The Contribution of an Electronic Conductivity Device to the Safety of Pedicle Screw Insertion in Scoliosis Surgery

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From the *Department of Pediatric Orthopaedics, Dana Children’s Hospital, The implantation of pedicle screws in spinal deformity correction surgery has evolved into the currently predominant fixation technique. Methodologies for optimizing placement of pedicle screws are fluoroscopy, electromyography, and intraoperative image-based navigation. A hand-held ECD was recently introduced.

Methods. Pedicle screw insertion was analyzed in 248 pediatric scoliosis patients (idiopathic, congenital, neuromuscular, syndromic). Group I included 150 procedures without the aid of the ECD and group II included 98 ECD-aided procedures. The two groups were matched by age, sex, etiology, Cobb angle, and surgical criteria. Data on screw position and concomitant neuromonitoring alarms were compared. Group I consisted of patients operated with both the hybrid construct and pedicle screw instrumentation, while group II consisted of patients operated solely with pedicle screws. Both groups were operated on by a single surgeon with the same neurophysiologic methodology. Clinically relevant misplaced pedicle screws were established by intraoperative monitoring alarms concomitant with pedicle screw insertion.

Results. A total of 1270 pedicle screw placements were analyzed in group I and compared with 1400 pedicle screw placements in group II. Neuromonitoring alarms concomitant with screw placement occurred in 10 procedures in group I (6.6%) compared with 3 in group II (3.0%). The contribution of the electronic device to reducing the number of neurophysiologic alarms was significant (P = 0.048, Fisher exact test). Nine of the 13 monitoring alarms (69%) were associated with implantation adjacent to the apex of the spinal curve.

Conclusion. The use of an ECD significantly reduced the incidence of clinically relevant misplaced screws in a variety of scoliosis patients, thereby increasing the safety of pedicle screw implantation.

Key words: electronic conductivity device, pedicle screws, scoliosis.

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The use of pedicle screws in spinal deformity correction surgery has soared over the last two decades to become the most common technique for thoracic and lumbar spinal fixation. Pedicle screw placement, particularly in scoliosis surgery, can be challenging even for an experienced surgeon because of the deformation of the anatomy and the changes in vertebral morphology. Pedicle screw misplacement has been reported in 10% to 55% of cases, and can lead to complications such as nerve root spinal cord injury or vascular injury resulting in paraplegia or severe neurologic sequelae. Classic methodologies for verification of optimal placement of pedicle screws include a free-hand technique, intraoperative fluoroscopy, triggered electromyography, intraoperative image-based navigation, and most recently, the use of a hand-held electronic conductivity device (ECD). A multicenter study performed by Bolger et al analyzed a total of 521 thoracic and lumbar pedicle screws in 97 degenerative patients with the aid of an ECD (PediGuard, SpineGuard, Paris, France). The device was shown to have high overall sensitivity and specificity values (98% and 99%, respectively) for detecting pedicle breaches, as well as high (>94%) negative and positive predictive values. Betz et al compared 62 screws placed manually with 60 screws placed with an ECD in degenerative patients, and showed greater efficacy with the use of the ECD. Furthermore, in a *in vitro* study on fresh-frozen specimens showed that the use of an ECD can be a valuable adjunct in cervical pedicle screw insertion as well. Pedicle screw placement, particularly in scoliosis surgery can be challenging even for an experienced surgeon because of the deformation of the anatomy and the changes in vertebral morphology.
The goal of the current clinical study was to evaluate the contribution of an ECD (PediGuard) to the safety of thoracic and lumbar pedicle screw placement in a large group of patients with scoliosis of diverse etiologies. The indication for clinically relevant screw misplacement was an intraoperative neurophysiologic monitoring alarm at the time of or immediately after pedicle screw implantation. Somatosensory evoked potentials (SSEP) and transcranial electric motor evoked potentials (tcMEP) monitoring techniques are routinely applied during all scoliosis correction procedures in our institution, and reflects common practice. Intraoperative neurophysiologic monitoring has been shown to possess high sensitivity and specificity for intraoperative neurologic injury, and have been described as standard of care in scoliosis surgery, obviating the need for a wakeup test after spinal correction. As such, neurophysiologic alarms, when occurring concomitantly with the screw placement, was interpreted as a clinically relevant detrimental sign.

MATERIALS AND METHODS
This study was performed according to the Declaration of Helsinki and approved by the institutional ethical committee. A retrospective analysis of 248 pediatric patients with scoliosis of various etiologies (idiopathic, congenital, neuromuscular, syndromic) was performed in which 150 patients (group I) who were operated between 2003 and 2007 without the use of ECD were compared with 98 patients (group II) who were operated between 2008 and 2009 with the use of the PediGuard. Both groups were operated on by a single senior spine surgeon and continuously monitored with intraoperative multimodal evoked potentials (SSEPs, MEPs) and electromyography (EMG) by a single neurophysiologist. All pedicle screws were implanted using the free-hand technique, according to the guidelines previously described in details by Kim et al. The default surgical approach was to implant pedicle screws in all spinal levels on the concave side of the scoliotic curve, and in every other spinal level on the convex side. Whenever the pedicle width was found by the surgeon to be extremely narrow or deformed, thus endanger a safe screw implantation, that particular segment was skipped.

Pedicle screw data including dimension, screw level relative to spinal apices, and concomitant neuromonitoring alarms were collected and compared. The two study groups were matched by age, sex, scoliosis etiology, Cobb angle, and surgical criteria. We had initially used hybrid instrumentation and gradually transferred to an all pedicle screw construct in group I, while pedicle screws alone were used in group II.

Clinically relevant misplacement of pedicle screws was established by true intraoperative neurophysiologic monitoring alarms, on the basis of the criteria delineated in the literature. All external factors, for example, technical, anesthetic, global-physiologic, were ruled out before being attributed to specific screw insertion. An alarm was raised if there were significant nonlinear attenuation or latency shifts (beyond 10%) of posterior tibial nerve cortical SSEP, or if there were sudden and significant attenuation of unilateral or bilateral lower extremity tcMEP amplitudes.

Intraoperative Neurophysiological Monitoring
All neurophysiologic data were recorded with a 16/32 channel intraoperative evoked response unit (Axon Systems, NY) placed according to the international 10-20 scalp positioning system at positions C3’, C4’, and Cz’ with referencing to Fpz at the forehead. Bipolar stimulation of either posterior tibial nerve was performed using pregelled surface electrodes (Axon Systems, NY) placed on prepped skin at the posterior aspect of the medial malleoli. A subdermal ground electrode was placed at the shoulder. Averages of 100 to 500 sweeps (scale 100 milliseconds window, 0.5–2 μV vertical scale/division) were collected at 4.2 stimulations/second to improve the signal-to-noise ratio, and the resultant peak-to-peak amplitude of the P37 potential was compared with that of the baseline data that had been collected preoperatively. The criteria for significant change of the SSEP were 50% attenuation of the P37 amplitude and/or a more than 10% latency prolongation.

SSEPs
SSEPs were collected from subdermal needle electrodes (Axon Systems, NY) placed in the bilateral thenar, quadriceps, and anterior tibialis muscles (recording parameters: 100 milliseconds time sweep, bandpass filter 20–3000 Hz) after transcranial stimulation (5 anodal/cathodal pulse train, 500 μsecond/pulse, 333 Hz train frequency, 80–215 mA intensity) with subdermal corkscrew-style electrodes (Axon Systems, NY).

tcMEP
These were recorded with paired subdermal needle electrodes (Axon Systems, NY) placed in the bilateral thenar, quadriceps, and anterior tibialis muscles (recording parameters: 100 milliseconds time sweep, bandpass filter 20–3000 Hz) after transcranial stimulation (5 anodal/cathodal pulse train, 500 μsecond/pulse, 333 Hz train frequency, 80–215 mA intensity) with subdermal corkscrew-style electrodes (Axon Systems, NY).

tcMEP data were collected approximately every 2 to 10 seconds during intrapediculuar exploration and screw placement. The criteria for change indicating neurologic injury were sudden abolishment of data or more than 90% amplitude attenuation of either anterior tibialis and/or quadriceps tcMEP waveform. tcMEP data from the thenar channels were used as controls, and if abolished together or separately from the anterior tibialis data, technical, or anesthetic factors were suspected and investigated.

Changes in either lower extremity SSEP or tcMEP data, when occurring together with significant changes in upper extremity tcMEP data were excluded as significant clinical events related to pedicle exploration or screw placement.

Electromyography
The technique of pedicle screw stimulation for verification of accurate placement can be found elsewhere. Electromyographic recordings were made in free-running fashion with paired needle electrodes (Axon Systems, NY) placed in the bilateral middle and lower rectus abdominal, quadriceps, and anterior tibialis muscles. Parameters were 2 seconds/window, bandpass 30 to 2000 Hz. The recordings were both visualized and projected on the system loudspeaker for recognition. In group I and the first year’s procedures of group II, all T4–L5-implanted pedicle screws were stimulated in situ at increasing intensities to a maximum of 25 mA to establish the threshold at which
evoked EMG responses were triggered and thus extrapolate proper placement within the pedicle. Screws with motor thresholds lower than 10 mA were removed, and the trajectory was inspected for cortical bone breaches, and at the discretion of the surgeon were either repositioned or removed without reimplantation. The technique of pedicle screw stimulation for verification of accurate placement can be found elsewhere. 6,8,9,11,21–23 Significant changes in SSEP and tcMEP data as described earlier after ruling out confounding factors were immediately brought to the attention of the surgical team for appropriate intervention, including removal of implanted screw or replanning of pedicle trajectories when indicated.

The ECD
The ECD (PediGuard; Figure 1) is a free-hand drilling instrument, designed with an electronic conductivity sensor at its sharp tip, which can translate relative values of electronic conductivity into an audible and visual signals. It works on the premise that cancellous bone within the pedicle possesses lower resistance than the cortical bone and soft tissues that surround it, and thus can provide the surgeon live feedback as to whether the trajectory has strayed from within normal intrapedicle spatial boundaries.

Statistical Methods
Numerical variables are summarized by mean ± SD. The rate of abnormal neuromonitoring events within each group was compared by Fisher exact test. The statistical comparison used the number of screws as the unit of analysis, rather than individual patients.

RESULTS
A total of 248 pediatric scoliosis patients (170 girls and 78 boys) with various etiologies who were operated upon between 2003 and 2009 were retrospectively enrolled. Their mean age was 14.06 ± 3.38 years, and the mean Cobb angle was 70.91° ± 18.67°. The patients were divided into two groups and were compared by age, sex, Cobb angle, etiology of the scoliosis, and surgical criteria (Table 1). Group I included 150 patients (65% girls) who were operated between 2003 and 2007 without the aid of an ECD for pedicle screw placement, and group II consisted of 98 patients (74% girls) who were operated between 2008 and 2009 with the aid of an ECD. The distribution of scoliosis etiology was as follows: 33 (13.5%) had congenital scoliosis, 141 (56.7%) had idiopathic scoliosis, and 74 (29.8%) had neuromuscular or syndromatic scoliosis.

Hybrid instrumentation was initially used for fixation and gradually switched to an all-pedicle screw construct in group I, while pedicle screws alone were used in group II. The mean preoperative Cobb angle in groups I and II were 73.3° ± 21.3° and 68.9° ± 16.1°, respectively (Table 1). Curve correction obtained in the coronal plane in both groups was similar (P < 0.05 compared to preoperative values, Table 1). Table 2 summarizes the number of procedures, the total number of screws per group as well as the average number of screws per procedure. There was average of 8.5 screws per procedure in group I and an average of 14.3 screws per procedure in group II. A total of 1270 pedicle screws were analyzed in group I compared with 1400 in group II. Data pertaining to pedicle screws were compared, including screw position relative to spinal apices and the triggering of a concomitant neuromonitoring alarm. Table 2 displays the significant group difference in the number of monitoring alarms during pedicle insertion (P = 0.048). Ten group-I patients had neuromonitoring events concomitant with screw placement compared with three group-II patients (Table 3). No patient had more than one event.

<table>
<thead>
<tr>
<th>TABLE 1. Demographic Data</th>
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<tbody>
<tr>
<td>Females (%)</td>
</tr>
<tr>
<td>--------------</td>
</tr>
<tr>
<td><strong>Group 1</strong></td>
</tr>
<tr>
<td>97 (64.7)</td>
</tr>
<tr>
<td><strong>Group 2</strong></td>
</tr>
<tr>
<td>73 (74.5)</td>
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TABLE 2. Data on Screws and Monitoring Events

<table>
<thead>
<tr>
<th>Procedures (N)</th>
<th>Screws (N)</th>
<th>Average No. of Screws Per Procedure</th>
<th>No. of Monitoring Events</th>
<th>Incidence of Events per Procedure</th>
<th>Incidence of Events Per Screws</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group I</td>
<td>150</td>
<td>1270</td>
<td>8.5</td>
<td>10</td>
<td>6.6%</td>
</tr>
<tr>
<td>Group II</td>
<td>98</td>
<td>1400</td>
<td>14.3</td>
<td>3</td>
<td>3.06%</td>
</tr>
</tbody>
</table>

Group I: procedures without the aid of the ECD; Group II: procedures with the aid of the ECD.

*P = 0.048.

Figure 2A is a radiograph of a 13-year-old patient with idiopathic scoliosis, with a main right thoracic curve of 68° (T4–T11) and a left lumbar curve of 55°. After placement of the right T6 pedicle screw, the left-sided anterior tibialis tcMEP were abolished (black arrow). The affected tcMEP gradually returned to normal minutes later (gray arrow). The contralateral tcMEP as well as the bilateral thenar tcMEP remained stable throughout, supporting a specific reversible neurologic event caused by the insertion of the specific screw (Figure 2B). The thoracic curve was subsequently corrected to 26° (62% of correction; Figure 2C), the patient woke up without any neurological deficit, and the postoperative results were excellent.

Overall, 9 of the 13 (69%) monitoring alarms were associated with implantation at the apex of the thoracic curve or one level adjacent to the apex. It is noteworthy that all neuromonitoring alarms were resolved by the end of the procedure and none of the 248 study patients had any neurologic sequella.

No correlation was found between the incidence of neuromonitoring events and age, sex, magnitude of the curve, degree of correction, or etiology of scoliosis. The contribution of the ECD to the safety of pedicle screw insertion was proven by a statistically significant difference between the two groups (P = 0.048, Fisher exact test; Table 2).

DISCUSSION

The use of all-pedicle screw constructs in scoliosis surgery continues to gain in popularity, although their use in the thoracic spine carries a potential risk of neurologic and vascular complications because of morphologic aberrations of

<table>
<thead>
<tr>
<th>Sex</th>
<th>Age</th>
<th>Diagnosis</th>
<th>Main Curve</th>
<th>Correction (%)</th>
<th>Apex</th>
<th>Problematic Screw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group I</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Female</td>
<td>17</td>
<td>Trisomy 10</td>
<td>D5–L1, 103°</td>
<td>42</td>
<td>D9</td>
</tr>
<tr>
<td>2</td>
<td>Female</td>
<td>12</td>
<td>Juvenile</td>
<td>D7–D12, 114°</td>
<td>60</td>
<td>D10</td>
</tr>
<tr>
<td>3</td>
<td>Female</td>
<td>13.9</td>
<td>AIS</td>
<td>D6–D11, 57°</td>
<td>62</td>
<td>D8–9</td>
</tr>
<tr>
<td>4</td>
<td>Female</td>
<td>12.8</td>
<td>Juvenile</td>
<td>D5–D11, 82°</td>
<td>49</td>
<td>D8</td>
</tr>
<tr>
<td>5</td>
<td>Female</td>
<td>6.7</td>
<td>Congenital</td>
<td>D2–D7, 80°</td>
<td>58</td>
<td>D5</td>
</tr>
<tr>
<td>6</td>
<td>Male</td>
<td>13.9</td>
<td>AIS</td>
<td>D6–D11, 70°</td>
<td>59</td>
<td>D9</td>
</tr>
<tr>
<td>7</td>
<td>Female</td>
<td>15.6</td>
<td>AIS</td>
<td>D7–L1, 70°</td>
<td>63</td>
<td>D10</td>
</tr>
<tr>
<td>8</td>
<td>Female</td>
<td>18.7</td>
<td>AIS</td>
<td>D5–D11, 60°</td>
<td>60</td>
<td>D8</td>
</tr>
<tr>
<td>9</td>
<td>Female</td>
<td>16</td>
<td>AIS</td>
<td>D6–D12, 70°</td>
<td>66</td>
<td>D9</td>
</tr>
<tr>
<td>10</td>
<td>Male</td>
<td>18.5</td>
<td>Syndromatic</td>
<td>D5–D11, 58°</td>
<td>62</td>
<td>D7</td>
</tr>
</tbody>
</table>

Group II                      |
| 1    | Female | 15.8 | AIS         | D4–D11, 84°    | 63   | D8    | Lt. D8           |
| 2    | Female | 8    | Congenital  | D10–L2, 40°    | 60   | D12   | Lt. D12          |
| 3    | Female | 12.9 | AIS         | D4–D11, 68°    | 62   | D7    | Rt. D6           |

Group I: procedures without the aid of the ECD; Group II: procedures with the aid of the ECD.

AIS indicates adolescent idiopathic scoliosis.
Figure 2. A, Preoperative AP radiograph of a 13-year-old patient with idiopathic scoliosis with a main right thoracic curve of 68° and a left lumbar curve of 55° (Table 3, group II, third patient). B, An example of a neuromonitoring event concomitant with pedicle screw insertion. After placement of the right T6 pedicle screw, the right-sided tcMEP data were abolished (black arrow), and gradually returned to normal minutes later (gray arrow). C, Her postoperative AP X-ray showing thoracic curve of 26° (62% of correction).
the pedicles and vertebrae. Several methods have been utilized to increase the accuracy of pedicle screw placement, which has become the most common technique for correction and fusion in spinal deformity surgery. The free-hand technique for thoracic screw placement introduced by Kim et al. was found to be accurate, reliable, safe, and time-saving without exposing the patient and the surgeon to radiation. Only 1.7% of the 3204 screws that were used in that study were misplaced medially and no neurological complication was recorded.

We recently became familiarized with a new technology on the basis of electronic conductivity. The ECD is integrated into the drilling tool, and allows real-time detection of bone perforation through electronic conductivity variation. The device is designed to detect the initiation of iatrogenic breaches in the vertebral pedicle wall prior to screw insertion. In the current study, we analyzed the results of the free-hand technique that incorporated the ECD (group II) to evaluate the ECD's contribution to the safety and accuracy of pedicle screws insertion in pediatric scoliosis patients. Bolger et al. were the first to use the ECD on 97 degenerative spine patients; they demonstrated its simplicity, safety, and sensitivity. Zeller et al. published a preliminary report on screw insertion with the use of the ECD in five consecutive pediatric patients (26 screws) with cervical spinal disorders. They reported that 30.8% of the screws were placed an average of 1.33 mm deeper than planned. We did not experience such inaccuracy in any of the 2670 screws that we implanted and now describe.

To date, there are very few articles in the English literature that deal with the contribution of an electronic device to the accuracy of pedicle screw insertion in degenerative lumbar and cervical spine patients. To the best of our knowledge, this is the first systematic evaluation of the contribution of an electronic device to the safety of pedicle screws insertion in a large group of pediatric patients with scoliosis of diverse etiologies. The reported clinical sensitivity and specificity of intraoperative evoked potential alarms are quite high. and, as such, we considered such changes to be clinically relevant. We also attributed the neuromonitoring alarms to screw misplacement only when they were appeared concomitantly or within a few minutes after specific implantation. Neurophysiologic alarms that appeared later during the procedure, for example, during the corrective maneuver, were not included in the analysis as they were not directly attributed to pedicle screw placement and are therefore beyond the scope of this article. It should be noted, however, that significant neuromonitoring events would provide a sensitive marker for medial (in relation to the spinal cord) or inferior (related to nerve roots) screw misplacement only, and the misplacement would have to be to the extent that the screw either contuses the spinal cord directly or indirectly by “splintering” of intracanal bony tissue. Lateral or superior misplacement of the screw, or even minimal medial misplacement, would potentially go unnoticed by evoked potential changes. However, given the reported high level of sensitivity and specificity of evoked potential changes to iatrogenic neurologic injury, we would not consider such a misplacement to be clinically relevant, and would not, in turn, be concerned to revise it. The sensitivity and specificity of evoked potentials monitoring in our series was not possible as all evoked potential changes resolved by the end of the procedure, and no significant neurologic sequelae were detected. Therefore, it was not possible to test the clinical correlation of abolished neurophysiologic data.

Several studies described a retrospective measurement method to evaluate accuracy based on postoperative computed tomography (CT). We believe that while this type of analysis contributes to the knowledge on the methodology of screw placement, we feel it is limited as it does not reflect real time information and therefore cannot aid in optimizing pedicle screw insertion on a practical, intraoperative level. Furthermore, it may be argued that barring any significant neurologic deficit, the amount of ionized radiation to which the patient is exposed outweighs potential clinical or didactic benefit that CT may offer to the surgeon.

Our early group I patients had been fixated with a hybrid system, while the later patients benefitted from thoracic pedicle screw fixation alone. In contrast, the complete series of group II patients was an all-pedicle screw construct. As pedicle screws are more invasive, we would have thought that group II would theoretically be at greater risk for neurologic injury than group I because thoracic pedicle screws are more invasive than sublaminar/pedicle hooks, and are placed in deformed and delicate anatomy compared with lumbar levels. As such, we might have expected more intraoperative alarms in group II experience greater postoperative morbidity. Surprisingly, our findings showed the opposite effect: there was a significant decrease in the number of clinically relevant neuromonitoring alarms ($P = 0.048$) with the use of the electronic device. Moreover, this finding is even more significant considering that group II had more implanted pedicle screws per patient (average of 14.3 vs. 8.5 screws in groups II and I, respectively).

The most deformed areas in scoliosis patients are the concave side and the apices of the curvature. Liljenqvist et al. demonstrated that the pedicles at these two regions have a small endosteal width, which, at times, might preclude safe screw placement of any sort. Interestingly, although the use of the ECD contributed to the accuracy and safety of pedicle screw insertion, still 9 of the 13 analyzed monitoring alarms were associated with implantation at or one level adjacent to the apex of the curve.

Unlike the multicenter study by Bolger et al. which enrolled 11 senior surgeons who used different surgical techniques and relied on diverse experience and methods (tactile feel, probing, fluoroscopy, CT, EMG, SSEP) to identify the optimal screw location, our study was performed in one institute by the one surgeon and one neurophysiologic team, thus minimizing the number of variables.

The current study includes the greatest number of scoliosis patients (N = 248) as well as the greatest number of implanted pedicle screws (N = 2670) compared with earlier reports. All of our patients had significant curve magnitudes (average...
Cobb angle of 70°), which are more surgically challenging. We feel that the context of our series testifies to the ECD’s methodological and clinical value, and can be a good reference point for continued clinical investigation and experience with this tool.

Pedicle screw placement in deformity patients, particularly at the more strategic areas, that is, the concavity and apices of spinal curvature, continue to pose a major challenge for the spine surgeon. This study has demonstrated that the use of the ECD, a simple tool with a short learning curve, significantly increased the safety of pedicle screw insertion and decreased the incidence of clinically relevant misplaced screws in scoliosis patients.

There are some limitations of the current study. First, it is a retrospective study. Second, the two groups were enrolled on a serial basis and not in parallel, effectively making it a historically controlled study with all the associated disadvantages, such as improvement in surgical technique with cumulative experience, potentially biasing the later patients with better results irrespective of the ECD use. While optimally, a prospective randomized study is the ideal method to compare different surgical techniques, a retrospective historically controlled approach has been used as a valid scientific method in several publications.

Several aspects of our work minimize the shortcoming of a historically controlled study; first the incidence of the neuromonitoring events during pedicle screws insertion was equally distributed along the years the study was conducted (see sequential numbers in Table 3), and not clustered at the beginning as would be expected from a surgeon on a steep learning curve. This, taken together with the fact that even with the start of this study the surgeon was an experienced senior spine specialist should minimize the theoretical downsides of this historically controlled study.

In our experience, the use of the ECD improved pedicle screw insertion safety. We continue to use the ECD on a routine basis in all scoliosis surgery performed at our institution.

Further studies are necessary to determine whether such advantages are relevant in other surgical contexts involving pedicle screw insertion.

### Key Points

- This retrospective, controlled, clinical study compared 150 pediatric scoliosis patients operated without the aid of an ECD with 98 similar patients been operated with the use of the ECD, having identical neuromonitoring methodology.
- Clinically relevant misplacement of pedicle screws was established by intraoperative neurophysiological monitoring alarms concomitant with screw insertion.
- There were significantly fewer intraoperative monitoring alarms related to pedicle screw insertion in the group where the ECD was used (P = 0.048).
- Our data demonstrate that the use of an ECD significantly increases the safety of screw implantation in scoliosis surgery.

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### References


