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Intraoperative somatosensory evoked potential monitoring during anterior cervical discectomy and fusion in nonmyelopathic patients—a review of 1,039 cases

Patrick N. Smith, MD[a], Jeffrey R. Balzer, PhD[b], Mustafa H. Khan, MD[a], Rick A. Davis, MD[a], Donald Crammond, PhD[b], William C. Welch, MD[b], Peter Gerszten, MD[b], Robert J. Sclabassi, MD, PhD[b], James D. Kang, MD[a], William F. Donaldson, MD[a,*]

[a]*Department of Orthopedic Surgery, University of Pittsburgh, 3741 Fifth Avenue, Suite 1010, Pittsburgh, PA 15213, USA*

[b]*Department of Neurological Surgery, University of Pittsburgh, B-400 Presbyterian, Pittsburgh, PA 15213, USA*

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Abstract

BACKGROUND CONTEXT: Intraoperative somatosensory evoked potential (SSEP) monitoring has been shown to reduce the incidence of new postoperative neurological deficits in scoliosis surgery. However, its usefulness during cervical spine surgery remains a subject of debate.

PURPOSE: To determine the utility of intraoperative SSEP monitoring in a specific patient population (those with cervical radiculopathy in the absence of myelopathy) who underwent anterior cervical discectomy and fusion (ACDF) surgery.

STUDY DESIGN: Retrospective review.

PATIENT SAMPLE: A total of 1,039 nonmyelopathic patients who underwent single or multilevel ACDF surgery. The control group (462 patients) did not have intraoperative SSEP monitoring, whereas the monitored group (577 patients) had continuous intraoperative SSEP monitoring performed.

OUTCOME MEASURE: A new postoperative neurological deficit.

METHODS: SSEP tracings were reviewed for all 577 patients in the monitored group and all significant signal changes were noted. Medical records were reviewed for all 1,039 patients to determine if any new neurological deficits developed in the immediate postoperative period.

RESULTS: None of the patients in the control group had any new postoperative neurological deficits. In the monitored group there were six instances of transient SSEP changes (1 due to suspected carotid artery compression; 5 thought to be due to transient hypotension) which resolved with the appropriate intraoperative intervention (repositioning of retractors; raising the arterial blood pressure). Upon waking up from anesthesia, one patient in the monitored group had a new neurological deficit (partial central cord syndrome) despite normal intraoperative SSEP signals.

CONCLUSIONS: ACDF appears to be a safe surgical procedure with a low incidence of iatrogenic neurological injury. Transient SSEP signal changes, which improved with intraoperative interventions, were not associated with new postoperative neurological deficits. An intraoperative neurological deficit is possible despite normal SSEP signals.

Keywords: Cervical spine surgery; ACDF; SSEP; Radiculopathy; Neurophysiological monitoring

FDA device/drug status: not applicable.

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* Corresponding author. Division of Spinal Surgery, Department of Orthopedic Surgery, University of Pittsburgh Medical Center, 3741 Fifth Avenue, Suite 1010, Pittsburgh, PA 15213. Tel.: (412) 605-3218; fax: (412) 687-3724.

E-mail address: donaldsonwf@upmc.edu (W.F. Donaldson)

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Introduction

Intraoperative somatosensory evoked potential (SSEP) monitoring is a frequently used modality for detecting and preventing neurological injury during spine surgery. Its use during scoliosis surgery has dramatically reduced the incidence of new postoperative neurological deficits by approximately one-half [1–7]. However, despite the demonstrated usefulness of SSEP monitoring during scoliosis surgery, debate exists concerning its utility for other types of surgical procedures, such as cervical spine surgery [8].

Anterior cervical discectomy and fusion (ACDF) surgery is commonly used to treat cervical radiculopathy. During ACDF, intraoperative SSEPs are often monitored to detect spinal cord injury [9–12]. However, prior literature has provided mixed conclusions as to the utility of SSEP monitoring during anterior cervical surgery. Unfortunately, these previous studies combined data from corpectomy surgeries with discectomy surgeries and do not differentiate between patients with diagnoses of radiculopathy and myelopathy [8,13–16]. Because of the distinct differences between the pathophysiology of radiculopathy and myelopathy, and the differences between the technical aspects of discectomy and corpectomy surgeries, it is difficult to arrive at a firm conclusion regarding the utility of SSEP monitoring without studying these groups separately. Therefore, the goal of this study was to retrospectively review patients with a preoperative diagnosis of cervical radiculopathy in the absence of myelopathy who underwent single or multilevel ACDF either with or without intraoperative SSEP monitoring, and to determine if the use of intraoperative SSEP monitoring resulted in fewer new postoperative neurological deficits as compared with unmonitored cases. To our knowledge, this is the first study of its kind to specifically evaluate the usefulness of intraoperative SSEP monitoring in nonmyelopathic patients undergoing ACDF.

Materials and methods

Study design

This study is a retrospective review of ACDF surgery cases from 1995 to 2004 performed by four different spine surgeons from a single institution (WCW, PG, JDK, WFD). Criteria for inclusion in the study included those patients who had undergone one-, two-, or three-level, instrumented or noninstrumented fusion with either allograft or autograft bone with a preoperative diagnosis of cervical stenosis, radiculopathy, herniated nucleus pulposus, junctional stenosis, or nonunion from prior surgery. Corpectomy or hemicorpectomy surgery, tumor, or a diagnosis of myelopathy were used as exclusion criteria.

Patient population

A total of 1,039 patients were included in the study (Table 1). The control group consisted of 462 cases in which intraoperative SSEP monitoring was not performed. The monitored group consisted of 577 cases where intraoperative SSEP monitoring included cortical and subcortical recordings in response to simultaneous stimulation of the upper (median or ulnar) and lower extremity (tibial or peroneal) nerves.

Table 1
Numerical breakdown of patients by number of cervical spine levels being decompressed and fused in the control and monitored groups

	1-level ACDF	2-level ACDF	3-level ACDF
Control group (n=462)	242	213	7
Monitored group (n=577)	288	231	58
Total (n=1039)	530	444	65

ACDF=anterior cervical discectomy and fusion.

Neurophysiological monitoring

Baseline SSEPs were obtained after induction of anesthesia and before patient positioning in all cases. Continuous upper and lower extremity stimulation was performed simultaneously throughout the surgical procedure. The upper extremity nerve to be stimulated was chosen based on the level at which the decompression was to be performed. At our institution, the average cost of SSEP monitoring is approximately $600 to $800 per case.

Median/ulnar nerve SSEPs

The median or ulnar nerve was stimulated bilaterally in an alternating fashion at the wrist using subdermal needle electrode pairs. Scalp electrodes were P4/Fz and P3/Fz (according to the international 10-20 system), and a cervical electrode was localized at the C7 spinous process and referenced to Fz. Constant voltage stimulators using sufficient intensity to evoke a consistent response produced evoked sensory potentials. Stimulation frequency was 3.43 Hz with duration of 0.2 ms. Bandpass filters were set at 3–300 Hz with a gain of 20k for cortical recordings and 30–1,000 Hz with a gain of 50k for cervical recordings. Averages were computed for 128 trials.

Peroneal/tibial nerve SSEPs

Alternating bilateral tibial nerve stimulation was used unless reproducible responses were unattainable, in which case the peroneal nerve was stimulated. The tibial nerve was stimulated at the ankle using subdermal needle electrode pairs with proximally placed cathodes and the anode placed ~1 cm away. The peroneal nerve was stimulated using pairs of subdermal needles located at the head of the fibula and medially in the popliteal fossa. Recordings were obtained from the scalp and cervical region also using subdermal electrodes. Scalp electrodes were Pz/Fz and P3/P4 (according to the international 10-20 system), and the cervical electrode was localized at the C7 spinous process and referenced to Fz. Evoked sensory potentials were produced by constant voltage stimulators using sufficient intensity to evoke a consistent response. Stimulation frequency was 3.43 Hz with duration of 0.2 ms. Bandpass filters were set at 3–300 Hz with a gain of 20k for cortical recordings and 30–1,000 Hz with a gain of 50k for cervical recordings. Averages were computed for 128 trials.

Alarm criteria

Initial recordings, made after induction of anesthesia and before positioning, served as baselines. SSEPs were collected continuously (~1 average every 40 seconds) throughout the procedure. Reduction in primary somatosensory cortical amplitude in the cervically recorded response by greater than 50% or prolongation of response latency by greater than 10% unrelated to changes in anesthesia was viewed as being significant, and the surgeon was informed. These criteria have been previously validated and agreed upon in the literature as being of optimal sensitivity and specificity for detecting iatrogenic injury in the spinal cord [17]. While a 50% decrease in amplitude and 10% increase in latency are widely accepted as being significant, caution should always be taken and interpretation of significance should be considered on a case by case basis.

Medical record review

Patient records were reviewed for all 1,039 patients to determine if any new neurological deficits (motor or sensory) occurred in the immediate postoperative period. SSEP tracings for all 577 monitored patients were reviewed to determine if a significant decrease in SSEP signals occurred. For these patients, operative records were reviewed to determine whether or not any intraoperative intervention (e.g., repositioning of instrumentation, graft, or retractor; increasing blood pressure) led to an improvement of SSEP signals.

Results

SSEP signal changes

In the monitored group (577 patients), six instances of transient significant SSEP changes were observed (Table 2). One case was attributed to carotid artery compression which resolved with retractor repositioning (Patient 6), and five cases were thought to be due to transient hypotensive episodes which resolved with increasing blood pressure (Patients 1 through 5). After the aforementioned interventions, SSEP signal changes normalized and returned to baseline for all patients. No patient had persistent, irreversible SSEP changes equal to or greater than the threshold value (50% decrease in amplitude or a 10% increase in response latency).

New postoperative neurological deficits

None of the patients in the control group (462 patients) had a new postoperative neurological deficit.

In the monitored group (577 patients), none of the patients who had transient, reversible SSEP signal changes (Table 2: Patients 1 through 6) had a new postoperative neurological deficit. However, one patient in the monitored group had a new postoperative deficit (Table 2: Patient 7). This patient was a nonmyelopathic 43-year-old male who underwent an uneventful two-level (C4–C6) ACDF. There were no intraoperative complications. Postoperatively he woke up with a new neurological deficit, consisting of bilateral hand numbness in the absence of motor weakness. Neurosurgical evaluation was obtained, and a diagnosis of a partial central cord syndrome was made. No further imaging was obtained, and no subsequent interventions were undertaken. This deficit completely resolved during the patient's hospital stay. In this case no significant changes in the intraoperative SSEP recordings were observed at any point during the procedure.

Therefore, the incidence of a new neurological deficit in this study was 1 out of 1,039 cases (0.09%).

Discussion

The utility of intraoperative SSEP monitoring during spinal surgery was first established in the late 1970s. SSEP monitoring resulted in a decrease in the incidence of new postoperative neurological complications after surgery for spinal trauma and tumor resection [18–24]. Advances in intraoperative SSEP monitoring during scoliosis surgery in the 1980s are credited for contributing to the reduction in incidence of new neurological complications from 4–6.9% to approximately 0–0.7% [25–29].

Despite these successes, the utility of intraoperative SSEP monitoring during cervical spine surgery is still a subject of debate. For example, Epstein et al. reported that intraoperative SSEP monitoring during cervical spine surgery

Table 2
Patients with intraoperative SSEP changes or new postoperative neurological deficits

Patient	Age	Gender (M/F)	No. of ACDF levels	SSEP changes?*	Intraoperative maneuver leading to SSEP improvement	New postoperative neurological deficit?
1	46	M	Two (C5–C7)	Yes (Transient)	Increasing BP	No
2	51	M	One (C6–C7)	Yes (Transient)	Increasing BP	No
3	44	M	Two (C2–C4)	Yes (Transient)	Increasing BP	No
4	56	M	Two (C5–C7)	Yes (Transient)	Increasing BP	No
5	64	M	One (C5–C6)	Yes (Transient)	Increasing BP	No
6	70	F	Two (C4–C6)	Yes (Transient)	Retractor repositioning	No
7	43	M	Two (C4–C6)	No change	N/A	Yes (partial central cord syndrome)

ACDF=anterior cervical discectomy and fusion; SSEP=somatosensory evoked potential; BP=blood pressure; N/A=not applicable.
* Defined as 50% decrease in amplitude or 10% increase in latency.

decreased the incidence of new postoperative neurological injury from 3.7% to 0% [30]. In that study, 8 of 218 patients who were unmonitored became quadriplegic, whereas none of the 100 monitored patients had new postoperative deficits. Other studies have found intraoperative SSEP monitoring during cervical spine surgery to be less useful. Hilibrand et al. compared transcranial electric motor-evoked potential (tceMEP) monitoring and SSEP monitoring during cervical spine surgery [8]. Their data showed that the sensitivity and specificity of tceMEP monitoring was 100%, which compared with 25% sensitivity and 100% specificity for SSEP monitoring. Moreover, a significant ‘‘temporal difference’’ was reported with SSEP lagging behind tceMEP by 3 to 33 minutes. Deutsch et al. studied intraoperative SSEP monitoring during anterior thoracic vertebrectomy in 44 patients [31]. Four patients had a new postoperative neurological deficit despite stable intraoperative SSEP tracings. The study demonstrated a 9% false negative rate and 0% sensitivity for intraoperative SSEP monitoring. Jones et al. reported two cases of temporary quadriparesis after anterior cervical surgery with normal intraoperative SSEP tracings [32].

Although most of the aforementioned studies with SSEP and cervical surgery have included both ACDF and corpectomies, these procedures have significant differences. For example, cervical traction applied during corpectomy surgery is known to affect SSEP signals, possibly because of bulging of the disc and the posterior longitudinal ligament [14]. Also, cervical radiculopathy and myelopathy have distinct differences in their pathophysiologies. Unlike radiculopathy, vascular factors are thought to play a significant role in the development of cervical myelopathy which may render the spinal cord more sensitive to a surgical intervention [33]. Therefore, the usefulness of intraoperative SSEP monitoring in the setting of a specific diagnosis and a single surgical procedure needs to be more thoroughly evaluated. Two such reports have been recently published. In a review of 508 cervical corpectomy surgery cases, Khan et al. reported that SSEP monitoring has a low sensitivity for neurological deficits during cervical corpectomy surgery [34]. Similarly, Taunt et al. published their experience with 163 patients who underwent ACDF with SSEP monitoring [35]. They concluded that intraoperative SSEP monitoring does not appear to be useful during ACDF.

In our study, the incidence of new neurological deficits was 1 in 1,039 cases (0.09%). The rarity of this occurrence is in agreement with Jones et al. who reported 2,000 consecutive cases of anterior cervical discectomy surgery without any new deficits [32]. Because incidence affects the sensitivity and specificity of a test, the low incidence of neurological deficits during ACDF (in this group of nonmyelopathic patients) may make intraoperative SSEP monitoring of limited utility. It is interesting to note that there were six instances of transient SSEP changes in the monitored group, and they all resolved with specific interventions (1 case of carotid artery compression which resolved with retractor repositioning and 5 cases of hypotensive episodes which resolved with raising blood pressure). It is unknowable how many of the patients in the control group would have also demonstrated transient signal changes associated with vascular compression or hypotension, had intraoperative SSEPs been used. However, none of the 462 patients in the control group had a new postoperative neurological deficit. The clinical significance of the transient SSEP signal changes observed in the monitored group cannot be determined, because in each case an intraoperative intervention (ie, retractor repositioning, raising blood pressure) restored the transient SSEP signal changes to baseline values. However, it is possible that such transient SSEP signal changes, if uncorrected, might ultimately have resulted in clinical morbidity. Furthermore, although no iatrogenic injury occurred in the control group, it is not known if any of these patients experienced vascular compression or hypotension comparable to the monitored group. One way to evaluate the utility of intraoperative SSEP monitoring would be to design a prospective study whereby intraoperative SSEP monitoring is performed but the data are not shared with the surgeon or the anesthesiologist during the surgical procedure. However, ethical and legal considerations may make such a study unfeasible.

A possible reason for the limited utility of SSEP monitoring during anterior cervical surgery may be related to the region of spinal cord being monitored when employing SSEPs. SSEP monitoring is thought to assess the functional integrity of the ascending dorsal column pathways exclusively. It could be argued that anterior cervical surgery, regardless of its nature, has a higher likelihood of endangering the anterolateral corticospinal motor tracts, located more anteriorly in the spinal cord. For this reason, procedures involving a higher risk to the spinal cord (ie, corpectomy, cervical laminectomy in myelopathic patients) may warrant the use of multimodality monitoring such as combined SSEP and tceMEP monitoring, which when used together can more fully assess integrity of the posterior as well as anterior spinal cord.

The strength of this study is that it focuses on a subset of patients with a narrowly defined diagnosis (radiculopathy without myelopathy) who underwent a specific surgical procedure (ACDF). Also, because four different surgeons performed the surgical procedures, the fact that only 1 of 1,039 patients had a new postoperative neurological deficit suggests that ACDF is associated with a low risk of neurological injury in the hands of well trained orthopedic and neurological surgeons alike. Finally, this study had a cohort of unmonitored patients for comparison. The major weakness of this study is that it was retrospective in nature. Also, the rarity of iatrogenic intraoperative injury during ACDF surgery may necessitate studying a much larger number of patients in order to determine whether SSEP monitoring is efficacious. Finally, the decision whether or not to obtain intraoperative SSEP monitoring was not based on a uniform preoperatively agreed-upon set of criteria. It is possible that based on personal preference and prior experience, the surgeons may have decided to obtain neurophysiological monitoring in patients thought to be at higher risk. Therefore, it is possible that the monitored group had a higher underlying risk of sustaining an intraoperative iatrogenic injury as compared with the control group. In this respect, a prospective randomized clinical trial may be more informative.

Conclusion

ACDF surgery in nonmyelopathic patients has a low incidence of iatrogenic spinal cord injury. A neurological deficit occurred in the presence of normal intraoperative SSEP signals. In this retrospective study, intraoperative SSEP monitoring during ACDF surgery in nonmyelopathic patients was not superior to unmonitored cases.

References

[1] Drummond DS, Schwartz DM, Johnston DR, Farmer JF. Neurological injury complicating surgery. In: DeWald RL, editor. Spinal deformities: the comprehensive text. New York: Thieme, 2003:615–25.
[2] Ecker ML, Dormans JP, Schwartz DM, Drummond DS, Bulman WA. Efficacy of spinal cord monitoring in scoliosis surgery in patients with cerebral palsy. J Spinal Disord 1996;9:159–64.
[3] Luk KD, Hu Y, Wong YW, Cheung KM. Evaluation of various evoked potential techniques for spinal cord monitoring during scoliosis surgery. Spine 2001;26:1772–7.
[4] Noordeen MH, Lee J, Gibbons CE, Taylor BA, Bentley G. Spinal cord monitoring in operations for neuromuscular scoliosis. J Bone Joint Surg [Br] 1997;79:53–7.
[5] Nuwer MR, Dawson EG, Carlson LG, Kanim LE, Sherman JE. Somatosensory evoked potential spinal cord monitoring reduces neurologic deficits after scoliosis surgery: results of a large multicenter survey. Electroencephalogr Clin Neurophysiol 1995;96:6–11.
[6] Padberg AM, Bridwell KH. Spinal cord monitoring: current state of the art. Orthop Clin North Am 1999;30:407–33.
[7] Schwartz DM, Drummond DS, Schwartz JA, et al. Neurophysiological monitoring during scoliosis surgery: a multimodality approach. Semin Spine Surg 1997;9:97–111.
[8] Hilibrand AS, Schwartz DM, Sethuraman V, Vaccaro AR, Albert TJ. Comparison of transcranial electric motor and somatosensory evoked potential monitoring during cervical spine surgery. J Bone Joint Surg [Am] 2004;86:248–53.
[9] Bohlman HH. Cervical spondylosis with moderate to severe myelopathy: a report of 17 cases treated by Robinson anterior cervical discectomy and fusion. Spine 1997;2:151–62.
[10] Bohlman HH, Emery SE, Goodfellow DB, Jones PK. Robinson anterior cervical discectomy and arthrodesis for cervical radiculopathy. J Bone Joint Surg [Am] 1993;75:1298–307.
[11] Gore DR, Sepic SB. Anterior cervical fusion for degenerated or protruded discs: a review of one hundred forty-six patients. Spine 1984;9:667–71.
[12] Robinson RA, Walker AE, Ferlic DC, Wiecking DK. The results of anterior interbody fusion of the cervical spine. J Bone Joint Surg [Am] 1962;44:1569–87.
[13] Chistyakov AV, Soustiel JF, Hafner H, Kaplan B, Feinsold M. The value of motor and somatosensory evoked potentials in evaluation of cervical myelopathy in the presence of peripheral neuropathy. Spine 2004;29:E239–47.
[14] Kombos T, Suess O, DaSilva C, Ciklatekerlio O, Nobis V, Brock M. Impact of somatosensory evoked potential monitoring on cervical surgery. J Clin Neurophysiol 2003;20:122–8.
[15] May DM, Jones SJ, Crockard HA. Somatosensory evoked potential monitoring in cervical surgery: identification of pre- and intraoperative risk factors associated with neurological deterioration. J Neurosurg 1996;85:566–73.
[16] Sebastian C, Raya M, Olalla E, Lemos V, Romero R. Intraoperative control by somatosensory evoked potentials in treatment of cervical myeloradiculopathy: results in 210 cases. Eur Spine J 1997;6:316–23.
[17] Balzer JR, Rose RD, Welch WC, Sclabassi RJ. Simultaneous somatosensory evoked potential and electromyographic recordings during lumbosacral decompression and instrumentation. Neurosurgery 1998;42:1318–25.
[18] Brown RH, Nash CL Jr. Intraoperative somatosensorisch evozierte kortikale potentiale bei spinalen operationen. In: Schramm J, editor. Evozierte Potentiale in der Praxis. Berlin: Springer Verlag, 1985:153–82.
[19] Jones SJ, Carter L, Edgar MA, Morley T, Ransford AO, Webb PJ. Experience of epidural spinal cord monitoring in 410 cases. In: Schramm J, Jones SJ, editors. Spinal cord monitoring. Berlin: Springer Verlag, 1985:215–20.
[20] Maccabee PJ, Levine DB, Pinkhasov EI, Cracco RQ, Tsairis P. Evoked potentials recorded from the scalp and spinous processes during spinal column surgery. Electroencephalogr Clin Neurophysiol 1983;56:569–82.
[21] Roye WP Jr, Dunn EL, Moody JA. Cervical spinal cord injury: a public catastrophe. J Trauma 1988;28:1260–94.
[22] Ryan TP, Britt RH. Spinal and cortical somatosensory evoked potential monitoring during corrective spinal surgery with 108 patients. Spine 1985;11:352–61.
[23] Veilleux M, Daube J. The value of ulnar somatosensory evoked potentials in cervical myelopathy. Electroencephalogr Clin Neurophysiol 1987;68:415–23.
[24] Veilleux M, Daube J, Cucchiara RF. Monitoring of cortical evoked potentials during surgical procedures on the cervical spine. Mayo Clin Proc 1987;62:256–64.
[25] Engler GL, Spielhotz NJ, Bernhard WN, Danziger F, Merkin H, Wolff T. Somatosensory evoked potentials during Harrington instrumentation for scoliosis. J Bone Joint Surg [Am] 1978;60:528–32.
[26] Keith RW, Stambough JL, Aweder SH. Somatosensory cortical evoked potentials: a review of 100 cases of intraoperative spinal surgery monitoring. J Spin Disord 1990;3:220–6.
[27] Meyer PR, Cotler BH, Gireesan GT. Operative neurological complications resulting from thoracic and lumbar spine internal fixation. Clin Orthop 1998;237:125–31.
[28] Whittle JR, Johnston IH, Besser M. Recording of spinal somatosensory evoked potentials for intraoperative spinal cord monitoring. J Neurosurg 1986;64:601–12.
[29] Wilber RG, Thompson GH, Shaffer JW, Brown RH, Nash CL Jr. Postoperative neurological deficits in segment spinal instrumentation. J Bone Joint Surg [Am] 1984;66:1178–87.
[30] Epstein NE, Danto J, Nardi D. Evaluation of intraoperative somatosensory-evoked potential monitoring during 100 cervical operations. Spine 1993;18:737–47.
[31] Deutsch H, Arginteanu M, Manhart K, et al. Somatosensory evoked potential monitoring in anterior thoracic vertebrectomy. J Neurosurg Spine 2000;92:155–61.
[32] Jones SJ, Buonamassa S, Crockard HA. Two cases of quadriparesis following anterior cervical discectomy with normal perioperative somatosensory evoked potentials. J Neurosurg Psychiatry 2003;74:273–6.
[33] Seyal M, Mull B. Mechanisms of signal change during intraoperative somatosensory evoked potential monitoring of the spinal cord. J Clin Neurophysiol 2002;19:409–15.
[34] Khan M, Smith PN, Balzer JR, et al. Intraoperative somatosensory evoked potential monitoring during cervical spine corpectomy surgery. Spine 2006;31:E105–13.
[35] Taunt CJ Jr, Sidhu KS, Andrew SA. Somatosensory evoked potential monitoring during anterior cervical discectomy and fusion. Spine 2005;30:1970–2.