuous conus medullaris trauma resulting in the development of new symptoms and/or new neurological deficit.

In spite of FT can be anatomically recognized, mapping techniques, that is, stimulating motor nerve roots to identify and locate the FT before cutting, are recommended. At present, this is one of the simplest surgeries for tethered cord which can be performed more quickly and in a perfectly tailored surgical field. However, in some cases, there is a positive mapping response with low intensity stimulation of the FT, affected by an individual threshold variability of motor rootlets in pediatric population. The aim of this study is to demonstrate the usefulness of a double methodology for FT certification.

**MATERIALS AND METHODS**

The prospective study collected and reviewed retrospectively, from 2015 to 2018, 40 patients undergoing a sectioning surgery for FT. We considered patients with magnetic resonance imaging (MRI) showing fibrolipoma FT or thickened FT aged from 6 months to 18 years old. The main indications of surgery were patients with urodynamic abnormalities ruling out other causes, neurogenic bowel/bladder, before scoliosis correction and FT abnormality, FT pathology with syringomyelia, progressive lower extremities orthopedic deformities, conus medullaris low inserted, and clinical symptoms of TCS. We excluded patients with other causes of TCS and patients who had previously undergone lumbosacral spine surgery to prevent the need for isolation of scar tissue in neural structures.

Anesthesia was performed with total intravenous anesthesia, avoiding neuromuscular blockade. Gauze bite blocks were intraorally used in all cases.

**Intraoperative neurophysiological monitoring**

We used the NIM Eclipse Medtronic IOM system, with disposable subdermal double needle electrodes, which are 12mm in length and 0.4mm in diameter (27 gauge).

The needle electrodes are placed in groups of muscles innervated by the nerve roots which had the greatest risk of injury during release. These muscles included the bilateral quadriceps femoris, tibialis anterior, gastrocnemius medial, abductor hallucis, and anal sphincter.

Recording parameters for free-run and triggered EMG are set with filters between 20 and 3,000 Hz, gain 100 μV/Div, and time base 5 m/div.

**Traditional mapping technique**

Single-pulse stimulation is performed with repetitive constant current, 200 μS pulse duration at 1–2 Hz, using a monopolar flush-tip/ball tip probe, or bipolar probe when is available preferably. Mapping technique comprises stimulating the motor nerve roots of cauda equina and getting a unilateral, asymmetrical, and single radicular response from muscles studied according to its dominance and participation. When the FT is stimulated, non-response is expected. Mapping of each motor or sensory nerve roots was not performed.

**High intensity stimulation**

This proposed methodology consists in stimulation of an isolated FT using high intensity current as much as 20 mA, obtaining a bilateral, symmetrical, and polyradicular response from all cauda equina nerve roots studied. This technique complements the traditional technique when stimulation of the FT with low intensity evokes a response from any muscle, despite proper separation and dissection of the surrounding neural elements. When the FT is stimulated, an all-response is expected. Latencies of the responses were not assessed and not compared.

**Surgical technique**

Minimally invasive posterior approach to L5-S1 level is performed and under microscopic view, the dura mater opened, the nerve roots are recognized, and any of them is stimulated for obtaining motor threshold. The FT is identified anatomically followed by arachnoidal dissection, isolated by vascular a band, maintaining a dry surgical field, and placing cottonoids over surrounding nerve roots. If the mapping technique does not evoke any muscle response using ≥3 mA, the FT is coagulated and cut. Alternatively, if any muscle response is obtained, the region surrounding the FT is explored certifying absence of neural elements; if the response persists, the current intensity is increased until 20 mA. When this stimulation evokes response from all muscles studied, the FT is coagulated and cut. During this study, we performed double neurophysiological certification in all cases, despite no response with traditional technique.

**RESULTS**

In all cases (40/40), patients were studied with MRI showing kind of FT and if conus medullaris is normally located [Figure 1a and b]. The surgery was performed using a tailored approach in all. The FT was identified, dissected of surrounding nerve roots, separated by vascular bands, stimulated, and finally cut [Figure 2a-e].

Traditional motor mapping technique could identify FT in 65% (26/40) of patients, using intensity >3 mA without
eliciting a response, increasing stimulation intensity up to 5 mA to ensure absence of nerve roots before sectioning, while threshold of motor nerve roots was elicited with <1 mA.

Despite low-intensity stimulation (<1 mA), muscle response was still present in 35% (14/40) of cases and was almost always an anal sphincter response, either unilateral or bilateral. When this happens, optimization of the dissection surrounding the FT is performed. In this scenario, 25% (10/40) of patients still have a muscle response despite an isolated FT.

After improved the dissection and isolation, an increment of the stimulation intensity up to 20 mA evoked response of the cauda equina in all cases (40/40), obtaining a bilateral-polyradicular-symmetrical response in all muscles included in the recording. This double certification allowed safely cut FT in all patients [Figure 3a and b].

Stimulating a non-isolated nerve root at 1 mA threshold was obtained and at 20 mA evokes a mainly unilateral-polyradicular-asymmetrical response [Figure 4a and b].

Notably, all patients of this case series did not develop a new neurological worsening.

DISCUSSION

As an integral methodology of intraoperative neurophysiological monitoring, motor root mapping techniques can accurately differentiate neurological tissues from other non-neurological surrounding structures. The FT is stimulated before release to ascertain if nerve roots are present around it, and comparing the threshold as a prognosis factor. The conus medullaris and cauda equina easily evoke a response with an appropriate stimulation technique, unlike FT. The FT sectioning surgery is currently rapidly evolving in a tailored surgical field. This may result in inappropriate stimulation as a result of current propagation, which could cause confusion in taking the final surgical decision despite a clear anatomical appearance of the FT.

FT is a midline non-neurological structure. However, in accordance with their common embryological origin, a true anatomical and histological continuum was found between the conus medullaris and FT. Considering this, another supportive fundamental element is a stimulation-induced response that is bilateral, symmetrical, and polyradicular, with the current ability to depolarize FT and in an antidromic way nerve roots arising from the conus medullaris [Figure 5]. We strongly believe that this is not spreading when FT is completely isolated and in a dry surgical field, and when a FT is stimulated outside the dura mater and is dissected from the arachnoid and other nerve roots. After nerve root stimulation,
**Figure 3:** Double neurophysiological certification of filum terminale (FT). (a) Traditional mapping technique, stimulation of FT at 3.2 mA without motor nerve roots response, confirming FT. (b) High-intensity stimulation of the same FT. Note the bilateral, polyradicular, and symmetrical response in all muscles studied, confirming FT. Quadriceps femoris (vastus lateralis), tibialis anterior, gastrocnemius medial, abductor hallucis, anal sphincter.

**Figure 4:** Stimulation of intradural, wet and non-isolated right sided nerve root. (a) Close to the threshold <1 mA, obtaining a single muscle response from the same side (arrow). (b) High-intensity stimulation at 20 mA of the same nerve root. Note the response preferably unilateral, polyradicular for current spreading, and highly asymmetrical. Quadriceps femoris (vastus lateralis), tibialis anterior, gastrocnemius medial, abductor hallucis, and anal sphincter.
we expect a unilateral, asymmetrical, and monoradicular response with low current intensity, independent of high variability, and considerable radicular overlapping.\textsuperscript{[7]}

Some authors have reported that a 1:100 ratio between the motor root and the filum threshold for FT identification predicts that, if all nerve roots are sufficiently separated from FT in the adult\textsuperscript{[5]} and pediatric patients,\textsuperscript{[9]} using voltage stimulation, expecting no response elicited or activation of a motor nerve root secondary to contiguity. We used constant current and a ratio 1:20 to limit current spreading. The first neurophysiological certification of FT is no response, in which normal intensity above the threshold of the motor nerve roots is used. The second certification involves responses from all the motor nerve roots of the cauda equina. This double neurophysiological certification of FT is not time-consuming, highly reproducible, morbidity-free, cost-effective, and extremely accurate for FT identification.

**CONCLUSION**

From a practical point of view, this methodology is proposed to accurately confirm FT, locate it, and safely cut it. There is no doubt that future research is needed to rule out current spreading and understand the exact mechanism of the response. The Double Neurophysiological Certification improves the gap of the traditional motor mapping technique of the cauda equina in a tailored surgical approach and can be used in various more complex surgeries in this area.

**Declaration of patient consent**

Patient’s consent not obtained as patients identity is not disclosed or compromised.

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**Conflicts of interest**

There are no conflicts of interest.

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