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Original Investigation

Intraoperative Neuromonitoring in Surgery of Cauda Equina and Conus Medullaris Tumors

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ABSTRACT

AIM: To demonstrate the value of special intraoperative neuromonitoring techniques for cauda equina and conus medullaris tumors (CECMT) by describing standard methods used at our center.

MATERIAL and METHODS: Neurophysiological records were retrospectively reviewed for 16 patients (eight females and eight males; age range: 27–60 years) who underwent surgery for CECMT at our department between 2016 and 2018.

RESULTS: Motor and/or sensorial deficits were preoperatively identified in 10 patients; no patients had bladder or sexual dysfunction. Motor evoked potential (MEP) loss occurred in seven patients with full or partial recovery. No changes were seen in pudendal somatosensory evoked potential (SEP) or bulbocavernosus reflex (BCR), and morphological deterioration and amplitude loss of tibial SEPs were present in four patients. Postoperatively, no new neurological deficits and/or bladder and sexual dysfunction were present.

CONCLUSION: Pudendal SEP and BCR are useful tests for monitoring CECMT surgeries. BCR is an easily obtainable modality for preserving sacral functions and recommended as a primary monitoring modality in conjunction with traditional neurophysiological techniques during CECMT surgery.

KEYWORDS: Bulbocavernosus reflex, Pudendal SEP, Intraoperative neuromonitoring, Cauda equina, Conus medullaris, Neoplasm

ABBREVIATIONS: PI: Partial improvement, **CI:** Complete improvement

INTRODUCTION

Cauda equina and conus medullaris tumors (CECMT) are very rare, and surgeries for these tumors can result in devastating complications such as bladder and sexual dysfunction. Thus, intraoperative monitoring (IOM) is a routine for CECMT surgery, with tibial nerve somatosensory evoked potentials (SEPs) and muscle motor evoked potential (mMEPs) being the most commonly used IOM techniques. However, these techniques cannot be used to assess the functionality of the sacral nervous structures that provide neural control of micturition, defecation, and sexual function. New modalities for evaluating sacral functions have been introduced into IOM practice (2,3,6,7). These modalities include root stimulation and recording techniques of the anal sphincter by trigger EMG (tEMG), detection of neurotonic discharges showing nerve irritation by free-running EMG (fEMG), recording sensory evoked potentials after electrical stimulation of the dorsal penile or clitoral nerve (pudendal SEP), and recording the bulbocavernosus reflex (BCR) to assess the functionality of the S2–S4 sacral segments (2,3,6,7). Although traditional neurophysiological techniques (SEPs and MEPs) are well known, specialized neurophysiological techniques like pudendal SEP and BCR are not used at all centers.

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This paper aims to describe the standard neurophysiological techniques used at our center to show the usefulness of tests such as pudendal SEP and BCR during CECMT surgeries.

MATERIAL and METHODS

This is a study of patients who underwent surgery for CECMT with accompanying IOM atIstanbul University-Cerrahpasa (IUC), Department of Neurosurgery, from 2016 to 2018. Demographic information, histopathological diagnoses, resection rates, preoperative and postoperative neurological examinations, and intraoperative neurophysiological recordings of 16 patients were retrospectively evaluated.

All procedures were performed in accordance with the 1964 Helsinki Declaration and its later amendments. Written informed consent was obtained from all patients.

Neuromonitoring

A standardized institutional set-up was used. Recordings from the iliopsoas (I), quadriceps femoris (QF), vastus lateralis (VL), tibialis anterior (TA), gastrocnemius (GK), abductor halluces (AH), and sphincter ani externus muscles (AS) ensured that all segments from L1 to S4 were recorded. Stainless steel needle electrodes (13–19 mm, Xi'an Friendship Medical Company) were used to record muscle responses and stimulate peripheral nerves. Disposable corkscrew electrodes were used for the stimulation of the motor cortex from the scalp to elicit MEPs and to record cortical SEPs. IOM was performed using the Cadwell elite IOM system and monitored by a neurophysiologist (E.T).

When necessary, a mapping technique was used to identify nerve roots and their corresponding spinal levels. The functionality of sensory and motor pathways and reflex circuits was continuously assessed. The sensory pathway was evaluated by stimulating the tibial and dorsal nerves of the penis/clitoris (terminal branches of the pudendal nerve) and recording cortical responses from scalp electrodes. The motor pathway was evaluated with MEPs, which were obtained by transcranially stimulating the motor cortex and recording from the lower extremity muscles and sphincter muscles. The BCR was elicited by electrical stimulation of the dorsal nerve of the penis/clitoris and recorded from AS muscles to monitor the functional state of the S2–S4 sacral segments and corresponding roots, sensory fibers, and motor nerve fibers. In addition, fEMG from the lower extremity muscles and AS muscles was monitored for any spontaneous activity that might indicate acute injury to the innervating nerve roots. All surgical procedures were viewed on a screen in the operating room during surgery.

Total intravenous anesthesia (TIVA) comprising propofol (1.5–2 mg/kg for anesthesia induction and 6–10 mg/kg/h for maintenance) plus remifentanil (0.15µg/kg/min) was used in 13 patients, and inhalational anesthesia (sevoflurane, MAC 0.5, BIS 40–60) was used in three patients. A short-acting muscle relaxant (rocuronium, 0.5 mg/kg) was used only for endotracheal intubation.

RESULTS

The mean age of the 16 patients (eight males and eight females) was 44 years (range of 27–60 years). The histopathological diagnoses were classical ependymoma in four patients, myxopapillary ependymoma in three patients, tanycytic ependymoma in one patient, schwannoma in six patients, meningioma in one patient, and neurinoma in one patient. Total resection was achieved in 14 patients, and two patients diagnosed with meningioma and tanycytic ependymoma had subtotal resection. During preoperative neurologic examinations, motor deficits were detected in seven patients, five patients had sensorial deficits, and no patients had bladder or sexual dysfunction. Demographic information and surgical outcomes are summarized in Table I.

Loss of MEP occurred during resection in seven patients. These patients had classical ependymoma (Pt3 and 5) and tanycytic ependymoma (Pt7) at L2 and schwannoma (Pt11, 12, 13, and 15) at T12 and L2. Three patients (Pt5, 7, and 12) showed mild motor deficits on their preoperative neurological exam, and the others were neurologically intact. The surgeon was informed as soon as the MEP amplitude diminished more than 50% or was completely lost during surgery. In these cases, surgery was interrupted, systemic changes and anesthesia were checked, and blood pressure was elevated. With these interventions, total or partial MEP improvement was achieved by the end of surgery. There were no false positive responses in the patients.

Morphological deterioration and amplitude loss of tibial SEPs were observed in four patients (Patients 3, 5, 13, and 16) with subsequent complete recovery. These patients had schwannoma (Patients 12 and 15) at the T12 spinal level and ependymoma (Patients 3 and 5) at L2.

Two patients (Patients 6 and 7) underwent subtotal resection. Pt6 had residual meningioma filling the L5 to S2–3 segments. This patient had been operated on at another center two years earlier and did not have any neurological deficits on preoperative neurological examination. During the operation, the sacral nerve roots seemed adherent to the huge tumor mass and could not be safely dissected. Pt7, who had tanycytic ependymoma, showed sensorial deficits at right L1 and left L4–S1 dermatomal levels preoperatively. MEP responses were completely lost in the lower extremity muscles on the left side during resection, causing subtotal resection. Partial improvement was seen in MEP responses by the end of surgery.

Pudendal SEPs and BCRs could not be recorded in two patients who had volatile anesthesia during surgery. These patients showed variability in their MEP and/or BCR responses. Pudendal SEPs and BCR responses did not change in other patients. Postoperatively, no new neurological deficits and/or bladder and sexual dysfunction were present in any patients (Table I).

Case Illustration

A 49-year-old female presented with lower back pain radiating into her left leg. Preoperative magnetic resonance

Table I: Demographic Information, Surgical Resection Rates, Histopathology, Preoperative Neurologic Examination, IOM Changes during the Surgery, and Postoperative New Neurologic Deficit of Patients

Patient No	Age, Gender	Histopathology	Preop Neurological Status	Resection	IOM Changes during the Surgery	Postop Neurological Status
1	38, M	Miksopapillary Ependymoma WHO 1	Neurologically Intact	Total		No Addicional Deficit
2	50, F	Classical Ependymoma WHO 2	Paraparesia, Hypoestesia	Total	MEP Response Variability, Lack of BCR Responses	No Addicional Deficit
3	48, F	Classical Ependymoma WHO 2	Neurologically Intact	Total	MEP Amplitude Decrement and SEP Amplitude Decrement	No Addicional Deficit
4	27, M	Celluler Schwannoma	Monoparesia, Hypoestesia	Total		No Addicional Deficit
5	49, F	Classical Ependymoma WHO 2	Monoparesia	Total	MEP Loss with PI and SEP Morphological Deterioration	No Addicional Deficit
6	31, M	Meningioma	Hypoestesia	Subtotal	MEP Response Variability	No Addicional Deficit
7	27, F	Tanycyctic Ependymoma	Hypoestesia	Subtotal	MEP Loss with PI	No Addicional Deficit
8	60, M	Schwannoma	Monoparesia	Total		No Addicional Deficit
9	60, F	Neurinoma	Hypoestesia	Total		No Addicional Deficit
10	43, F	Myxopapillary Ependymoma WHO 1	Neurologically Intact	Total		No Addicional Deficit
11	57, M	Schwannoma	Neurologically Intact	Total	MEP Loss in Right Side with PI, Total in Left with CI	No Addicional Deficit
12	27, F	Schwannoma	Monoparesia	Total	MEP Loss with PI and SEP Loss with CI	No Addicional Deficit
13	55, M	Cellular Schwannoma	Neurologically Intact	Total	MEP Loss with CI	No Addicional Deficit
14	29, M	Classical Ependymoma WHO 2	Monoparesia	Total		No Addicional Deficit
15	59, F	Cellular Schwannoma	Neurologically Intact	Total	MEP Loss and SEP Loss with PI	No Addicional Deficit
16	49, E	Myxopapillary Ependymoma WHO 1	Monoparesia	Total		No Addicional Deficit

PI: *Partial improvement* ***CI:*** *Complete improvement.*

imaging (MRI) revealed a 18 × 16 × 12 mm intradural mass, homogeneously Gd-enhanced at the level of L3 (Figure 1). During surgery, loss of MEPs was seen in the right AH, AS, and TA muscles, and tibial SEP morphology deteriorated bilaterally. These MEP and SEP changes occurred after the appearance of neurotonic discharges in the fEMG of muscles innervated by the S1–S4 roots during resection (Figures 2 and 3). Pudendal SEP and BCR responses (Figure 4) did not change at this time. After the corrective interventions mentioned above, all responses partially or completely improved by the end of surgery (Figures 2 and 3). This patient presented no additional neurological deficits in the postoperative period. The tumor was completely removed (Figure 5). Final pathology was classical ependymoma WHO Grade II.

■ DISCUSSION

BCR is the most appropriate method for monitoring the functional integrity of the sacral sensory and motor nerve fibers and spinal segments at the CE and CM intraoperatively. BCR is easily elicited by electrical stimulation of the dorsal nerve of the penis/clitoris and is recorded from the perineal or external anal sphincter muscles (2,10). The main advantage of this method is that both stimulation and recording are performed outside the surgical field, in contrast toother methods (7) performed in the surgical area that require specific recording electrodes, extra time, and experience. As a result, BCR recording does not interrupt surgery while evaluating both sacral sensory and motor fibers. Baseline BCR acquisition rates have

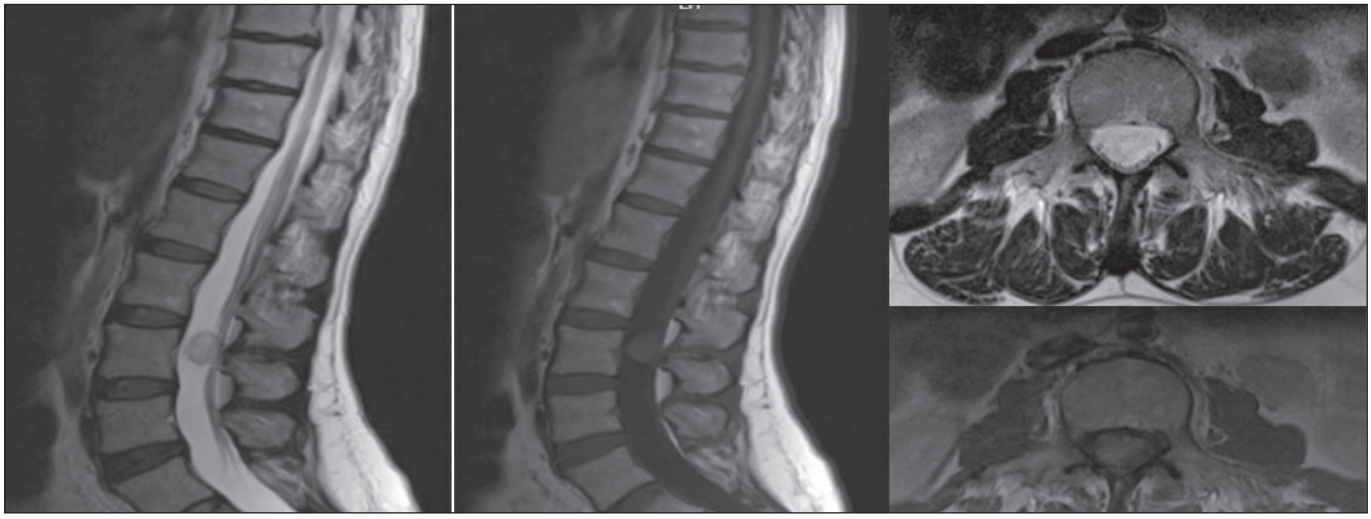

Figure 1: T1, T2 sagittal, and T2 axial MRI showing an 18 ×16 × 12 mm intradural mass homogeneously Gd-enhanced at the level of L3.

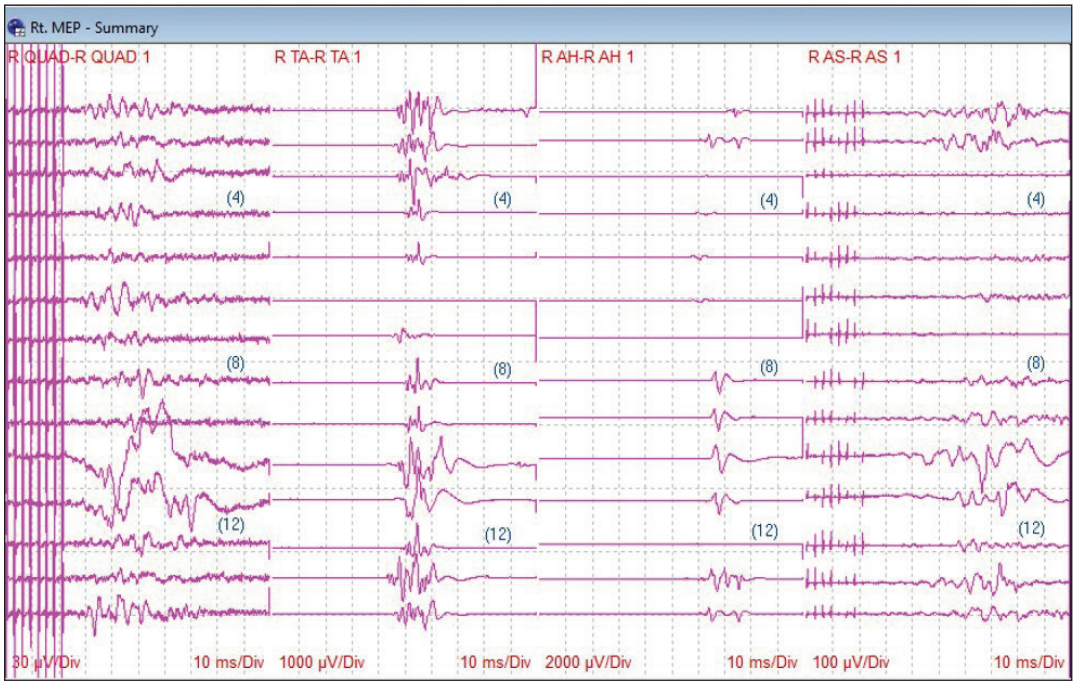

Figure 2: Loss of MEPs in the right abductor halluces, anal sphincter, and tibialis anterior muscles.

improved with developments in stimulation techniques and TIVA usage (8,10). We achieved BCR responses in all patients when TIVA was used. BCR responses were easily recorded in both male and female cases, although the reported rates for eliciting BRC in women are low in the literature (8). BCR is the best monitoring technique for evaluating the integrity of sacral sensory and motor fibers.

The deleterious effects of volatile anesthetics on MEP responses and the need for TIVA when using MEPs are well known (4,9,11). However, we had to use volatile anesthetics in three patients since propofol could not be used. Variability in MEP responses and difficulty obtaining baseline MEPs were noted in these patients, consistent with previous reports (4,9). Notably, two of the five muscles recorded (VL and AS) in these two patients did not produce baseline MEP recordings despite their normal function.

Likewise, the influence of volatile anesthetics on BCR responses is similar to MEP acquisition because pudendal motor neurons are involved in BCR (10). We could not record BCR or certain muscle MEPs in three patients. Previously, Deletis and Vodusek demonstrated the suppressing effect of both inhalation agents and muscle relaxants on BCR (3). Therefore, TIVA is preferred, and inhaled agents should be avoided when monitoring this reflex (12). Although they are limited, our findings are in line with the literature (3,8,9). Regarding acquisition of BCR responses, it has been reported

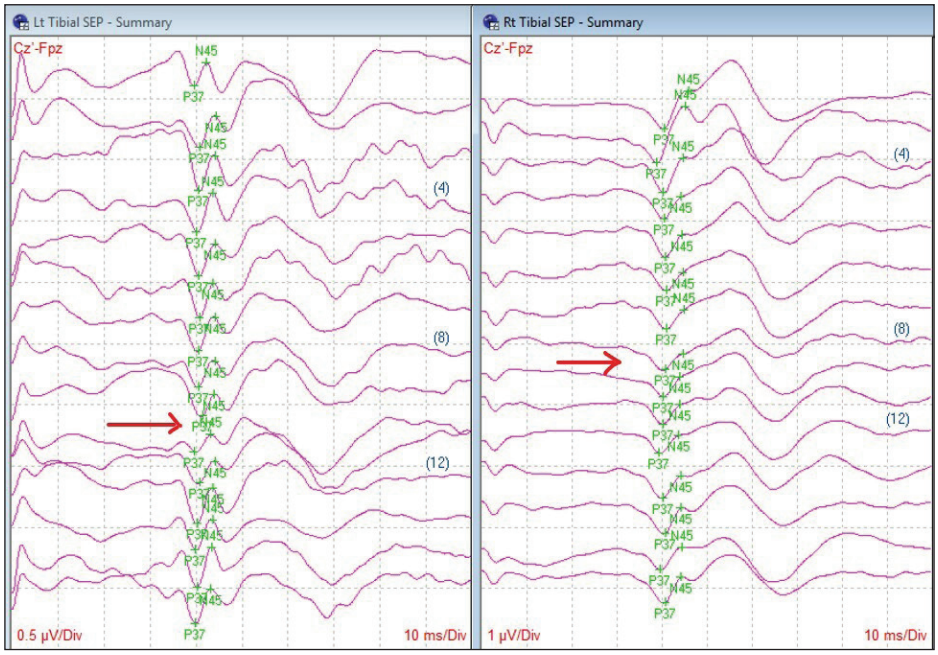

Figure 3: Deterioration of bilateral tibial SEPs morphologically.

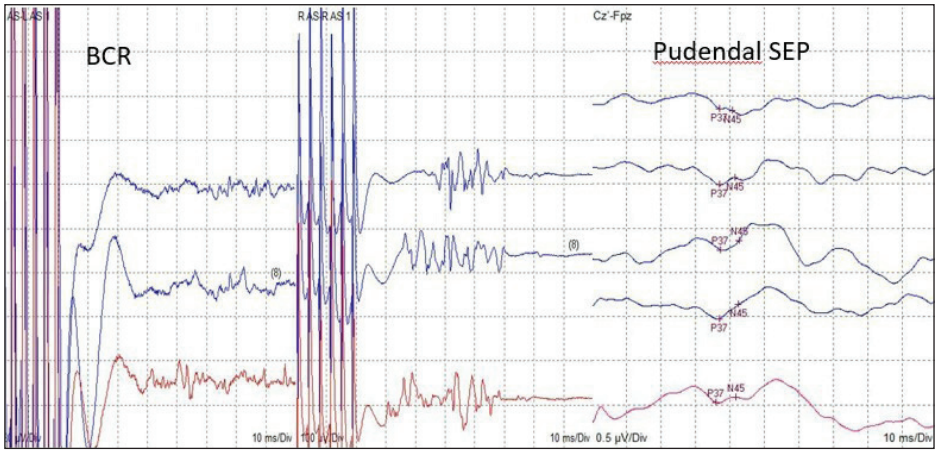

Figure 4: Pudendal SEPs and BCR at baseline and at the end of surgery.

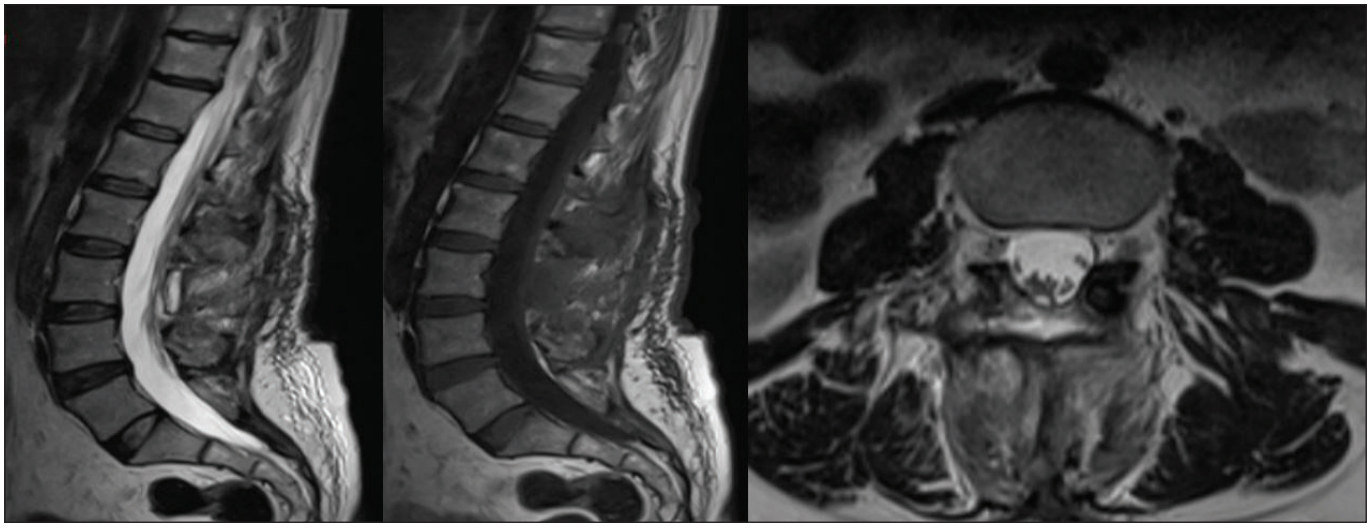

Figure 5: Postoperative sagittal and axial MRI of the patient.

that a train of four electrical stimuli is optimal for eliciting BCR in anesthetized patients (10). However, in our study, the BCR response was obtained with a minimum train of five stimuli and an ISI of 2.5 ms in anesthetized patients.

Pudendal SEPs are stimulated electrically from the dorsal nerve of the penis/clitoris and recorded as a cortical response on the scalp (1). Abnormalities in SEPs and BCR responses in patients with impotence have been reported (5). Pudendal SEPs are possible in IOM; however, the availability and reliability of pudendal SEPs are not clear. Cohen obtained pudendal SEPs in only 11 of 154 patients (1). In the present study, we attempted pudendal SEP recordings in 12 patients and were successful in all but one case. Eliciting pudendal SEPs was difficult in some patients, especially women. Ultimately, we achieved responses in our patients using low-frequency stimulations, such as 2.79 Hz, an intensity of 40 mA, and a duration of 300–400 ms. The lack of pudendal SEPs when volatile anesthetics are avoided and the patient is neurologically intact suggests ineffective or insufficient stimulation or displacement of the stimulant electrode.

BCR is superior to pudendal SEPs in two aspects. First, pudendal SEP can be challenging to record and requires averaging many responses over a period of time. Second, BCR is the most suitable monitoring modality for CE and CM. The afferent pathways of the BCR are the sensory fibers of the pudendal nerves, the efferent pathways are the motor fibers of the pudendal nerves and anal sphincter muscles, and its reflex center is the S2–S4 spinal segment. Thus, BCR evaluates the functional state of three distinct anatomical structures. In addition, as the response is obtained after only one train of stimuli, it is not time-consuming. BCR monitoring is thus recommended as the primary monitoring modality in conjunction with traditional IOM techniques for CECMT surgery.

This study has several limitations. First, the number of cases is quite small and includes no morbidity. There is also little evidence for the quantification and interpretation of pudendal SEPs and BCRs, and we have presented no evidence that monitoring prevents dysfunction.

CONCLUSIONS

Neurosurgical outcomes can be improved by increasing the functionality of monitoring options for patients with a significant risk of a poor outcome. BCR is the most suitable monitoring method for lower sacral segments, and tibial SEPs and MEPs monitor higher levels of the cord. The presence of the BCR response at the end of surgery indicates good postoperative urinary, fecal, and sexual function.

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