Neurophysiologic Monitoring Can Predict Iatrogenic Injury During Acetabular and Pelvic Fracture Fixation

Manny Porat, MD · Fabio Orozco, MD · Nitin Goyal, MD · Zachary Post, MD · Alvin Ong, MD

Received: 5 April 2013 / Accepted: 1 July 2013 / Published online: 8 August 2013
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Abstract *Background:* Nerve injury during acetabular and pelvic fracture fixation can have devastating consequences for trauma patients already in a compromised situation. *Questions/Purposes:* This study aims to evaluate the efficacy of multimodality intraoperative neurophysiologic monitoring during acetabular and pelvic fracture fixation in identifying emerging iatrogenic nerve injury. *Methods:* Sixty patients were retrospectively identified after surgical fixation following acetabular or pelvic fracture. Neuromonitoring during surgery was performed using three different modalities, transcranial electric motor evoked potential (tceMEP), somatosensory evoked potential (SSEP), and electromyographic (EMG) monitoring. Each modality was evaluated for sensitivity

and specificity of detecting an intraoperative nerve injury. *Results:* tceMEP monitoring was found to be 100% sensitive and 86% specific at detecting an impending nerve injury. The sensitivity and specificity of SSEP were 75% and 94%, while EMG sensitivity was unacceptably low at 20% although specificity was 93%. *Conclusions:* Multimodality neuromonitoring of transcranial electric motor and peroneal nerve somatosensory evoked potentials with or without spontaneous EMG monitoring is a safe and effective method for detecting impending nerve injury during acetabular and pelvic surgery.

Keywords neurophysiologic monitoring · acetabular fracture · pelvic fracture

This work was performed at the Rothman Institute at Thomas Jefferson University.

Level of Evidence: Level IV: Case Series. See levels of evidence for a complete description.

Electronic supplementary material The online version of this article (doi:10.1007/s11420-013-9347-7) contains supplementary material, which is available to authorized users.

M. Porat, MD
Reconstructive Orthopedics,
737 Main Street, Suite 6
Lumberton, NJ 08048, USA

F. Orozco, MD · Z. Post, MD · A. Ong, MD
Rothman Institute,
2500 English Creek Avenue, Building 1300,
Egg Harbor Township, NJ 08234, USA

N. Goyal, MD
Anderson Orthopaedic Clinic,
2445 Army Navy Drive,
Arlington, VA 22206, USA

M. Porat, MD (✉)
200 Bowman Drive, Suite E-100,
Voorhees, NJ 08043, USA
e-mail: mannyporat@yahoo.com

Introduction

One of the most feared complications of surgery to correct a deformity secondary to pelvic and acetabular fracture is iatrogenic nerve injury. The reported incidence of neurologic deficit in such deformity surgery ranges from 1–18%, with as high as a 24% permanent disability rate [6, 7]. Intraoperative neurophysiologic monitoring (IONM) of somatosensory evoked potentials and/or lower extremity electromyography either alone or in combination has been suggested as one means of reducing the incidence of intraoperative nerve insult through early detection of developing injury and, hence, modification in surgical course or introduction of other interventional strategies [1, 2, 8, 14, 15]. Yet, IONM has not enjoyed the same widespread acceptance among trauma surgeons as found among spine surgery. A survey of trauma surgeons demonstrated that only 15% use a very limited form of IONM consisting only of lower extremity somatosensory evoked potentials [11].

Pelvic and acetabular fractures are often the result of high-energy blunt trauma. These injuries are typically associated with concomitant soft tissue, organ, and long-bone fractures that can have devastating consequences. Surgical correction, when indicated, often is challenging, fraught with potential

complications, and requires diligent preoperative planning. Due to the proximity of major neural (e.g., sciatic and femoral nerves) and neurovascular structures, iatrogenic nerve injury is a well-known complication of this surgery. Multimodality intraoperative neurological monitoring has become a mainstay in corrective spine surgery owing to its exquisitely high sensitivity and specificity for detecting emerging injury to the spinal cord and/or nerve roots, particularly during placement of spinal instrumentation [6]. To this end, it would seem reasonable that similar results could be achieved during joint reconstructive surgery for identifying irritation or developing nerve injury secondary to retractor or fixation construct placement that could be impinging on a nerve or a feeding vessel. Such timely notification would then facilitate some form of intervention such as cessation from a particular surgical maneuver, removal of a retractor, or elevating mean arterial pressure in the context of hypotension that may underlie developing nerve ischemia. The end goal of neuromonitoring, if effective, then would be to minimize the incidence of neurologic deficit. Drawing from the spine surgery literature, somatosensory evoked potential monitoring, while highly specific, appears to carry an unacceptably low sensitivity for timely detection of developing neural injury, that is, while the presence of significant signal alterations correlates highly with new-onset neurologic deficit, absence of such change does not ensure against an untoward surgical outcome [9, 13]. Likewise, intraoperative electromyographic (EMG) monitoring is limited in that it is helpful only when there is direct irritating excitation of a nerve such as from traction or heat transfer during electrocautery; however, it does not provide any information as to the functional integrity of the nerve and is insensitive to developing microvascular changes in nerve function [3–12].

Owing to the dearth of published data and broadly based clinical experience, there remains ongoing debate about the value of somatosensory evoked potential and/or EMG monitoring for early detection and reversal of emerging neural injury and consequent reduction in the incidence of neurologic deficit during acetabular and pelvic fixation [4]. Over the past decade, studies in spinal deformity surgery have advocated the use of transcranial electric motor evoked potential (tceMEP) monitoring for early detection of emerging spinal cord and/or nerve root injury, in combination with somatosensory evoked potentials (SSEP) and EMG recording to form a multimodality neurophysiologic surveillance battery. There is a growing body of literature with evidence from large-series retrospective investigations demonstrating a test sensitivity of 90–100%, and specificity ranging from 85% to 100% for tceMEP monitoring [4, 5, 10, 12, 13]. The purpose of this study was to determine the efficacy of tceMEP monitoring in the detection of developing nerve injury in patients undergoing acetabular or pelvic fracture reduction with internal fixation, as well as to compare test operating characteristics (sensitivity/specificity) with the more frequently used SSEP and EMG monitoring modalities.

Patients and Methods

The present investigation analyzed the results of a single surgeon series using multimodality neuromonitoring (i.e.,

tceMEPs, peroneal nerve SSEPs, and lower extremity spontaneous EMG) during fracture fixation. Criteria for a significant neuromonitoring change prompting surgical notification and rescue intervention have been detailed elsewhere by Hilibrand et al. and Schwartz et al., respectively [9, 10]. Briefly, for tceMEPs, the criterion for a significant change was defined as an amplitude decrease of at least 65% relative to a stable baseline. For SSEPs, the conventional 50% amplitude loss criterion was used while that for EMG was defined as a sustained neurotonic activity that failed to resolve despite all attempts to release traction, alter screw position, or remove fixation altogether.

Sixty patients, 43 males (72%) and 17 females (28%), ranging in age from 19 to 77 years old (mean age=43 years) were retrospectively identified through chart review as having either an acetabular or pelvic fracture and underwent operative fixation performed by the senior author (AO) between 2003 and 2010. Inclusion criteria for patients were acetabular or pelvic fracture, operative fixation of fracture, and neuromonitoring during the case. Exclusion criteria included no neuromonitoring during case, nonoperative treatment, and mortality prior to obtaining postoperative physical exam. Patient physical characteristics of height, weight, and body mass index were documented (Table 1). Institutional Review Board consent was obtained prior to reviewing patients' charts.

Patient's injuries were categorized according to OTA classification. The most common acetabular injury, 15 patients, was 62-A1, posterior wall. The next most common injury, ten patients, involved anterior and posterior column 62-C2.1. Seven patients were classified as having a posterior wall and column injury, 62-C2.3. Three patients had a transverse fracture (62-B1), and three additional had an anterior column injury (62-A3). The remaining patients were as follows: two patients had a transverse and posterior wall (62-B1.3), one patient had a T type (62-B2), one patient sustained a posterior column (62-A2), and one had an isolated anterior wall (62-A3). Finally, 17 patients were classified as having a disruption of the sacroiliac joint and pubic symphysis (61-B).

In the majority of cases (29), fracture fixation was achieved via a Kocher–Langenbeck approach alone, followed next by the ilioinguinal approach alone (13). The remaining approaches included Pfannenstiel incision (eight), percutaneous fixation (eight), and a combined Kocher–Langenbeck/ilioinguinal approach in the remaining case. Additional long-bone and nonspine injuries were commonly encountered in addition to pelvic and acetabular trauma and were seen in 21 (35%) patients.

Multimodality neurophysiologic monitoring guidance consisting of upper and lower extremity transcranial electric motor and somatosensory evoked potentials, as well as lower extremity spontaneous electromyography, was attempted in all 60 operative patients. The primary emphasis of intraoperative neuromonitoring was to protect sciatic nerve function, with particular attention paid to preservation of the vulnerable peroneal distribution responsible for dorsiflexion of the foot. Transcranial motor evoked potentials and spontaneous electromyographic activity were recorded from both tibialis anterior and gastrocnemius muscles innervated by the peroneal and tibial branches of the sciatic nerve, respectively.

Table 1 Physical characteristics (height, weight, and body mass index) of the study patients

	Number	Average age	Range	Average weight	Range	Average weight	Range	Average BMI	Range
Females	17	43.6	19–73	161.7	154.9–170.7	72.5	43.09–113.4	27.7	17.4–40.4
Males	43	43.1	19–77	176.9	160–195.1	84.6	31.3–147.9	27.8	19.5–46.8

Somatosensory evoked potentials to stimulation of the superficial peroneal nerve at the fibular head also were routinely recorded to supplement monitoring of motor function.

Bilateral upper extremity tceMEPs were also recorded first from the dorsal interosseous muscle and SSEPs to ulnar nerve stimulation both as a technical and anesthesia control in the event of a significant loss of signal amplitude from the operative lower extremity. A totally intravenous anesthetic regimen based on continuous infusion of propofol and fentanyl or remifentanyl was utilized to optimize transcranial electric motor and cortical somatosensory evoked potential recordings as described for spinal cord monitoring [9, 13]. Use of neuromuscular blocking agents was avoided following intubation to ensure maximal motor evoked potential amplitudes and reliable spontaneous electromyographic recordings.

A retrospective analysis of patient charts was completed, focusing on demographics, fracture type, surgical approach, preoperative and postoperative neurological status as well as type and extent of neurophysiological monitoring response change, including resolution following surgical or anesthesia intervention. Patients' charts were reviewed and assigned to one of three groups, no neuromonitoring alerts during surgery, one or more neuromonitoring alerts that resolved following rescue intervention, or a neuromonitoring alert that remained unresolved by closing of the case. The neuromonitoring data for each modality individually were then compared to outcome derived from neurologic examination obtained in the immediate postoperative period. From these data sets, a series of contingency tables was developed for assessing true-positive, true-negative, false-positive, and false-negative outcomes and, hence, calculation of operating characteristics for each respective neurophysiological monitoring modality (i.e., tceMEP, SSEP, EMG).

Results

Of the 60 patients, neuromonitoring could be performed on 53, primarily due to inability to record reliable transcranial electric motor evoked potentials prior to incision. One patient had a lower extremity fiberglass cast on the ipsilateral leg, thereby precluding placement of any recording electrodes over appropriate myotomes. Of the remaining 53 patients, immediate postoperative motor examination was unreliable in four, thus preventing any valid comparison to the neuromonitoring results. In total, therefore, correlation between neuromonitoring and immediate postoperative physical examination was available in 49 of the 60 (82%) of the original cohort.

Operating characteristics for each of the three neuromonitoring modalities were calculated (Table 2). In 38 of

the 49 (78%) monitored patients, tceMEPs remained stable and unchanged throughout surgery, and all awoke with intact neural function (true negative). Nine of these (24%) showed significant ($\geq 65\%$) tceMEP amplitude loss requiring surgical notification, all of which recovered to near-baseline values following rescue intervention. In contrast, 11 additional patients (22%) who demonstrated significant transcranial motor evoked potential (tceMEP) amplitude loss either did not respond at all to intervention during surgery or showed partial recovery. Five (45%) of the 11 patients with unresolved tceMEP amplitude loss at closing presented with new-onset or worsened neural deficit (true positive), whereas the remaining six appeared neurologically intact when evaluated postoperatively (false positive). Of note was that in contrast to the nine patients in the true-negative group who showed marked tceMEP amplitude loss that resolved to near-baseline values following intervention, or the five true positives who showed essentially no amplitude improvement even with rescue intervention, most of these six patients resolved only partially; regardless, they were categorized as false positives for purposes of this investigation. Hence, tceMEP monitoring was 100% sensitive and 86% specific.

Peroneal nerve SSEPs were recorded along with tceMEPs in 36 (73.5%) patients, 31 of whom showed no significant amplitude ($\geq 50\%$) changes. Of these, 30 awoke without any untoward neurologic compromise. The remaining patient who had unchanged SSEPs awoke with ipsilateral weakness on the operative side and was a false negative based on SSEP monitoring alone; however, tceMEPs identified the developing nerve injury correctly. Sensitivity and specificity of peroneal nerve SSEPs for detection of evolving sciatic nerve injury, therefore, was 75% and 94%, respectively.

Of the three neuromonitoring modalities, EMG was the poorest predictor of neurologic deficit. Of 48 patients monitored with spontaneous EMG in addition to tceMEPs, there were three false positives and four false negatives. Consequently, sensitivity was unacceptably low at 20% although specificity was 93% similar to the other two neuromonitoring modalities.

Discussion

We investigated whether impending injury to the sciatic nerve during pelvic and acetabular surgery can be accurately detected by multimodal neurophysiologic monitoring. We concluded that transcranial electric motor and peroneal nerve somatosensory evoked potentials can accurately detect impending nerve compromise. Sole EMG monitoring does not appear to be a safe and reliable method for detection of nerve injury.

This investigation was limited in several respects. First, it was a retrospective review making it susceptible to examiner

Table 2 2×2 contingency tables used to calculate test operating characteristics for tceMEP, peroneal nerve SSEP, and spontaneous EMG monitoring

tceMEP	No deficit	Deficit
Positive	6	5
Negative	38	0
Sensitivity=100%		
Specificity=86%		
SSEP	No deficit	Deficit
Positive	2	3
Negative	30	1
Sensitivity=75%		
Specificity=94%		
EMG	No deficit	Deficit
Positive	3	1
Negative	40	4
Sensitivity=20%		
Specificity=93%		

bias. Consequently, conservative cutoff values were used to classify patients for calculating test operating characteristics so as not to achieve inflated results. One of the more limiting factors of a retrospective chart review relates to dependence on postoperative motor examination results as performed by a variety of physicians and/or nurses with no specific assessment criteria. For example, patients were documented as having either grossly intact motor function or not; that is, no attempt was made at grading, and there were no preunderstood definitions involving examination technique or recording of the results. Further, the time between closure and neurologic exam can have a significant effect on correlating to neuromonitoring data since it is possible that neuromonitoring changes identified intraoperatively reflected true neural compromise that may have resolved by the time the patient was actually examined in the postanesthesia care unit.

As predicted from the spine surgery literature, tceMEP monitoring was 100% sensitive in detecting neurological compromise during pelvic and acetabular fixation. Five of 49 patients monitored with tceMEPs showed significant amplitude loss that failed to improve to any remarkable degree following intervention, and all awoke with postoperative neurologic deficit. Although six other patients with tceMEP alerts failed to show postoperative neurologic compromise and, hence, were classified as false positives, it is noteworthy that the majority of these did recover partially which was in stark contrast to the five patients who showed no such amplitude improvement and awoke with deficit. It is plausible, therefore, that the specificity would improve if the criterion for what represented a significant improvement was raised.

Unlike some previously reported studies, lower extremity somatosensory evoked potential monitoring was much less sensitive (75%) than its tceMEP counterpart (100%) [1, 2, 14]. It would appear that when peroneal SSEPs serving as the only neuromonitoring modality do change during the surgical course, the likelihood of evolving nerve injury is significant and warrants immediate attention. Absence of such a change, however, carries a small but real opportunity for a false negative.

Monitoring of spontaneous EMG is not recommended as a sole modality or even in combination with SSEPs in acetabular or pelvic reconstructive surgery. This is best

understood from a neurophysiology perspective in that spontaneous EMG is not a test of nerve function, but rather nerve irritation secondary to stretch, temperature change, or the like. Microvascular changes as a precursor to nerve ischemia cannot be detected with EMG. Because EMG is unable to assess nerve function, it carries an excessively high false-negative (80%) rate and should not be given much credence when used alone. This finding is contrary to that of earlier investigations [3, 11].

This study suggests that multimodality neuromonitoring of transcranial electric motor and peroneal nerve somatosensory evoked potentials with or without spontaneous EMG monitoring is a safe and effective method for detecting impending nerve injury during surgery. Trauma patients, already in a compromised state, and surgeons, preparing for potentially challenging cases, can benefit from additional neurophysiologic monitoring. These cases can be difficult and long surgeries, fraught with complications.

Disclosures

Conflict of Interest: Manny Porat, MD; Nitin Goyal, MD; and Zachary Post, MD, have declared that they have no conflict of interest. Fabio Orozco, MD, is a paid consultant for Medtronic and Stryker, outside the work. Alvin Ong, MD, is a paid consultant for Medtronic, Stryker and Smith and Nephew, outside the work.

Human/Animal Rights: All procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2008 (5).

Informed Consent: Informed consent was waived from all patients for being included in the study.

Required Author Forms Disclosure forms provided by the authors are available with the online version of this article.

References

1. Baumgaertner MR, Wegner D, Booke J. SSEP monitoring during pelvic and acetabular fracture surgery. *Journal of Orthopaedic Trauma*. 1994; 8: 125-133.
2. Calder HB, Mast J, Johnstone C. Intraoperative evoked potential monitoring in acetabular surgery. *Clinical Orthopaedics and Related Research*. 1994; 305: 160-167.
3. Devlin VJ, Schwartz DM. Intraoperative neurophysiologic monitoring during spinal surgery. *Journal of the American Academy of Orthopaedic Surgeons*. 2007; 15: 549-560.
4. Eggspuehler A, Sutter MA, Grob D, et al. Multimodal intraoperative monitoring during surgery of spinal deformities in 217 patients. *European Spine Journal*. 2007; 16: S188-S196.
5. Eggspuehler A, Sutter MA, Grob D, et al. Multimodal intraoperative monitoring (MIOM) during cervical spine surgical procedures in 246 patients. *European Spine Journal*. 2007; 16: S209-S215.
6. Haidukewych GJ, Scaduto J, Herscovici D Jr, et al. Iatrogenic nerve injury in acetabular fracture surgery: a comparison of monitored and unmonitored procedures. *Journal of Orthopaedic Trauma*. 2002; 16: 297-301.

7. Helfet DL, Anand N, Malkani AL, et al. Intraoperative monitoring of motor pathways during operative fixation of acute acetabular fractures. *Journal of Orthopaedic Trauma*. 1997; 11: 2-6.
8. Helfet D, Koval K, Hissa EA, et al. Intraoperative somatosensory evoked potential monitoring during acute pelvic fracture surgery. *Journal of Orthopaedic Trauma*. 1995; 9: 28-34.
9. Hilibrand AS, Schwartz DM, Sethuraman V, et al. Comparison of transcranial electric motor and somatosensory evoked potential monitoring during cervical spine surgery. *The Journal of Bone and Joint Surgery American Volume*. 2004; 86: 1248-1253.
10. Kelleher MO, Tan G, Sarjeant R, et al. Predictive value of intraoperative neurophysiological monitoring during cervical spine surgery: a prospective analysis of 1055 consecutive patients. *Journal of Neurosurgery: Spine*. 2008; 8: 215-221.
11. Morgan SJ, Jeray KJ, Phieffer LS, et al. Attitudes of orthopaedic trauma surgeons regarding current controversies in the management of pelvic and acetabular fractures. *Journal of Orthopaedic Trauma*. 2001; 15: 526-532.
12. Pring ME, Trousdale RT, Cabanela ME, et al. Intraoperative electromyographic monitoring during periacetabular osteotomy. *Clinical Orthopaedics and Related Research*. 2002; 400: 158-164.
13. Schwartz DM, Auerbach JD, Dormans JP, et al. Neurophysiologic detection of impending spinal cord injury during surgery for adolescent idiopathic scoliosis: a comparison of transcranial electric motor and somatosensory evoked potential monitoring. *The Journal of Bone and Joint Surgery American Volume*. 2007; 89: 2440-2449.
14. Sutherland CJ, Miller DH, Owen JH. Use of spontaneous electromyography during revision and complex total hip arthroplasty. *The Journal of Arthroplasty*. 1996; 11: 123-233.
15. Vrahas M, Gordon RG, Mears DC, et al. Intraoperative somatosensory evoked potential monitoring of pelvic and acetabular fractures. *Journal of Orthopaedic Trauma*. 1992; 6: 50-58.