Diagnostic accuracy of somatosensory evoked potential monitoring during scoliosis fusion.

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Abstract:

Objectives:

The goal of this review was to ascertain the diagnostic accuracy of intraoperative somatosensory evoked potential (SSEP) changes to predict perioperative neurological outcome in patients undergoing spinal deformity surgery to correct adolescent idiopathic scoliosis (AIS). The authors searched PubMed/MEDLINE and World Science databases to retrieve reports and/or experiments from January 1950 through January 2014 for studies on SSEP use during AIS surgery. All motor and sensory deficits were noted in the neurological examination administered after the procedure which was used to determine the effectiveness of SSEP as an intraoperative monitoring technique. Fifteen studies identified a total of 4763 procedures on idiopathic patients. The observed incidence of neurological deficits was 1.11% (53/4763) of the sample population. Of the patients with new postoperative neurological deficits 75.5% (40/53) showed significant SSEP changes, and 24.5% (13/53) did not show significant change. Pooled analysis using the bivariate model showed SSEP change with pooled sensitivity (average 84%, 95% confidence interval 59–95%) and specificity (average 98%, 95% confidence interval 97–99%). The diagnostic odds ratio of a patient who had a new neurological deficit with SSEP changes was a diagnostic odds ratio of 340 (95% confidence interval 125–926). Overall, detection of SSEP changes had excellent discriminant ability with an area under the curve of 0.99. Our meta-analysis covering 4763 operations on idiopathic patients showed that it is a highly sensitive and specific test and that iatrogenic spinal cord injury resulting in new neurological deficits was 340 times more likely to have changes in SSEP compared to those without any new deficits.

Diagnostic accuracy of somatosensory evoked potential monitoring during scoliosis fusion.

Iatrogenic spinal cord injury resulting in paraplegia or paraparesis after correction of spinal deformity is a devastating complication [1, 2]. Idiopathic scoliosis (IS) is considered the most common form of spinal deformation [3] with no recognized etiology[4]. The prevalence of Idiopathic scoliosis is about 2-4% of the population occurring between 10-16yrs of age[5], for which corrective surgery is the most effective treatment option in advanced cases[5, 6]. However, surgical intervention puts the integrity of the spinal cord at risk. Surgical complications are most often related to the placement of spinal instruments or the use of instrumentation to correct the spinal deformity by causing direct injury to the spinal cord or to the spinal vasculature [7]. Even though the incidence of neurological deficits is reported to be approximately 1%[2], this is a devastating complication with significant morbidity [8] in patients who are generally young and otherwise healthy. The use of intraoperative neurophysiological monitoring (IONM) of spinal cord function has been shown to reduce the risk of motor deficits or paraplegia [9, 10] and is commonly used in surgical procedures with the potential for incurring spinal cord injury [9, 11]. Intraoperative neurophysiological monitoring is a rapidly growing subspecialty of neurology[12] being utilized in more than 800,000 surgical procedures annually to reduce the incidence of neurological complications[10].

Somatosensory evoked potential (SSEP) monitoring during corrective IS surgery plays an important role in reducing the incidence of devastating neurological deficits by the continuous monitoring of dorsal column function of the spinal cord [13 9]. It is reported that significant changes of SSEP may correspond to correction of the spinal deformity [9, 10, 14], and reflect possible permanent neurological injury if not corrected. Significant changes in SSEPs are defined as a 50% decrease in amplitude and/or a 10% increase in latency of the cortical SSEP waveform when compared to baseline values [15-17]. SSEP monitoring can detect impending deficits with high sensitivity and specificity [9, 10, 14]. Transcranial motor evoked potential (TcMEP) monitoring of the corticospinal pathway has also been shown to identify impending motor deficits [18, 19]. However, unlike SSEPs, TcMEPs do not have defined or accepted alarm criteria to accurately alert the surgeon of a significant change that predicts an impending neurological deficit.

The predictive value of SSEP changes during idiopathic scoliosis to detect spinal cord ischemia and spinal cord injury remains to be determined. The primary aim of this study was to conduct a systematic review of the scientific literature in order to evaluate whether changes in SSEPs during idiopathic scoliosis procedures are diagnostic for new onset post-operative neurological deficits. The goal of this review was to ascertain the sensitivity, specificity, diagnostic odds ratio, and area under receiver operating characteristic (ROC) curves of the intraoperative SSEP changes in relation to neurological outcome in patients undergoing surgery to correct for idiopathic scoliosis.

Methods:

Type of Studies

Peer-reviewed publications were included in the assessment if they were (1) randomized controlled trails, prospective, or retrospective cohort reviews, (2) conducted in patients with idiopathic scoliosis, (3) conducted in surgical procedures for idiopathic scoliosis that utilized intraoperative SSEP monitoring , (4) reported immediate post-operative neurological assessment, (5) included ≥ 25 patients as the total sample size were included, and (6) were published in English. *Participants:* All study participants underwent a surgical procedure to treat idiopathic scoliosis. No patient was excluded due to age in the study. *Index Test:* For the purposes of the study SSEP monitoring was the index text, which was compared to a reference standard (below). There were no restrictions as to the provision of additional monitoring modalities. *Target conditions:* The study focused on patients with idiopathic scoliosis of the thoracic and lumbar spine. *Reference Standards:* Post-operative neurological deficits were defined as any new deficit or loss of motor or sensory deficits. Loss of function was further defined by a motor or sensory deficit recorded in the immediate post-operative time period. It should also be noted that post-operative

neurological examinations were typically not performed by a neurologist and may not have complied with any common reference standard.

Literature Search criteria and Strategy

In order to execute the search, the following terms were used: "scoliosis," "spinal deformity," or "corrective spinal deformity," to identify patients who had idiopathic scoliosis. We utilized the following terms "intraoperative neurophysiological monitoring," "somatosensory evoked potentials," "somatosensory evoked potential," or "intraoperative neurophysiological monitoring," to identify patients who underwent SSEP monitoring during scoliosis surgery. The index test was somatosensory evoked potential monitoring during surgical procedures for idiopathic scoliosis. The neurological exam after the procedure was used as the reference standard to determining the effectiveness of the SSEPs as a intraoperative monitoring technique. All motor and sensory deficits including bladder symptoms were regarded as deficits. The authors searched PubMed/MEDLINE and World science database for reference lists of retrieved reports and/or experiments from January 1950 through January 2013 for studies on SSEP use during idiopathic scoliosis surgery.

Data Extraction and Analysis

Two authors (H.LC. and P.D.T.) independently screened all titles and abstracts to identify studies that met the inclusion criteria and extracted relevant articles (Figure 1). Subsequently, each author constructed an excel spreadsheet listing articles that were to be eliminated and the reasons for the elimination dictated by the number corresponding to the appropriate inclusion criteria (i.e.1-6). The two excel spreadsheets were compared and after disagreements were reconciled, a final list of articles that met the study inclusion criteria was assembled (Table 1).

The following data was extracted from each study a) First author and year of publication, b) study design, c) SSEP(s) and other IONM modalities were used and recorded when SSEP baselines were obtained, d) Study data: total sample size, idiopathic sample size, SSEP changes, reversible and/or irreversible changes to SSEP e) Outcome data: reversible or irreversible neurological deficit, which was deemed any persistent neurological motor deficit (weakness, paraplegia) or sensory deficits which was present post-operatively (post-op) as independently stated by each individual study. SSEP change was classified as a greater than 50% decrease in the amplitude and/or a 10% increase in latency of cortical N20-P25 complex of the upper extremity SSEP. An irreversible SSEP change was deemed as a significant amplitude and/or latency change, which did not return to baseline at the end of the procedure. Further, a reversible SSEP change was an intraoperative change that returned to baseline at the end of the operation.

Data Extraction and Management

The number of true positives, false negatives, false positives, and true negatives in patients with idiopathic scoliosis were extracted and tabulated for each study. True positives (TP): patients with SSEP changes and with a new post-operative motor deficit. False negatives (FN): patients with no SSEP changes and with a new post-operative motor deficit. True negatives (TN): patients with no SSEP changes and no new post-operative motor deficits. False positive (FP): patients with SSEP changes and without a new post-operative motor deficit.

Assessment of Methodological quality

The review authors used the QUADAS 2 tool to assess the susceptibility to bias of the included studies [20]. We assessed patient selection, index test, reference standard, and flow and timing as the four domains. Patient selection refers to avoiding nonconsecutive or nonrandom sampling, case-control, or inappropriate exclusion. The index test refers to proper SSEP monitoring. The reference standard refers to proper testing for neurological function. Flow and timing refers to the interval between the index and reference tests, whether all patients received the same reference test and whether all patients were included in the analysis. If the answers to all signaling questions in a domain are "yes" then the "low" risk grade is given. If the answer to any signaling question is "no" then a "high" risk grade is given. The

"unclear" category was only used where the reported data was insufficient to permit a judgment. The methodological quality of the included studies was assessed independently by two review authors and disagreement was resolved by reexamination of primary literature. (Figure 2)

Statistical analysis

We used Stata 13 for the statistical analyses (StataCorp. 2013. Stata Statistical Software: Release 13. College Station, TX: StataCorp LP). Meta-analysis was conducted using the bivariate model to fit the data into a hierarchical summary receiver operating curve (HSROC), which is a technique that yields useful summary estimates of diagnostic test performance[ref: Reitsma, J.B., et al., Bivariate analysis of sensitivity and specificity produces informative summary measures in diagnostic reviews. J Clin Epidemiol, 2005. 58(10): p. 982-90.]. We were also able to calculate area under the receiver operating curve (AUROC), pooled sensitivity, specificity and diagnostic odds ratio (DOR) through the above-mentioned bivariate model for the HSROC. Datasets where TP+FN = 0, or TN+FP =0,could not be reliably incorporated into our meta-analysis because accurate estimates of either sensitivity or specificity were not available.

Results:

A search of literary databases, PubMed and Web of Science identified 676 articles based on key search words. After a full assessment of abstracts and the full-text articles (Fig. 1), 50 articles met inclusion criteria for further analysis. Our final results, based on the application of all inclusion criteria which required papers to separately analyze SSEP results for AIS, led to a total of 15 articles (Table 1). All 15 studies were prospective and/or retrospective cohort studies. Eleven studies provided data in a format which could be included in a meta-analysis.

Each study outlined the SSEP alarm criteria used during surgery, which differed between the studies constituting a 50–70% decrease in N20-P25 cortical amplitude, and/or 10% increase in latency (Table 1). Table 2 shows the demographics of the total population of 6147 patients, of which a sample population of 4763 had AIS. Of the sample population (4763), 3.7% (175) showed significant SSEP change during surgery (Table 2). In the 175 patients with SSEP change, there was a 22.9% (40/175) incidence of neurological deficits. In the 4588 patients without SSEP change, there was a 0.27% (13/4588) incidence of neurological deficits. In the six papers that documented transient and persistent SSEP change 33% (11/33) had neurological deficits with reversible SSEP change, 64% (21/33) had neurological deficits with irreversible SSEP change, and 3% (1/33) had neurological deficit unrelated to SSEP change. Additionally, four studies (449 total patients and 324 idiopathic patients) noted significant SSEP changes but no neurological deficits.

There was an observed incidence of neurological deficits in 1.11% (53/4763) of the sample population. Of the patients with new postoperative neurological deficits 75.5% (40/53) showed significant SSEP changes, and 24.5% (13/53) did not show significant change.

The forest plot (Fig. 2) shows sensitivity and specificities of the ability of SSEP to predict neurological deficits for each study. Individual study sensitivities ranged between 59–95%, and specificity ranged between 97–99%. Combined data from all studies without accounting for possible covariates, such as age, body size, and skin temperature, showed SSEP change had strong specificity (average 98%, 95% confidence interval 97–99%) with reasonable sensitivity (average 84%, 95% confidence interval 59–95%). SSEP had excellent ability to discriminate performance with an AUROC of 0.99 (Fig. 3). The pooled diagnostic odds ratios with SSEP from 11 individual studies of patients with neurological deficit was 340 (95% confidence interval 125–926).

The positive likelihood ratio for SSEP change in individuals with post-procedure neurological deficit was calculated to be 42 while the negative likelihood ratio was estimated to be 0.16. A Fagan's nomogram was drawn after assuming the pre-test probability of neurological deficit to be equal to the incidence of

deficits in our cohort (1.11%). With this assumption, the post-SSEP change probability of deficit was estimated to be 32%. The probability of not experiencing a new deficit without SSEP change was found to be 99.82%.

Discussion:

Patients presenting with a new neurological deficit after correction of idiopathic scoliosis are 340 times more likely to have significant SSEP changes reported during the procedure. Somatosensory evoked potentials assess the integrity of the dorsal column pathways. There are multiple explanations for why SSEP changes reflect postoperative findings of a new motor deficit. For example, previous studies have shown that SSEP changes occur secondary to ischemia that is primarily attributed to spinal cord hypoperfusion [21], or, to a change in the structural integrity of the spinal cord that involves compressive vectors that compromise dorsal column transmission [10, 22]. By comparison, other studies have shown that the amplitude of cortically-generated SSEP components remain relatively unchanged until cerebral cortical blood flow is reduced to approximately 20 ml/min/100 g [23-25]. Additionally a further decrease of cerebral blood flow to between 15 and 18 ml/min/100 g results in cortical neurons to be unable to generate SSEPs [26]. Thus, graded changes in SSEP latencies and/or amplitude of a 50% decrease in amplitude and or a 10% increase in latency, permit the neurophysiologist to inform surgeons of evolving and reversible SSEP changes that may indicate impending neurological injury [15-17]. Significant loss of SSEPs during correction of the spinal deformity surgery [8, 9, 13] can indicate neurological deficits if not corrected shortly after the onset of SSEP changes [9, 14]. Experimental studies in animal models demonstrate that a loss of SSEPs is a precursor of "ion pump failure" at the cellular level resulting in ionic imbalance and eventually leading to cell death[22]. After the "electrical failure", loss of SSEPs and before the "ion pump failure" occurs there might be a time window during which restorative interventions may be initiated[27]. Thus, the high specificity of SSEPs monitored during surgical correction of idiopathic scoliosis deformities for new onset motor deficits, serves as a neurophysiological biomarker for spinal cord injury.

SSEP monitoring provides real time neurological assessment during surgeries that may place the spinal cord at risk. Results indicate that SSEP changes possess a high specificity of 98% and sensitivity of 84% indicating spinal cord injury during the surgical procedure. The lower sensitivity could be attributed to how some patients are categorized as true positives (TP). In this study, the total observed false-positive (FP) rate was 2.7%, which is higher than the 0% to 1.8%, reported range of other studies for cranial and spinal surgery [28-30]. We categorized patients who had a change in SSEP and neurological deficits as true positives and patients with change in SSEPs and without neurological deficits as false positives (FP). However, when there is a SSEP change during scoliosis surgery, there is an intervention by the surgical team including but not limited to increasing the mean arterial pressure, administration of methylprednisolone and in some cases making adjustments to the surgical procedure such as reversing derotation of the spine or removal of instrumentation. These interventions are not documented consistently in the included studies. Based on experimental animal studies, SSEP changes indicate ischemia in the brain or spinal cord, which without intervention could have resulted in infarction and subsequent neurological deficit. Hence our sensitivity is lower because we categorized patients with SSEP changes and no neurological deficit as FP despite the real possibility that surgical intervention, based on an evolving SSEP change, ultimately prevented neurological injury.

In our study we found an overall low false-negative rate of 0.22%. False-negative (FN) reports with ranges of 0% to 3.5%, defined as new post-operative motor deficits without significant SSEP changes, call into question the diagnostic accuracy of SSEP monitoring [31-33]. While SSEPs changes may accurately reflect extensive spinal cord injury that includes the dorsal column pathways, but more restrictive injury that is localized to the motor tracts or anterior horn of the spinal gray matter, may go undetected with SSEP monitoring alone [31, 34, 35]. Hence SSEPs lack of specificity in directly monitoring corticospinal pathways can lead to incorrectly diagnosing TP as FN causing missed post-operative motor and sensory deficits [36, 37]. Due to the small but certain likelihood of FN reporting, transcranial motor evoked potential (TcMEP) monitoring, of the corticospinal pathways, may be of value in identifying

impending spinal injury[18, 19] in order to mitigate FN reporting based upon SSEP monitoring alone. However, a previous publication calculated that the addition of TcMEP monitoring in IS surgery causes an absolute risk reduction of only 0.063%, but only when the number needed to treat was 1,587 patients for one spinal cord injury to not be detected by SSEPs alone [10]. While TcMEP's have an increased role during neurological procedures and may minimize FN reporting, the absence of uniform alarm criteria for TcMEPs raises challenges in interpreting changes in TcMEP data during scoliosis surgery. Our study does suggest that IONM involving SSEPs is a robust and sensitive monitoring modality for IS corrective surgery.

While this study is a comprehensive literature review with quality assessment measures, it does have its limitations. The limitations include variation in the collection and interpretation of data, and the differences in surgical teams' response to SSEPs changes during scoliosis surgery, which could not standardize for the current analysis. The reference standard, post-operative neurological assessment was not uniformly reported in the literature.

Conclusion

Iatrogenic spinal cord injury resulting in new neurological deficits was 340 times more likely to occur in patients who had changes in SSEPs during surgical correction. Our meta-analysis of 5947 operations on idiopathic patients showed that SSEP monitoring alone is a highly sensitive and specific test in predicting new neurological deficits in patients undergoing idiopathic scoliosis.

Figures: Figure Document

Acknowledgement

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