Clinical Measurement

Monitoring evoked potentials during spinal surgery in one institution

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Purpose: To review the experience of one tertiary care institution with somatosensory evoked potential (SSEP) monitoring during spinal surgery in order to assess the ability to monitor and predict neurological outcome effectively.

Methods: Records of all patients undergoing spinal surgery during 18 mo were retrospectively reviewed. Information from the patient chart included preoperative neurological status, surgical procedure, anaesthetic management, and postoperative neurological outcome. Information regarding the techniques used and interpretation of all SSEP tracings were obtained from evoked potential data sheets completed for each patient. The incidences of clinically important SSEP changes and new postoperative neurological deficits were analysed.

Results: Somatosensory evoked potential monitoring of the lower and upper extremities with non invasive techniques was used in 309 patients undergoing surgery on the cervical (88), thoracic (52), and lumbar spine (169). Thirty seven patients (11%) did not have suitable tracings for interpretation and 17 (5.5%) had baseline tracings described as poor. An intraoperative SSEP change occurred in 16 patients (6%) with SSEP and seven (2.6%) had a new neurological deficit postoperatively. Three persistent deficits were predicted by permanent SSEP change, and one transient deficit by a transient SSEP change. False positive results occurred in 12 patients (4.4%) and false negative results occurred in three (1.1%), with a sensitivity of 57% and a specificity of 95%. The incidence of SSEP changes was greater in the thoracic (18%) than in the cervical (1.2%) or lumbar (5.4%) groups ($P < 0.05$).

Conclusion: Effective SSEP monitoring was possible despite the many factors which may have interfered with monitoring. More improvements in the techniques and conditions of monitoring are needed to decrease the incidence of false positive and negative results.

Objectif : Revoir l'expérience acquise dans un centre tertiaire avec le monitoring des potentiels évoqués somatosensoriels (SSEP) durant la chirurgie du rachis dans le but d'en évaluer la capacité à surveiller et à prédire de façon efficace le pronostic neurologique.

Méthodes : Les dossiers de tous les patients subissant une chirurgie du rachis sur une période de 18 mois ont été revus de façon rétrospective. Les informations colligées à partir des dossiers étaient l'état neurologique préopératoire, la procédure réalisée, le protocole anesthésique et l'état neurologique postopératoire. Les données concernant les SSEP quant à la technique utilisée et quant à l'interprétation de tous les tracés ont été retrouvées dans les feuilles de données des SSEP complétées pour chaque patient. On a analysé l'incidence de survenue de changements des SSEP cliniquement importants de même que celle des nouveaux déficits neurologiques postopératoires.

Résultats : Le monitorage des potentiels évoqués somatosensoriels au moyen de techniques non invasives, recueillis à partir des membres supérieurs et des membres inférieurs, a été utilisé chez 309 patients opérés au niveau de la colonne cervicale (88), thoracique (52) et lombaire (169). Trente sept patients (11%) avaient des tracés qui ne permettaient pas une interprétation et 17 patients (5,5%) avaient des tracés où la ligne de base était de piètre qualité. Une modification des SSEP a été notée chez 16 patients (6%) et sept d'entre eux (2,6%) présentaient un nouveau déficit neurologique en postopératoire. Trois déficits persistants ont été prédits par des modifications permanentes des SSEP, et un déficit transitoire par des modifications temporaires des SSEP. Des faux positifs ont été notés chez 12 patients (4,4%) et des faux négatifs chez 3 patients (1,1%), ce qui témoigne d'une sensibilité de 57% et d'une spécificité de 95%. L'incidence des modifications des SSEP a été plus élevée dans le groupe thoracique (18%) que dans les groupes cervical (1,2%) et lombaire (5,4%) ($P<0,05$).

Conclusion : Le monitorage efficace des SSEP a été possible en dépit des nombreux facteurs pouvant interférer avec ce monitorage. D'autres améliorations des techniques et des conditions de monitorage sont nécessaires pour diminuer l'incidence des faux positifs et des faux négatifs.

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MONITORING of spinal cord function is frequently performed in the operating room during spinal surgery.[1-6] The goals of monitoring are to warn the surgeon of impending ischaemia to the spinal cord, permitting correction of the cause of impairment before permanent damage occurs. The second goal is to help to predict the neurological outcome of the patient. One of the most widely used techniques of spinal cord monitoring is with somatosensory evoked potentials (SSEP).[2,4] Many factors, such as the influence of anaesthesia, preoperative condition of the patient, and expertise of the monitoring team, may influence the ability of the sensory evoked potential monitoring to be effective.[3,4] The purpose of this study was to review the experience of one tertiary care institution with SSEP monitoring during spinal surgery in achieving these goals of monitoring.

Methods

With approval from the institutional ethics committee, the charts of all patients undergoing spinal surgery during an 18 mo period (1994–95) were retrospectively reviewed. All procedures were performed by both neurosurgeons and spinal orthopaedic surgeons at The Toronto Hospital, Western Division, where all patients undergoing spinal surgery routinely have SSEP monitoring. Patients that qualified for this study had completed hospital charts as well as completed data sheets for evoked potential monitoring including paper copies of the actual tracings. The patient chart was reviewed for demographic data, diagnosis, surgical procedure, preoperative neurological deficits, medical problems, the anaesthetic management, and for postoperative complications including new neurological deficits. The information obtained from the evoked potential data sheets included the modalities and parameters used. The evoked potential tracings were reassessed and all changes were noted. The evoked potential waveforms used in this review included the spinal (popliteal fossa or lumbar spine for lower extremity and brachial plexus or cervical spine for upper extremity) and the somatosensory cortical components.

Clinically important changes for SSEP were considered to be a decrease in the amplitude >50% and/or an increase in latency > 1 msec of the cortical peak. These changes were classified as bilateral or unilateral, and transient, if they recovered by the end of the procedure, or permanent if they were present at closing. Changes in evoked potentials that were defined as the result of changes in anaesthesia or temperature were not included. Neurological deficits were described as sensory or motor and were classified as transient, lasting < 24 hr or persistent if they were present at time of discharge. Standard practice during all the surgical procedures was to have the evoked potential technician inform the surgeon of all evoked potential changes and have the surgeon initiate the appropriate intervention whenever possible. The anaesthetic management was at the discretion of the anaesthetist.

Patients were divided into three groups according to the site of surgery; cervical, thoracic, or lumbar. The incidence of all evoked potential changes and new neurological deficits were tabulated and analysed. The ability of a SSEP change to predict a new deficit was documented for all patients and also compared among the three groups. Statistical analysis was by chi square testing. $P < 0.05$ was considered significant.

Results

The charts and evoked potential data sheets for 309 patients were complete and were used for this review. The procedures performed included surgery for scoliosis (65) and fractures (22), and laminectomy for disc (102), stenosis (84), tumour (25), syringomyelia (6), and abscess (5), with or without instrumentation. The surgical procedures were performed by 13 consultant surgeons, and all the monitoring was performed by three evoked potential technicians with variable training and less than three years of intraoperative experience. Demographic data of the patient and the anaesthetic management with the use of isoflurane and nitrous oxide are shown in Table I.

Somatosensory evoked potential monitoring was done with standard parameters for stimulating and recording for each modality. Only non invasive techniques of stimulating and recording were used. Subdermal needle electrodes were used for stimulating over the peripheral nerves and for recording from the spinal and somatosensory cortical sites. Bilateral tracings of all modalities were performed. Lower extremity monitoring with the posterior tibial nerve was used in 213 patients, upper extremity with median nerve in two patients, and both posterior tibial and median nerve in 34 patients. Some patients also had other modalities of SSEP and EMG but these were not analysed in this study. Seventeen patients (5.5%) had baseline tracings that were described as poor but were used intraoperatively for clinical assessment. These were used in the data analysis and are noted in Table II. Thirty-seven patients (11%) did not have suitable baseline tracings for interpretation during their baseline assessment. These patients were eliminated from the analysis of the results in Table III.

In total, of the 272 patients with adequate tracings, 16 patients (6%) developed a clinically important change in their evoked potentials (Tables II, III). These changes were observed using the posterior tibial nerve modality.

Fourteen were changes in both amplitude and latency, one was only amplitude and one was only latency. These changes occurred during surgery for scoliosis (5), disc (4), stenosis (6), and tumour (1). Six patients had a permanent change, but only three had a new postoperative neurological deficit. Two patients in the lumbar group showed improvement in their evoked potentials after surgical decompression. Patients undergoing thoracic surgery had a greater incidence of SSEP changes than either the cervical or lumbar surgery groups (Table III).

Ten patients (3.1%) had a new neurological deficit postoperatively. Three (0.9%) deficits were persistent, and were predicted by a change in the evoked potential. One deficit was sensory (numbness in one leg) following lumbar disc surgery, one was motor (foot drop which was improving at time of discharge) after scoliosis surgery and another patient had both sensory and motor deficits following resection of a thoracic spinal cord tumour. Three patients had transient deficits (numbness, or weakness in one extremity) and no SSEP change during surgery for disc (1), stenosis (1), and scoliosis (1). Only one patient had a transient change in SSEP and a transient deficit after lumbar surgery for stenosis. Three transient deficits occurred in patients in whom the baseline evoked potentials were not recordable [lumbar disc (2), thoracic scoliosis (1)]. The results for the ability of evoked potentials to predict a neurological deficit, including the incidence of false negative and positive results and the sensitivity and specificity of the monitoring are shown in Table III. Overall, there were four true positive, three false negative, and 12 false positive results, nine of which were transient changes in SSEP. In three patients a permanent SSEP change did not predict a deficit. The false negative results occurred in one patient during thoracic surgery for scoliosis and during lumbar surgery for disc (1) and stenosis (1). The false positive results occurred in one patient during cervical surgery for spondylosisthesis, five in the thoracic [scoliosis (4), disc (1)], and six in the lumbar group [stenosis (4), disc (2)].

Discussion

The surgical treatment of deformities of the spine and lesions of the spinal cord carry a small but important risk of damage to the spinal cord which may lead to serious consequences. The risk is greatest when corrective forces are applied to the spine such as during scoliosis surgery or when the cord is being invaded such as for tumour surgery. The recognition that some of these complications are potentially avoidable has led to the development and promotion of spinal cord

TABLE I Demographic data

	Total	*Cervical*	*Thoracic*	*Lumbar*
n	309	88	52	169
Age (yr)	49 ± 17	50 ± 15	46 ± 21	49 ± 17
Sex (FM)	149:160	37:51	26:26	86:83
Isoflurane (ET %)	0.7 ± 0.3*	0.7 ± .2	0.7 ± 0.4	1.2 ± 0.5
Nitrous oxide (ET %)	57 ± 10†	55 ± 11	56 ± 9	58 ± 10

values = mean ± SD
* (n = 295), † = (n = 297)

TABLE II Incidence of SSEP and new neurological deficits

	Neurological Deficits	*No Deficit*
Cervical (n=88)		
SSEP Change		
Permanent	–	1
Transient	–	-
No SSEP Change	–	83 (4*)
No EP Tracing	–	4
Thoracic (n=52)		
SSEP Change		
Permanent	2P (1S&M, 1M)	1
Transient	–	4
No SSEP Change	1T (M)	31 (8*)
No EP Tracing	1T (S)	12
Lumbar (n = 169))		
SSEP Change		
Permanent	1P (S*)	1
Transient	1T (M)	5
No SSEP Change	2T (S,S*)	137 (3*)
Improved	–	2
No EP Tracing	2T (S)	18

* = poor tracing
S = sensory, M = motor; P = persistent, T = transient;
n = number of patients

TABLE III The ability of SSEP changes to predict a neurological deficit

	Total	*Cervical*	*Thoracic*	*Lumbar*
n	272	84	39	149
Neuro deficits	2.6%	0%	7.7%	2.7%
(n)	(7)		(3)	(4)
EP changes	6%	1.2%	18%*	5.4%
(n)	(16)	(1)	(7)	(8)
Sensitivity	57%	0%	67%	50%
Specificity	95%	98%	86%	96%
True Positive	25%	0%	29%	25%
True Negative	98%	100%	97%	99%
False Positive	4.4%	1.2%	13%	4%
False Negative	1.1%	0%	2.6%	1.3%

* $P < 0.05$ from cervical and lumbar groups
n = number of patients

monitoring.[1–6] The first technique of monitoring was the wake-up test but, more recently, the term spinal cord monitoring, has been taken to mean neurophysiological monitoring with SSEP and motor evoked potentials.[5]

Many reports have examined the ability of SSEP monitoring to predict neurological deficits and influence outcome in spine surgery.[2–4,6] The incidence of new neurological deficits occurring after scoliosis surgery when SSEP was used for monitoring was reported to be 1.6% in a large international survey reported by Dawson *et al.* in 1991.[2] In 1995, Nuwer *et al.* reported the results from a large multicentre follow up survey of US centres.[4] They reported 51,263 cases of SSEP monitoring during scoliosis surgery and found the incidence of new neurological deficits to be 0.55%. The incidence in our study was 2.5%. Our study included all spinal proce dures with only 21% being scoliosis surgery. Only three persistent deficits occurred and there were no major deficits such as paraplegia. Other complications that were outside the field of monitoring were not included, such as ulnar nerve palsy when no upper extremity monitoring was performed.

False positive results occur when there is an intraoperative SSEP change, but the patient wakes up with no new deficit. These have been reported to occur in 1.5 to 20% of patients.[3,4] In our series, when all changes, both transient and permanent, are considered the incidence was 4.4%. The transient changes in SSEP may indicate the prevention of a deficit by the correction of the factors resulting in ischaemia, such as excessive retraction or hypoperfusion.[4] Also, Kalkman *et al.* stated that the incidence of false positive results appears to be related to the experience of the monitoring team or an inability to maintain constant levels of anaesthesia.[3] The occurrence of all these factors are real possibilities in our series, but can not be verified in a retrospective review. False positive results may also provoke anxiety to the surgical team.[3] Again, this cannot be assessed in a retrospective review but is an area that would need future prospective study.

False negative results during spinal surgery have been frequently discussed as a real concern of the ability of SSEP monitoring to be effective. They occur when there is a new postoperative deficit but there had been no intraoperative change in the SSEP. The incidence has been stated to occur in 0.13 to 14% of patients.[4,6] The overall incidence in our series was 1.1%. Reports of false negative results have been criticized for lack of reliable baselines, for the failure to monitor the pathway at risk, or the event leading to the deficit may have occurred after monitoring had ceased.[1] All these reasons may account for the occurrence of false negative results in our study.

The cervical spine group had the least number of SSEP changes and neurological deficits which may reflect the small number of patients studied and the severity of their disease. This is in contrast to the study by May *et al.* who found a high sensitivity (99%) in that there were nine patients with a true positive result and only one false negative.[6] They had 24 false positive results and thus a lower specificity (27%). The authors stated that the high incidence of SSEP changes and deficits in their patients was related to the high degree of preoperative disability in their patients. In our study, evoked potential changes were greater in the thoracic group. This is probably due to the nature of the patients in this group. The majority of these patients were undergoing a corrective procedure for scoliosis where there is marked manipulation of the spinal column which may lead to compromised blood flow to the spinal cord. Four of the seven SSEP changes were transient in nature. Two patients were found to have an improvement in their SSEP during lumbar spinal decompression. This improvement has also been noted in patients with cervical spondylitic myelopathy following decompression and fusion.[7]

Many variables will affect the quality of sensory evoked potentials that are obtained intraoperatively. These include the set of parameters used for monitoring and for indicating change, the anaesthetic and physiological effects, neurological status of the patient, and the experience of the monitoring team and the interaction between them and the surgeon.[1,3] Each centre needs to establish their standards and have a consistent protocol. The most widely used modalities for spinal surgery involve the posterior tibial or peroneal nerve for the lower extremities and median or ulnar nerve for upper extremities. The criteria for a significant change is generally accepted at a 50% reduction of amplitude of the cortical peak and a 5–10% increase in latency.[2–4] In our institution, set protocols for monitoring were used although some of the recording and stimulating parameters were revised during the study time period in order to improve monitoring with changes in equipment and surgical techniques. Our criteria for a significant change followed the generally accepted limits.

Many anaesthetic agents and some physiological factors affect the amplitude and latency of the SSEP cortical waveform which may interfere with the ability to accurately interpret changes. These effects have been well reviewed.[3,8,9] Inhalational agents influence the quality of the tracings more than intravenous agents. SSEP monitoring has been shown to be feasible during low-dose isoflurane anaesthesia (< 1%) and during the combination of nitrous oxide and isoflurane.[9–11] In our series the majority of procedures were performed with the use of isoflurane and nitrous oxide. The overall mean end-tidal concentration of isoflurane was < 1% and nitrous oxide less than 60%, but the influence of these inhalation agents in specific cases can not be directly assessed in this review. Physiological factors such as temperature and blood pressure also influence the quality of the waveform.[3,8,9] Hypothermia results in an increase in latency and the effect of hypotension has been shown to become additive when blood flow to the spinal cord is compromised. In our review, the anaesthetic management including the agents used and the control of temperature varied greatly amongst the anaesthetists, as is the practice in our institution. In order to rule out changes in SSEP by anaesthetic or other physiological changes, the tracings were examined as to whether important changes were bilateral or unilateral as these effects are generally seen bilaterally. Also, in our institution, it is the practice of the evoked potential technicians to document any fluctuations in level of anaesthesia and other physiological parameters during monitoring. Another area of difficulty in clinical practice is the lack of baseline controls before the induction of anaesthesia and prior to positioning of the patient. This results from the difficulty of performing awake controls, particularly due to time restraints. Changes in SSEP may also occur as a result of poor positioning.[12] These changes may be present immediately or develop later on. As this was a retrospective review, it is possible that errors may have occurred in describing a change or lack of change due to any of these effects or difficulties.

Many patients with spinal disease have neurological deficits preoperatively and thus, may be poor candidates for effective SSEP monitoring.[6] Eleven percent of our study group had baseline tracings that were unsuitable for monitoring. Seventeen patients (5.5%) had tracings that were labelled as poor by the technician, but were used for monitoring. However, only one patient in our series had a postoperative deficit and no SSEP change when the baseline tracing was called poor. In addition to neurological deficits, technical difficulties may have resulted in some of these failures, but this information was not clearly available in this retrospective review.

The SSEP monitoring used in our institution during this study involved only non invasive techniques, that is the detection of the responses by subdermal needle electrodes. This technique has been criticized for having more technical problems in obtaining responses and that the cortical potentials are more sensitive to anaesthetic and other physiological effects. An alternative technique is to use invasive placement of electrodes into the subarachnoid or epidural space around the spinal cord or into spinous processes or interspinous ligaments.[13-15] The use of epidural electrodes alone or in combination with other techniques may be particularly helpful in patients with severe spinal cord damage preoperatively such as occurs with spinal cord tumours.[15]

The experience of the monitoring team is important in the usefulness of monitoring.[3,4] Nuwer *et al.* found in their survey that there was a clinically meaningful reduction of neurological deficits for teams with more SSEP monitoring experience compared to those with little experience.[4] It was hard to assess the experience within our own institution, as the experience of the surgeons varied greatly, and all the technicians had less than three years experience. Our overall results are comparable to other series in the literature. Also, in a retrospective review it is impossible to comment on the interaction of the monitoring team and the surgeons.

The limitations of sensory evoked potential monitoring are well recognized and lead to on-going discussions about the cost effectiveness of monitoring. The complexity of evoked potential monitoring requires expensive equipment and skilled personnel to perform the task. The cost of monitoring has been stated to be justified by the value in detecting and preventing neurological deficits against the cost of caring for a patient, particularly a young adult, for a lifetime with a major permanent deficit such as paraplegia.[4,16] It is difficult to indicate which specific procedures are best monitored from the information obtained in our review. The changes in SSEP and the neurological deficits occurred during all the various surgical procedures. This was a retrospective study and the total number of specific cases reviewed was small. As the experience of the persons performing and using the information is important in the overall results, an argument can be made for the monitoring of all possible cases.

In conclusion, this retrospective review of the monitoring of patients with SSEP during spinal surgery in one institution, showed that it was possible to monitor effectively despite the many factors that may influence monitoring. One modality monitoring is not always adequate as shown by the incidence of false negative results. Perhaps, in future, the addition of other modalities, such as motor evoked potentials, and invasive evoked potential techniques may help to eliminate some of these difficulties. The false positive results may reflect that the fact that monitoring does help to decrease the incidence of deficits by allowing intervention by the surgeon at times of ischaemia. Further improvements in the techniques of monitoring as well as the control of factors that influence evoked potentials are needed.

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