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Case report

Intraoperative neurophysiological monitoring of T9-T10 fracture in a patient with morbid obesity and ankylosing spondylitis: A case report with literature review

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ABSTRACT

Introduction: As the prevalence of obesity continues to rise, there is a growing need to identify practices that protect overweight patients from injury during spine surgery. Intraoperative neurophysiological monitoring (IONM) has been recommended for complex spine surgery, but its use in obese and morbidly obese patients is understudied.

Case report: This case report describes a patient with morbid obesity and ankylosing spondylitis who was treated for a T9-T10 3-column fracture with a planned, minimally invasive approach. Forty minutes after positioning the patient to prone, the IONM team identified a positive change in the patient's motor responses in the bilateral lower extremities and alerted the surgical team in a timely manner. It turned out that the pressure exerted by gravity on the patient's large pannus resulted in further dislocation of the fracture and narrowing of the spinal canal. The surgical team acknowledged the serious risk of spinal cord compression and, hence, immediately changed the surgical plan to an urgent, open approach for decompression and reduction of the fracture. The patient's lower extremities' motor responses improved after decompression. The patient was ambulatory on post-operative day 2 and pain-free at six-weeks with no other neurologic symptoms.

Significance: The use of IONM in this planned minimally invasive spine surgery for a patient with morbid obesity prevented potentially serious iatrogenic injury. The authors include a literature review that situates this case study in the existing literature and highlights a gap in current knowledge. There are few studies that have examined the use of IONM during spine surgery for morbidly obese patients. More research is needed to elucidate best practices for the use of IONM in spine surgery for morbidly obese patients.

1. Introduction

The prevalence of obesity in the United States is rising, with 1 out of every 2 adults expected to be obese, and 1 in 4 adults severely obese, within the next ten years (Ward et al., 2019). There is evidence that obese patients are at heightened risk for perioperative complications and iatrogenic peripheral nerve injury during spine surgery (Cao et al., 2016; Jiang et al., 2014; Patel et al., 2007). The use of intraoperative neurophysiological monitoring (IONM) with somatosensory evoked potentials (SSEPs) and transcranial motor evoked potentials (tcMEPs) is highly recommended for spinal surgery when the risk of complication is high, as may be the case for patients with morbid obesity (Clark et al., 2013; Stecker, 2012). However, there are currently few studies evaluating the unique challenges and benefits of IONM in spinal surgery for obese patients, despite ample evidence of their increased risk for spinal injury and the difficulties associated with patient positioning and intraoperative imaging (Katsevman et al., 2020). This case report highlights the importance of neurophysiological monitoring and challenges that we are facing in spinal surgery for morbidly

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obese patients, even when a minimally invasive approach is planned.

2. Methods

2.1. Intraoperative neurophysiological monitoring (IONM)

IONM was performed using Medtronic NIM-Eclipse E4 system. Standard scalp electrodes were placed using corkscrew electrodes (Medtronic, 945DME1001), according to the International 10-10 system, at Fpz, Cpz, Cp3 and Cp4 for EEG and SSEP recordings, and at C3 and C4 for tcMEP stimulation. An additional needle electrode (Medtronic, 945DSN2280, 13 mm, 27G) was placed at the right-side mastoid (Cv) to record subcortical responses of SSEPs referencing to Fpz. Needle electrodes (Medtronic, 945DSN2280, 13 mm, 27G) were also placed subcutaneously over ulnar nerves at the wrists and posterior tibial nerves at the ankles, bilaterally. Bilateral ulnar nerves and posterior tibial nerves were stimulated at 30–45 mA (300- μs pulse duration, 1.97 Hz for ulnar nerve stimulation, and 1.37 Hz for posterior tibial nerve stimulation) to elicit scalp SSEP responses in an interleaved fashion. EMG needle electrodes (Medtronic, 945DSN2280, 13 mm, 27G) were placed into the bilateral first dorsal interosseous (FDI), iliopsoas (IL), adductor longus (AD), vastus lateralis (QD), tibialis anterior (TA), gastrocnemius (GS), and abductor hallucis (AH) muscles to record spontaneous EMG activities and tcMEP responses. Train-of-Four (TOF) responses were measured by stimulating ulnar nerves and posterior tibial nerves with recordings from the ipsilateral FDI and AH muscles, respectively, to ensure adequate peripheral conduction and to validate subsequent EMG-based monitoring. tcMEPs were elicited using a train of biphasic constant-voltage stimulation (up to 800 V, 4–8 pulses, pulse duration 50–75 μs, 400–1000 Hz) between the C3 and C4 electrodes. Baseline tcMEPs were optimized to reliably elicit a motor response with a 450-V stimulation (8 pulses, 75 μs, 500 Hz); stimulations up to 475 V were tested, but did not provide a better response than 450-V stimulation. After optimization, stimulation parameters remained unchanged throughout the case. The recording settings (i.e., filter, sweep time, number of averages, etc.) were configured based on American Clinical Neurophysiology Society guidelines for SSEPs and tcMEPs (American Clinical Neurophysiology Society, 2006; Legatt et al., 2016). For the interpretation of SSEP recordings, a 50% drop in amplitude and/or a 10% prolongation in latency from baseline responses was considered to be a significant change in the SSEP. Similarly, the alarm criteria for tcMEP recordings was any amplitude decrease greater than 50% in monitored muscles. Significant changes in SSEPs and tcMEPs, if any, were immediately reported to the surgical team. Frequent communication with the anesthesia team was maintained throughout the case to 1) ensure patient was under appropriate anesthesia, and 2) determine whether any IONM signal changes were related to adjustments of anesthetics or variations in temperature/hemodynamics.

2.2. Anesthesia

Anesthesia was induced uneventfully using propofol and a short acting non-depolarizing muscle relaxant, rocuronium (60 mg). Dexamethasone (8 mg) was administered after induction to reduce the risk of vocal cord swelling, considering the patient had a difficult airway which required a combination of video laryngoscopy and fiberoptic bronchoscopy to correctly insert the endotracheal tube. Because neuromuscular blockade can interfere with motor evoked potentials, train-of-four monitoring was used to confirm no residual blockade existed. Anesthesia was maintained with infusions of propofol (150 mcg/kg/min) and remifentanil (0.05 mcg/kg/min). Volatile anesthetic gases were avoided in order to optimize conditions for neuromonitoring. An arterial line was inserted for close hemodynamic monitoring. After induction of anesthesia, the goal was to maintain the mean arterial pressure (MAP) within 10% of baseline (baseline MAP 70 mmHg) with intermittent bolus doses of phenylephrine and ephedrine. At one point during the procedure, the IONM team noted a significant decrease in the lower extremity tcMEP responses and a decision was made to augment MAP to >80 mmHg. A phenylephrine infusion (30–50 mcg/min) was started to maintain these MAP goals. There were no significant changes in hemoglobin or core body temperature during the case.

3. Case report

A 45-year-old male with morbid obesity (BMI 62.72 kg/m^2) and ankylosing spondylitis slipped and fell on ice while he was clearing snow off his car. He reported that he heard a popping sound and felt immediate pain in his back. He was transferred to our medical center and presented with severe axial thoracic pain, but no other neurologic symptoms including numbness, weakness, or paresthesia in his lower extremities. A computed tomography (CT) scan revealed a 3-column fracture through an ankylosed T9-T10 disc space and posterior elements (Fig. 1A). The T9-T10 fracture was considered to be unstable with disruption of all three spinal columns, typical of trauma in the setting of ankylosing spondylitis. Based on the fact that there was no significant spinal deformity or neurologic compromise requiring spinal decompression, a minimally invasive approach was initially favored with percutaneous instrumentation for stabilization from T7 to T12 using an intraoperative CT and image-guidance technique.

Due to the highly unstable nature of the spine fracture and risk of neurologic injury with transfer and positioning, the patient was intubated supine on a Jackson spinal table (MIZUHO OSI, Union City, CA). The Jackson table is capable of rotating 180 degrees from supine to prone positioning in order to maintain appropriate spinal precautions and minimize the risk of positioning. IONM was utilized to obtain pre-position baseline recordings. The baseline SSEPs and tcMEPs of the bilateral upper and lower extremities were obtained. All responses were reproducible with delayed and symmetrical latencies (~25 ms in the upper extremities, and ~51 ms in the lower extremities) in SSEPs. Once the Jackson spinal surgery top was secured, the Jackson table was rotated 180 degrees and the patient was flipped to the prone position. The patient's arms were placed on arm boards in the prone "superman" position, with sufficient padding around the elbows and axilla areas. Immediate post-flip SSEPs and tcMEPs were unchanged from pre-flip baselines (Fig. 2, marked by blue arrows). However, 40 min after positioning the patient prone, we noticed and reported a significant decrease in the tcMEP responses of the bilateral lower extremities (Fig. 2, marked by red arrows; Fig. 3A), although the lower-extremity SSEPs remained stable bilaterally (Fig. 4). Of note, despite not meeting the alarm criteria, there were some subtle increases in latency (~2 ms, Fig. 4) of the right posterior tibial nerve SSEPs. Meanwhile, the right-side ulnar nerve SSEPs started to show reduction in amplitude (>50%) both in the cortical and subcortical channels and almost became absent subsequently, despite increasing the stimulation current from 30 mA to 35 mA (Fig. 5, highlighted in red). This decrement was improved after repositioning the right-side arm board and providing more padding around the elbow. The amplitude reduction in right-side FDI muscle (Fig. 2, marked by orange arrow; Fig. 3B) might have resulted from the unsatisfactory positioning of the arm, which was consistent with the changes in right-side ulnar nerve SSEPs (Fig. 5). The right-sided upper extremity SSEPs and tcMEPs showed amplitude

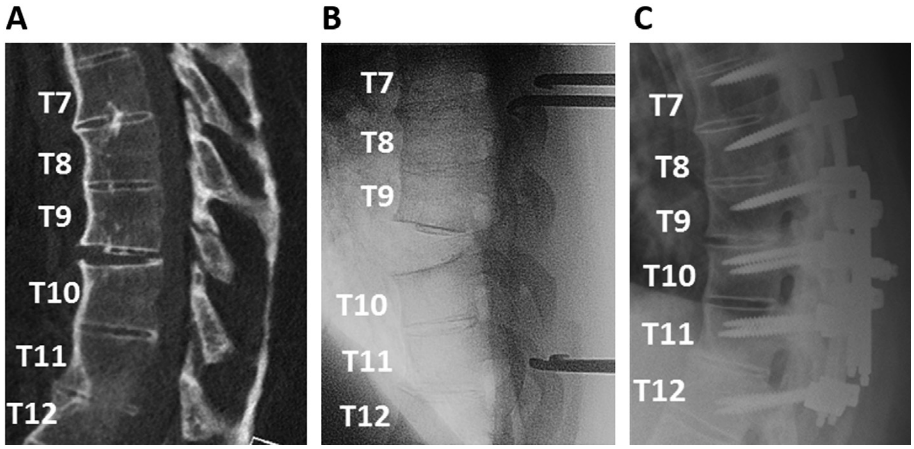

Fig. 1. Peri-operative O-arm/CT imaging of the thoracic spine. (A) Pre-operative CT imaging of the thoracic spine shows a 3-column fracture through an ankylosed T9-T10 disc space and posterior elements. (B) Forty minutes after flipping the patient to prone position, transcranial motor evoked potentials were significantly decreased in the bilateral lower extremities. Intraoperative O-arm scan confirmed enlarged distraction of the T9-T10 fracture. (C) Immediate post-operative O-arm scan demonstrated satisfactory instrumentation with restoration of the normal spinal alignment.

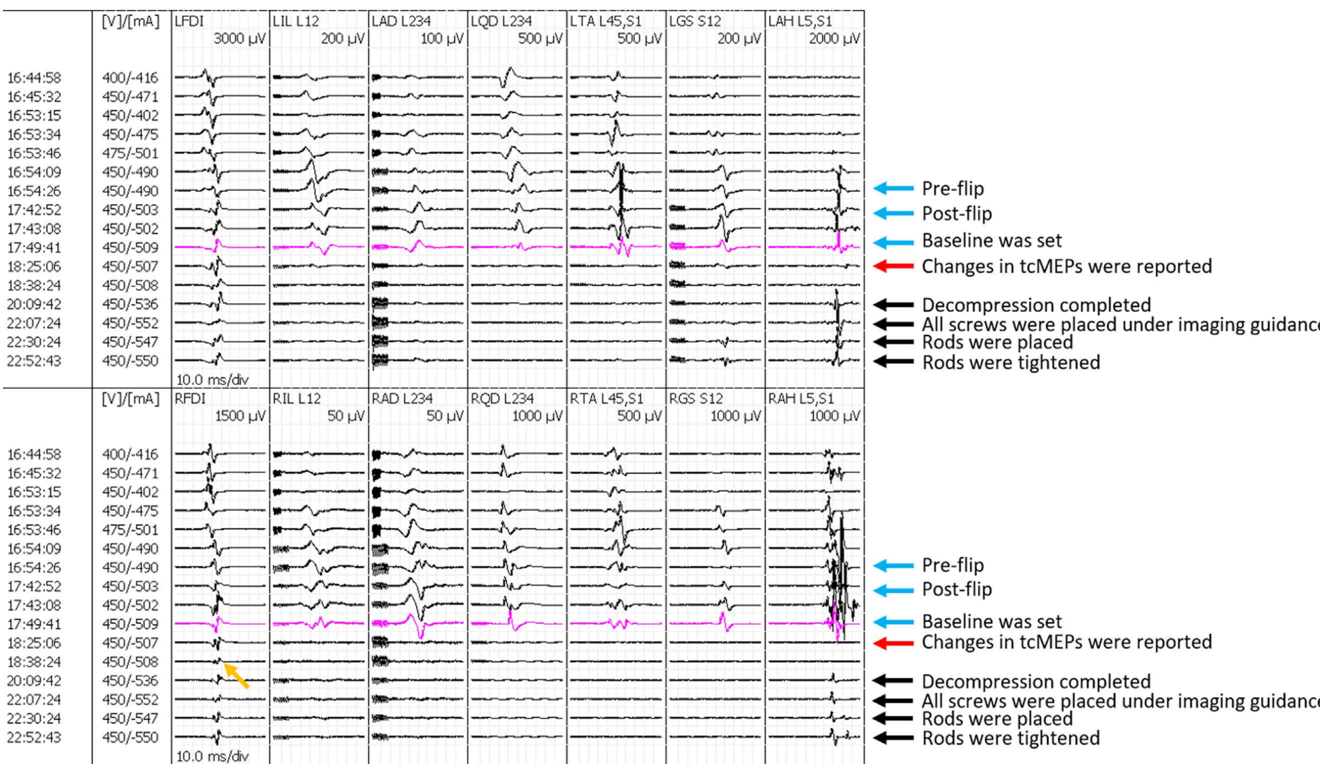

Fig. 2. Stack of transcranial motor evoked potentials (tcMEPs). Upper panel shows the tcMEPs of left-side upper and lower extremities. Lower panel shows the tcMEPs of right-side upper and lower extremities. Second column indicates the set stimulation voltage and actual delivered current. Constant-voltage stimulation was used to elicit tcMEPs following optimization of stimulation parameters at baseline. Blue arrows highlight the pre- and post-flip baseline, which did not raise any concerns regarding potential neurologic injuries from the flipping. Forty minutes after flipping, a significant decrement of tcMEPs in bilateral lower extremities were reported (marked by red arrows). Response of right first dorsal interosseous also showed a >50% decrease (orange arrow), which was resolved by re-positioning the right arm. After decompression and fusion, tcMEPs in the lower extremities improved with reproducible responses in distal muscles. However, tcMEPs in upper legs were still diminished. FDI: first dorsal interosseous; IL: iliopsoas; AD: adductor longus; QD: vastus lateralis; TA: tibialis anterior; GS: gastrocnemius; AH: abductor hallucis. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

fluctuations throughout the case that were not able to be fully corrected by repositioning and cushioning the arm.

There was no significant change in the anesthetics and hemodynamics at the time when IONM team noticed the sudden decrement in bilateral lower extremities' tcMEPs (Table 1). MAP remained higher than 75 mmHg and not significantly lower than baseline values. The IONM team verified all stimulation electrodes were secure in place and confirmed adequate stimulation for tcMEPs, ruling out the possibility that the signal loss was due to insufficient stimulation. At this point, based on the observation that bilateral lower extremities' tcMEPs continued deteriorating (Fig. 3B), an intraoperative O-arm/CT scan was obtained and revealed that there was new distraction of the T9-T10 fracture with loss of thoracic kyphosis, and significant narrowing of the spinal

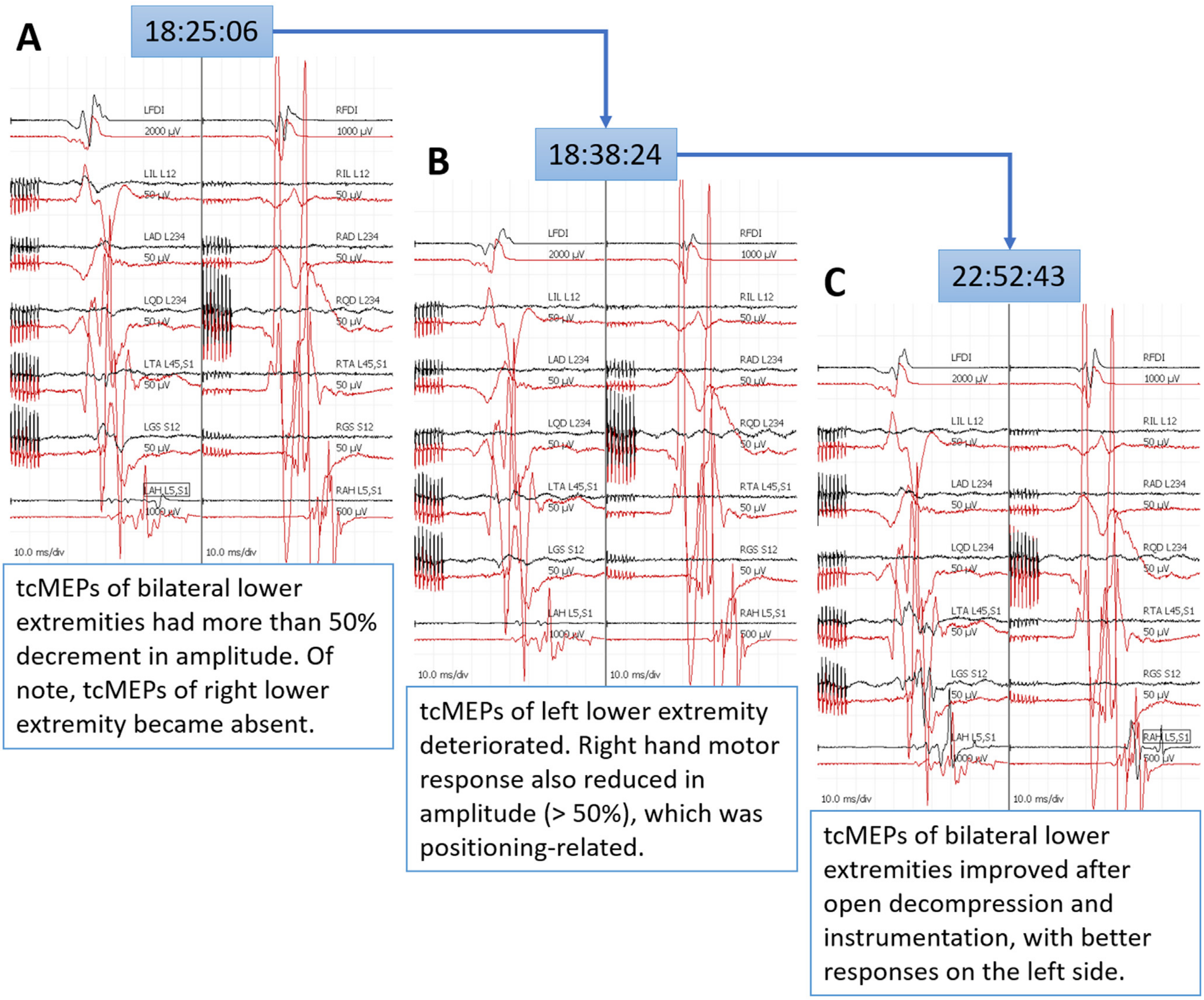

Fig. 3. Traces of transcranial motor evoked potentials (tcMEPs) at three critical time points. (A) At 18:25:06, tcMEPs showed unexpected significant decreases in bilateral lower extremities, with absent responses in right side. (B) At 18:38:24, tcMEPs of left lower extremity deteriorated. Right hand motor response also reduced in amplitude by more than 50%, which was positioning-related. (C) At 22:52:43, tcMEPs of bilateral lower extremities improved after open decompression and instrumentation. Black: traces at critical time points; Red: baseline tcMEP responses. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

canal concerning for spinal cord compression (Fig. 1B). It was presumed that traction on the large pannus from gravity had placed the spine in extension, which led to further dislocation of the fracture. In light of the neuromonitoring and radiologic findings, the surgical plan was changed from a minimally invasive percutaneous technique to an urgent, open approach for spinal cord decompression and open reduction of the fracture. Laminectomies at T9 and T10 were performed to decompress the spinal canal.

After decompression, tcMEP responses in the distal lower extremities improved, i.e., bilateral abductor hallucis muscles (Fig. 2). Using image-guidance techniques, pedicle screws were inserted bilaterally from T7 to T12 with connecting cobalt-chromium rods. Spinal alignment was restored after reduction of the distracted segments. Final tcMEP responses were present in the bilateral feet and left lower leg (Fig. 2, Fig. 3C). Both upper and lower SSEPs were stable and unchanged from baseline.

Immediate post-operative O-arm scan demonstrated satisfactory instrumentation with restoration of the normal spinal alignment (Fig. 1C). Large pressure-induced bruises were noted in bilateral groin areas, worse on the right. The patient woke up from anesthesia and was able to follow commands and move all four extremities. He had significant spontaneous movement throughout the left lower extremity (5/5 muscle strength). However, the right-side hip flexion did show some subtle weakness (4+/5 muscle strength), but otherwise 5/5 on segmental motor exam.

On post-operative day (POD) 1 the patient's motor and sensory exams were normal with no evidence of bowel or bladder dysfunction. He ambulated on POD 2. At a six-week evaluation he was neurologically intact without pain or other neurologic symptoms.

4. Discussion

Intraoperative neurophysiological monitoring has been recommended as a standard of care for complex spine surgery due to its ability to reduce the risk of perioperative spinal cord injury (Sutter et al., 2019). While IONM is less commonly used in minimally invasive surgeries, multiple studies have shown that patients

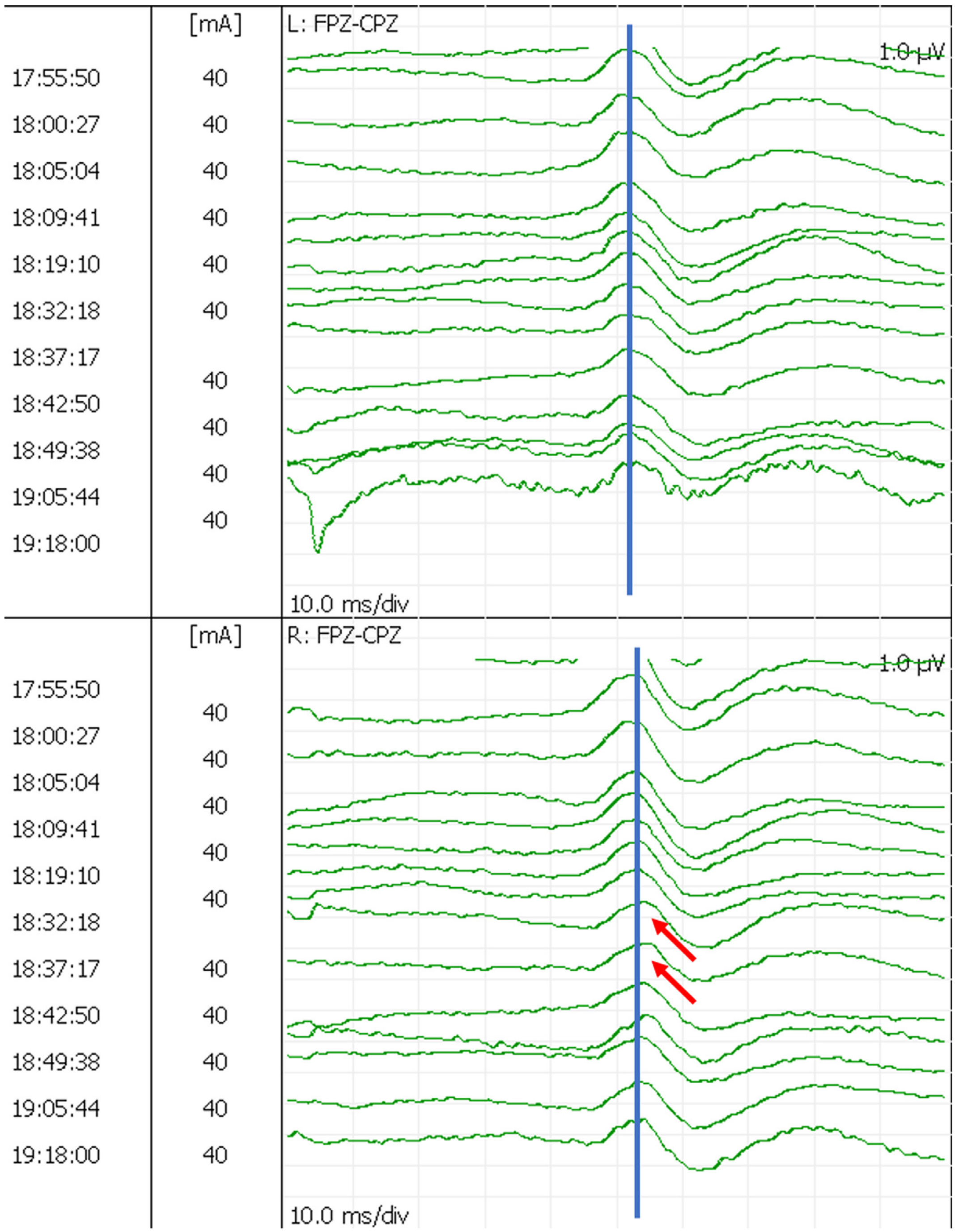

Fig. 4. Partial stack of posterior tibial nerve (PTN) somatosensory evoked potentials (SSEPs). When changes in tcMEPs were reported, there was no significant change noted in the PTN SSEPs. However, there were some subtle increments of latency (∼2 ms, marked with right arrows) in right-side PTN SSEPs after the changes in tcMEPs being noted, which did not meet the alarm criteria.

with a BMI greater than 30 kg/m^2 have an elevated risk for intraoperative complications and injury (Bono et al., 2018; Bundy et al., 2010; Cao et al., 2016; Goyal et al., 2019; Jiang et al., 2014; Patel et al., 2007).

This case report describes a patient with morbid obesity (BMI 62.72 kg/m^2) and ankylosing spondylitis who was treated for a T9-T10 3-column fracture with a planned, minimally invasive approach. During surgery, the pressure exerted by gravity on the large pannus resulted in further dislocation of the fracture and narrowing of the spinal canal, which justified open decompression and fracture reduction. The Jackson spinal table allows for controlled prone positioning and minimizes compression of the abdominal organs during spine surgery. However, for patients with a large pannus, prone positioning on the Jackson table may cause pressure to be exerted on anterior lumbar spine, exaggerating lordosis resulting in spinal extension (Bundy et al., 2010). The use of intraoperative neurophysiological monitoring with imaging allowed for early detection of the spinal compression, preventing serious injury or paralysis. The patient had no neurologic sequelae from the surgery, was ambulatory by POD 2, and pain free at six weeks.

There are a limited number of reports on the use of IONM in spinal surgery for obese patients. We conducted a literature review

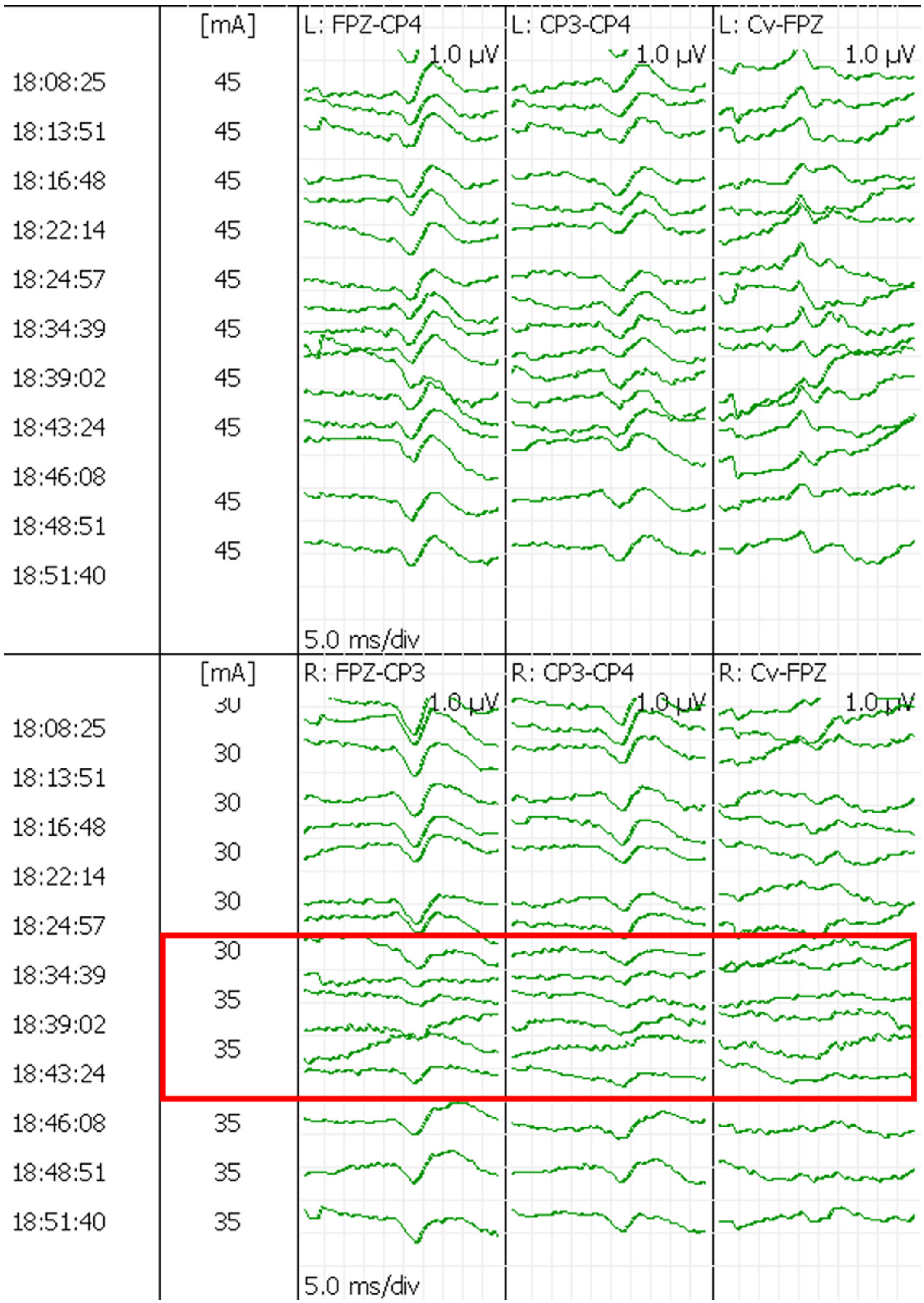

Fig. 5. Partial stack of ulnar nerve somatosensory evoked potentials (SSEPs). The patient was flipped to the prone position. The patient's arms were placed on arm boards in the prone "superman" position, with sufficient padding around the elbows and axilla areas. However, we still noticed a significant decrement in the right-side ulnar nerve SSEPs (highlighted in red rectangle) during the case. The SSEPs returned to baseline and remained stable after re-positioning the right arm and adjusting the padding around the elbow. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

using the following keywords in PubMed and Google Scholar: "spine surgery," "obes*," "morbid* obes*," "intraoperative neurophysiological monitoring," and "intraoperative neuromonitoring." A total of 220 references were reviewed in this study, including the full bibliographies of four recently published systematic review articles on either spine surgery in obese patients or the use of IONM in spine surgery (Charalampidis et al., 2020; Daniel et al., 2018; Goyal et al., 2019; Katsevman et al., 2020). Several articles in the literature discussed the intraoperative management of anesthesia during spine surgery for obese patients, but only two studies were identified that reported on the use of IONM during spine surgery in this patient population (Kim et al., 2007; Rodgers et al.,

Table 1
Brief summary of intraoperative mean arterial pressure (MAP) and temperature.

Time	MAP (mmHg)	Temperature (°C)	Comment
16:44	79	n/a	Pre-flipping. Patient was supine.
16:45	78	n/a	
16:53	79	n/a	
16:54	79	n/a	
17:42	86	36.6	Post-flipping. 80 mcg phenylephrine was given at 17:34 after flipping the patient (MAP was around 60 mmHg)
17:43	84	36.6	
17:49	84	36.5	
18:25	79	36.4	IONM team reported changes in lower extremities
18:38	75	36.4	160 mcg phenylephrine was given at 18:41 per surgeon's request
20:09	79	36.5	
22:07	82	37.2	
22:30	78	37.2	
22:52	94	37.2	

2010). We conducted a secondary review of all articles citing these two studies, and identified two additional articles on the topic (Deiner et al., 2010; Ushirozako et al., 2020). Relevant findings from the four studies are shown in Table 2.

Although our literature review found no sources reporting on the use of IONM in spine surgery for morbidly obese patients (BMI > 40 kg/m^2), the available studies do support the feasibility of IONM in obese patients (BMI > 30 kg/m^2), which may be enhanced by the use of longer intramuscular needles (Deiner et al., 2010; Jahangiri et al., 2019; Rodgers et al., 2010). While the sensitivity of tcMEP is quite high, increased body mass appears to be associated with elevated risk for false positive reduction of tcMEP, as initially reported by Kim et al. (Kim et al., 2007; Ushirozako et al., 2020). In fact, the current case had many concurrent risk factors for a false positive result as outlined by Kim and colleagues: significant loss of tcMEP without return to baseline, unchanged SSEP, and high BMI. We also considered the effect of hemodynamics, as the challenges of intraoperative anesthesia management during spine surgery for morbidly obese patients are well-documented in the literature (Epstein, 2017; Stevens et al., 2015). These patients are at higher risk for hemodynamic fluctuations, and many challenges in maintaining hemodynamics are exacerbated in the prone position, or during patient repositioning (Domi and Laho, 2012). In our case, the anesthesia team anticipated these changes and responded accordingly, as demonstrated in Table 1. The surgical team considered the timing and magnitude of the changes and determined that these were not significant hemodynamic fluctuations that could have contributed to the tcMEP changes observed in this case.

In this case, intraoperative imaging confirmed that IONM did identify a true-positive change, and the surgeons intervened by modifying the surgical plan to prevent further spinal cord injury. The distal lower extremities' tcMEPs improved after thoracic spinal decompression. The lack of motor response recovery in upper legs (worse on the right side) shown in Fig. 2 was likely the result of some peripheral compression. Local muscles and iliac crest compression from the Jackson table pads may apply pressure to major arteries and peripheral nerves, preventing elicitation of tcMEPs in the upper legs. This suspicion was supported by the presence of pressure bruises found across the patient's iliac crest and groin area after surgery, which were also worse on the right side. However, we did not have any direct evidence (i.e., intraoperative Doppler ultrasound exam) to definitively prove that the lack of tcMEP recovery in upper legs was associated with limb ischemia. Bilateral external anal sphincter tcMEPs and pudendal/perianal SSEPs monitoring may allow for rapid differentiation between spinal cord injury and limb ischemia (Lee et al., 2016). Overall, the risk of false positive loss of tcMEPs is greater in patients with high BMI; nonetheless, significant reduction of tcMEP signal is an extremely sensitive sign of intraoperative spinal damage, as demonstrated here. Intraoperative imaging may help the surgical team rule out false positives.

With the increasing frequency of spine surgery for patients with morbid obesity, it is important to elucidate appropriate treatment practices to reduce the risk of iatrogenic injury. Bariatric security straps can comfortably control a large abdominal pannus on the Jackson table, allowing for passage of fluoroscopy (Elgafy et al., 2016). Although they were not used in this case, bariatric straps may relieve additional pressure on the anterior spine for such patients, reducing the risk of perioperative complication.

5. Conclusions

This case report highlights the importance of IONM and intraoperative imaging in spine surgery for the morbidly obese patient even when a minimally invasive surgery is planned. Morbidly obese patients have a heightened risk of surgical complication due to a variety of factors, and their safety may require additional planning and monitoring. In this case, IONM successfully identified true-positive neurophysiological changes resulting from unexpected worsening of the spinal fracture, and immediately alerted the surgical team. The surgical team responded to the alert and modified the surgical approach from minimally invasive to an open procedure. Without the IONM findings and cohesive teamwork, this patient could have experienced a serious neurologic injury and potentially ended up with a permanent deficit.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Table 2
Summary of studies on IONM in spinal surgery for obese patients.

Study	Number of cases	Type of cases	Relevant findings	Outcomes for morbidly obese patients? (Y/N)
Kim et al., 2007	52	Cervical myelopathy	False positive tcMEP alerts were associated with higher BMI. Patients with BMI 35+ had higher rate of false positives.	N
Rodgers et al., 2010	313	Extreme lateral interbody fusion	Obesity (BMI > 30 kg/m^2) did not interfere with IONM.	N
Deiner et al., 2010	256	Spine surgery (all levels)	BMI was not an independent risk factor for failure to obtain baseline tcMEP signals.	N
Ushirozako et al., 2020	703	Spine surgery (all levels)	False positive tcMEP alerts were slightly elevated in obese patients (BMI > 30 kg/m^2)	N

tcMEP: Transcranial motor evoked potential. IONM: Intraoperative neurophysiological monitoring. BMI: Body mass index.

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