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ORIGINAL ARTICLE

Causal factors for position-related SSEP changes in spinal surgery

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Abstract

Background context Somatosensory evoked potentials (SSEPs) are effective in detecting upper extremity positional injuries; however, causal factors for which patient population is most at risk are not well established.

Purpose To review causal factors for intraoperative SSEP changes due to patient positioning.

Study design A case series with retrospective chart analysis was performed.

Patient sample 398 patient charts and intraoperative neurophysiological monitoring data from patients who underwent thoracolumbar and lumbosacral spine surgery were reviewed in a consecutive sequence from 2012 to 2013.

Outcome measures Adverse events (AE) with the upper extremity SSEP recordings were compared to the independent variables, sex, positioning, length of procedure, and body habitus.

Methods Thoracolumbar and lumbosacral spine surgeries using contemporaneous ulnar and median nerve SSEPs were reviewed. The one-way analysis of variance (ANOVA) test, Chi-square, and independent samples t test were used to determine statistical significance in having an upper extremity SSEP AE to the aforementioned independent variables.

Results The sample consisted of 209 males (52.5 %) and 189 females (47.5 %) ($n = 398$). AE to the upper extremity SSEP was seen in 44 patients. Sex was found to be statistically significant for isolated ulnar nerve AE ($P \leq 0.001$) with males being most at risk (87.5 %). AE for isolated median nerve SSEP was statistically significant for supine and prone positions ($P = 0.043$). Length of procedure was statically significant for isolated ulnar nerve SSEP AE ($P = 0.039$). BMI was statistically significant for generalized upper extremity SSEP AE ($P = 0.016$), as well as isolated ulnar SSEP AE ($P = 0.006$), isolated median SSEP AE ($P \leq 0.001$) and contemporaneous median and ulnar SSEP AE of the same limb ($P \leq 0.001$).

Conclusion Sex, patient positioning, length of procedure, and BMI are determinants for upper extremity neural compromise during thoracolumbar and lumbosacral spine surgeries.

Keywords Somatosensory evoked potentials · Spine surgery · Positional nerve injury · Intraoperative neurophysiological monitoring · Patient positioning

Introduction

Spinal surgery inherently carries a risk of iatrogenic neural compromise with reports of injury as high as 20 % in some case series [1, 2]. Methods to mitigate perioperative neural sequelae include the use of electrophysiological techniques such as somatosensory evoked potentials (SSEP) and transcranial motor evoked potentials (TCMEP) [3–10]. SSEPs were originally introduced intraoperatively to monitor spinal cord function during scoliosis corrections and over time intraoperative neurophysiological monitoring (IONM) has become increasingly used for most surgeries of the spinal column and canal [3, 4, 11–17]. The field has evolved from monitoring the function of the spinal cord (e.g., scoliosis correction) to monitoring for neural compromise that can occur outside an operative field during a

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surgical procedure (e.g., positional injury) [18, 19]. Intraoperative position-related injuries have been reported for some time and methods to reduce these events such as padding the arms and ensuring the arms are not rotated or abducted have been used [20, 21]. With the advent of electrophysiology in the operating room, neural function can be monitored and compromise can be detected before a potential injury becomes irreversible [22].

Intraoperative SSEP has become routine for the management of patients undergoing lumbar and thoracolumbar spine surgery. As the complexity of these surgical procedures increases, these patients are maintained in supine, prone, or lateral decubitus positions or a combination of all three for extended periods, increasing the likelihood of upper extremity neurologic and/or vascular compromise (Figs. 1, 2). It is documented that upper extremity SSEPs are a viable modality for predicting and preventing upper extremity neural injuries; however, the underlying causal relations, or who is most at risk, has not been well-established [1, 3, 15, 23–26].

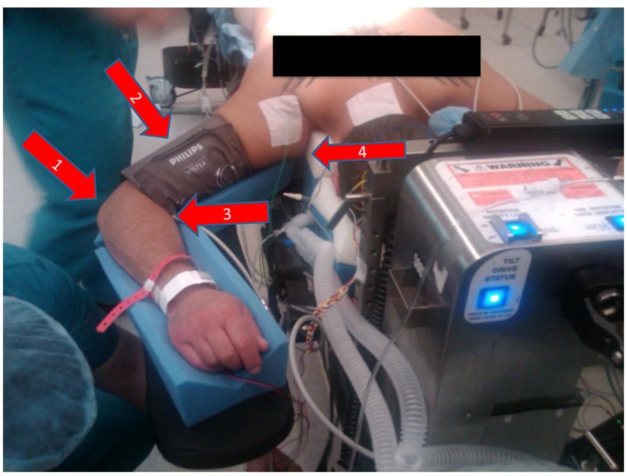

Fig. 1 Patient in a prone "superman" position. *Block arrows* indicate potential sites of positional injury (*1* ulnar nerve at the cubital tunnel; *2* vascular compromise of the limb due to blood pressure cuff; *3* median nerve at the ante cubital fossa; *4* brachial plexus at the axilla and/or upper chest)

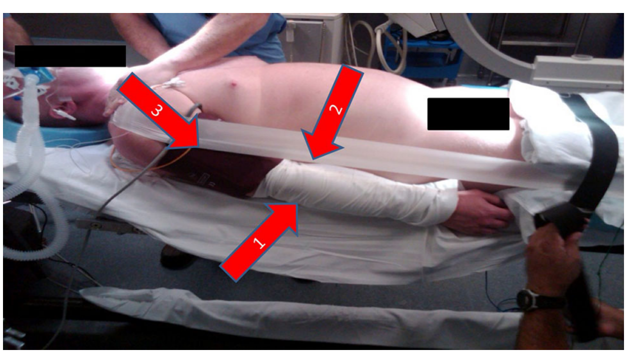

Fig. 2 Patient in a supine position with arms tucked. *Block arrows* indicate potential sites of positional injury (*1* ulnar nerve at the cubital tunnel; *2* median nerve at the ante cubital fossa; *3* vascular compromise of the limb due to blood pressure cuff; *1 and 2* vascular compromise of the limb due wrapping of the arm with bed sheet)

Methods

A retrospective chart review of 398 patients who underwent thoracolumbar and lumbosacral spine surgery was conducted. Data from contemporaneous ulnar nerve and median nerve SSEP recordings were reviewed. If an adverse event (AE) occurred with the upper extremity SSEP it was compared to the independent variables: sex, patient positioning, length of procedure, and body habitus for the determination of statistical significance. AE is defined as a change in the SSEP recordings as described by the American Clinical Neurophysiology Society [27] using an amplitude attenuation of >50 % and/or a prolongation of peak latency >10 %.

Statistical analysis used the IBM SPSS Statistics Version 22.0 (alpha = 0.05, two tailed). The one-way analysis of variance (ANOVA) test, Chi-square, and independent samples t test were used to determine statistical significance in having an AE in upper extremity SSEPs to the aforementioned independent variables. This study also included descriptive statistics to identify mean, median, mode, standard deviations and frequency of the variables.

Results

Sex, patient positioning, length of procedure, and body habitus, were reviewed and then compared to AEs of the intraoperative upper extremity SSEP recordings to determine statistical significance. The sample consisted of 209 males (52.5 %) and 189 females (47.5 %) ($n = 398$). Patient positioning was determined by the surgical procedure performed and included, prone (63 %), supine (7 %), lateral (2 %), supine and prone (16 %), lateral and prone (12 %), and supine and lateral and prone (1 %). The cohort had a mean length of surgery of 223 min. The mean body mass index (BMI) for the cohort was 30 kg/m^2. The subjects who demonstrated AEs of the intraoperative SSEP were deemed part of the study group ($n = 44$); the remainder of the cohort was the control group ($n = 354$).

Study group

The study group included 11 % of the sample ($n = 44$). 8 % of the study group ($n = 32$) exhibited an isolated AE to the ulnar nerve SSEP; whereas, 1.8 % ($n = 7$) presented contemporaneous AEs of the median and ulnar nerve SSEP in the same limb. 1 % of the sample ($n = 4$) exhibited isolated AEs to the median nerve SSEP. 0.3 % displayed an AE to the bilateral ulnar nerve SSEPs simultaneously ($n = 1$) and no subjects presented an AE for bilateral median nerve SSEP recordings.

Sex

Sex of the sample was only statistically significant for an AE of the ulnar nerve SSEP ($P < 0.001$) per the one-way ANOVA test and independent samples t test. Chi-square revealed that of the 32 subjects who exhibited AEs of their ulnar nerve SSEP, 87.5 % were male ($n = 28$). AEs of the median SSEP ($P = 0.367$), bilateral ulnar nerves ($P = 0.342$), and contemporaneous median and ulnar nerves of the same limb ($P = 0.313$) were not found to be statistically significant.

Surgical position

When surgical position was reviewed, the investigators found that an AE to the isolated median nerve SSEP is statistically significant ($P = 0.043$). Chi-square test reveals 50 % of isolated median nerve SSEP AEs occurred in the prone position and 50 % occurred in the supine position. All other SSEP AEs were not associated to patient positioning.

Length of procedure

The mean length of the procedure for the control group was 163 min. Patients who presented with an AE of the isolated ulnar SSEP had a mean length of procedure of 180 min and were found to be statistically significant ($P = 0.039$). The mean length of procedure for patients with an AE of the isolated median nerve SSEP was 145 min ($P = 0.908$). The one patient who presented with an AE of the bilateral ulnar SSEP had a procedure length of 300 min ($P = 0.091$), where the patients that presented AEs of the contemporaneous ulnar and median nerve SSEPs in the same limb had a mean procedure length of 209 min ($P = 0.581$).

BMI

The mean BMI for the study group was 37 kg/m^2 and the mean BMI for the control group was 30 kg/m^2. Per Levene's test for equality of variances, body habitus played a role in generalized AEs to the upper extremity SSEPs ($P = 0.016$). Per the one-way ANOVA analysis, body habitus was statistically significant in AEs of isolated ulnar nerve SSEP recordings ($P = 0.006$). These patients had a mean BMI of 32 kg/m^2. The one-way ANOVA also showed statistical significance in AEs of isolated median nerve SSEP recordings ($P < 0.001$) and AEs of contemporaneous ulnar and median nerve SSEP recordings of the same limb ($P < 0.001$), with mean BMIs of 41 and 37 kg/m^2, respectively. The BMI for the patient with bilateral ulnar SSEP degradation was missing from the data set.

Recovery

Intervention was implemented whenever an AE to the upper extremity evoked potential occurred. This included, adding padding to the cubital tunnel or flexing/extending the arm at the elbow (isolated ulnar changes), ensuring the ante cubital fossa was free of pressure (isolated median nerve changes), loosening the tuck of the arm (during anterior procedures), moving or removing the blood pressure cuff, and repositioning the arm at the shoulder (contemporaneous changes to the ulnar and median nerve SSEP). One patient did not have intraoperative recovery of the upper extremity SSEP with intervention (2.27 %). This patient, however, awoke neurologically intact and remained so throughout the first three postoperative follow-ups. One false negative was reported with a patient from the control group presenting at their first postoperative follow-up with a new-onset upper extremity neurological deficit; however, upon second and third follow-up, the patient no longer had any subjective upper extremity complaints. When reviewing the data from the study group's postoperative follow-ups, the study group yielded no new-onset neurological deficits. We report a sensitivity of 97.78 % and a specificity of 100 % for detecting upper extremity neural compromise during thoracolumbar and lumbosacral spine surgery with a PPV of 100 % and an NPV of 99.72 % using contemporaneous ulnar and median nerve SSEPs.

Discussion

Positional neural injuries have been reported in the literature before there were means to stimulate upper extremity nerves effectively during spine surgery and prior to the understanding of how electrophysiological studies can predict and prevent positional-related injuries [28–31]. A review of the literature for upper extremity injuries during thoracolumbar and lumbosacral spine surgeries found three prospective studies conducted [23, 30, 32], two literature reviews [6, 21], and one case report [33]. The remainder were retrospective analyses [1, 26, 34]. Each institution had their own criterion for alarm, and there was no consistency with the type of nerves used to evaluate for upper extremity neural sequelae during thoracolumbar and lumbosacral procedures. For example, O'Brien et al. [30] used median nerve stimulation at the wrist and ulnar nerve stimulation at the elbow to elicit SSEP responses. They discuss preventing brachial plexus injuries, but indicate that the upper extremity SSEP was not reliable in detecting isolated ulnar nerve injuries, with two of their patients presenting postoperatively with new-onset ulnar neuropathy undetected by intraoperative SSEP evaluation. In their study, they stimulated the ulnar nerve at the elbow, which is a common area for an ulnar nerve conduction block. It is possible they were at or proximal to the site of the lesion which in most circumstances would lead to a false-negative outcome [30]. In contrast, all ulnar and median nerve SSEPs that were analyzed in this chart review used wrist stimulation which allowed for the length of the arm to be evaluated. In another example, Lorenzini and Poterack [32] placed awake patients on an operating room table and induced positional injury while recording SSEPs. They had three patients who demonstrated symptoms that did not resolve with intervention. These symptoms are not discussed in detail and could have been pain symptoms (which was part of their inclusion criteria) [32]. The SSEP evaluates the tracts for two-point discrimination, touch, vibration and proprioception (dorsal column-medial lemniscus tract); however, SSEPs can indirectly monitor motor function of the spinal cord and peripheral nerves as well due to collateral perfusion. Pain neurons on the other hand found in the delta and c-fibers do not travel the dorsal column-medial lemniscus tract, but instead, the spinothalamic tract which cannot be assessed by an SSEP [22, 35, 36]. Baumann et al. [33], were the first to associate obesity and intraoperative positional injury; however, their study is a case report only. They explain how they noted an AE in the patient's ulnar nerve SSEP during a multi-level anterior cervical discectomy and fusion; however, adjusting the arm did not mitigate the problem and they decided to remove the fixed retractor system that was sweeping the carotid artery out of the way for their exposure to the disc space. They found that when they removed the retractor, the responses from the SSEP returned. They describe that the arm of the retractor was compressing the patient's arm causing a peripheral nerve injury; however, without median nerve SSEPs as a control, along with only recording cortical SSEPs and the responses only returning once the retractor was removed it cannot be ruled out that an occlusion of the carotid artery was occurring. It has been well established in the vascular literature [37–46] that SSEPs are sensitive in predicting cerebral ischemia after the carotid artery is clamped during a carotid endarterectomy and because Bauman et al. [33] only provide evidence of one case where the cortical SSEP recording was lost and subsequently recovered when the retractor (which is placed on the carotid artery during these procedures) was removed, Baumann et al. [33] cannot support obesity as the reason for the change in the SSEP. However, based on our findings, obesity is a risk factor for having an intraoperative upper extremity SSEP change due to patient positioning. In contrast, a study by Ying et al. [47] found that lower BMI was associated with an AE in the upper extremity SSEPs during craniotomy for microvascular decompression. All of their patients were positioned in a lateral decubitus position and the investigators postulate that the lack of body mass reduces cushioning in the arm making the nerves more at risk for an adverse event. In our cohort, we had no changes to the SSEP when a patient was positioned in the lateral decubitus position. Jellish et al. [48], however, had very similar findings to our study with patients in their cohort exhibiting SSEP alarms when the BMI reached 31.4 ± 8.0.

Approaches to minimize postoperative deficits

When intervention is implemented due to an AE of the upper extremity SSEP, we recommend an algorithm based on the specific SSEP change where we start distally and move proximally in our attempts to reverse the AE. For example, if there is an isolated AE to the ulnar nerve SSEP, the neurophysiologist should attempt to first address the area of the arm where the conduction block is likely occurring (medial epicondyle). From there if interventions such as placing a piece of foam under the cubital tunnel does not yield a return of the SSEP, flexing or extending the elbow may be the next step in intervention. In the event of a median nerve SSEP AE, the antecubital fossa should be assessed to ensure it is free of any compression. If this intervention does not yield a return of the evoked potential, the arm at the shoulder should be evaluated and moved as needed to assist in returning the potentials. When contemporaneous ulnar and median nerve SSEPs are affected by an AE, the arm should be evaluated to ensure there is nothing compromising perfusion to the limb. If there is nothing visually cutting off the blood supply to the arm, the shoulder should be repositioned, or padding should be added to the axilla.

Limitations of the study

We recognize limitations to the study. The variables reviewed were analyzed independently and not collectively and peripheral nerve SSEP changes due to patient positioning may be multifactorial. Further large-scale studies that include underlying pathology, hemodynamics, combined and independent variables are needed to validate the causal factors we have presented.

Table 1 Statistical significance of an SSEP change to the reviewed independent variables

Adverse event	Sex	Surgical position	Length of procedure	BMI
Ulnar nerve SSEP	**Statistically significant ($P < 0.001$)** **Males more at risk (87.5 %)**	Not significant	**Statistically significant ($P = 0.039$)** **Mean length: 180 min**	**Statistically significant ($P = 0.006$)** **Mean BMI: 32**
Median nerve SSEP	Not significant ($P = 0.367$)	**Statistically significant ($P = 0.043$)** **50 % supine** **50 % prone**	Not significant ($P = 0.908$) Mean length: 145 min	**Statistically significant ($P < 0.001$)** **Mean BMI: 41**
Bilateral ulnar nerve SSEP	Not significant ($P = 0.342$)	Not significant	Not significant ($P = 0.908$) Mean length: 300 min	N/A
Bilateral median nerve SSEP	No change in SSEP data	No change in SSEP data	No change in SSEP data	No change in SSEP data
Contemporaneous ulnar and median nerve SSEP of same limb	Not significant ($P = 0.313$)	Not significant	Not significant ($P = 0.581$) Mean length: 209 min	**Statistically significant ($P < 0.001$)** **Mean BMI: 37**

Bold indicates statistical significance ($P \leq 0.05$)

Conclusion

It has been previously established that SSEPs can predict impending position-related neural compromise [1, 30, 34]. Here we provide statistical evidence that causal factors such as, sex, patient positioning, length of procedure, and BMI are determinants for upper extremity neural compromise during thoracolumbar and lumbosacral spine surgery (Table 1). As a result of statistical significance established by multiple variables, the use of upper extremity SSEPs to prevent intraoperative positional injuries can be extended to other surgical disciplines that also have patients with these risk factors.

Compliance with ethical standards

Conflict of interest None.

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