Diagnostic accuracy of perioperative electromyography in the positioning of pedicle screws in adolescent idiopathic scoliosis treatment: a cross-sectional diagnostic study

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Abstract

Background: To investigate electromyography (EMG) thresholds for predicting pedicle screw positioning during adolescent idiopathic scoliosis (AIS) surgery.

Methods: 16 patients were included. Each screw was classified as “at risk for nerve injury” (ARNI) or “no risk for nerve injury” (NRNI) using CT and the diagnostic accuracy of EMG thresholds for predicting screw positions ARNI was investigated.

Results: 226 pedicles were analyzed. In the axial plane, 204 (90.3%) screws were considered as NRNI, and 22 (9.7%), as ARNI. In the sagittal plane, 183 (81%) pedicle screws were considered as NRNI, and 43 (19%), as ARNI. We observed a significant association between EMG responses and screw positioning ARNI. A 1-mA decrease in EMG threshold corresponded to a 12% increase in the odds of screw position ARNI (OR=1.12; p<.001). The positive predictive value of EMG for diagnosing ARNI was very low, with the highest 18% corresponding to a cutoff of 25 mA, but the negative predictive value was moderate to high (78%-93%) for every cutoff.

Conclusions: EMG had a poor accuracy for predicting screws ARNI but was effective for minimizing false-negative screws ARNI.

Background

The use of pedicle fixation is increasing in spinal arthrodesis and is especially common in the treatment of adolescent idiopathic scoliosis (AIS). First demonstrated in the lumbar segments of the spine [1, 2], the technique has also been proven to be safe when employed at thoracic levels [3-6]. Compared with the use of hooks or hybrid instrumentation (proximal hooks and distal pedicle screws), instrumentation with pedicle screws allows for better correction of spinal deformities in the coronal, sagittal and rotational planes, less correction loss, shorter constructions and improved lung function without increasing neurological complications [7, 8].

Due to peculiar vascular and neurologic anatomical features of the vertebrae and spinal canal, caution is needed during insertion of pedicle screws. For safety reasons, it is of utmost importance to ensure precise insertion and to confirm an intraosseous position [9]. Intraoperative neurophysiologic monitoring during pedicle instrumentation allows the early detection and prevention of neurological complications [10, 11]. Motor evoked potentials, somatosensory evoked potentials, free-running electromyography (EMG) and stimulated EMG can be used as monitoring techniques. Furthermore, stimulated EMG can be applied directly to the inserted screws [12].

In patients with scoliosis, rotational deformity increases the risk of perforating the pedicle cortical wall, which is not always easy to detect during surgical procedures. Intraoperative assessment of the position of the screws with conventional radiography or fluoroscopy can help detect misplaced implants, although computed tomography (CT) provides greater accuracy [13]. EMG can provide additional information to establish a link between the implants and neural elements.

However, the diagnostic accuracy of intraoperative EMG to detect pedicle screw malposition is not well understood. The aim of this study, therefore, was to investigate the relationship between EMG thresholds during AIS surgery and the positioning of pedicle screws as evaluated by CT in the postoperative period. The initial hypothesis was that lower EMG thresholds would be observed for screws at higher risk for nerve injury.

Methods

Design, setting, participants and ethics

This was an observational, cross-sectional study involving patients with AIS who underwent surgical treatment in the same hospital and in whom intraoperative EMG measurements were compared with the implant positions evaluated by CT. The Hospital dos Servidores Estaduais institutional review board approved this study, approval number 19134914.2.0000.5463 .

All consecutive patients who underwent surgery performed by the same surgical team in the same institution from March to December 2013 were included in the study. Patients were excluded if they had scoliosis with a known etiology (i.e., not AIS), if they were undergoing revision surgery, or if no postoperative CT was available for review.

All patients were operated by a posterior approach, with insertion of pedicle screws from the same manufacturer (DePuy, Synthes, Raynham, MA, USA) by the "free hand" technique [9] and under intravenous anesthesia [14]. Neurophysiological monitoring was employed in all surgeries using the same technique and device.

Variables and measurements

After pedicle screw insertion, EMG was performed by directly stimulating the implants, using a monopolar electrode (cathode) and a subdermal needle electrode inserted into the paravertebral musculature (anode). Stimulation was performed with a frequency of 3 Hz, a duration of 0.1 ms and an increasing intensity until an EMG response could be observed [12]. The maximum intensity used was 30 milli-amperes (mA). For each screw, the lowest intensity able to generate a measurable response was recorded as the EMG threshold for that screw. If no response was observed, a value of 30 was assigned to that screw.

Within three months of surgery, patients underwent CT to evaluate the implant positioning and classification according to the criteria proposed by Abul-Kasim et al. [15]. This grading system was developed to distinguish between lateral, medial and anterior cortical perforations and foraminal perforation and is based on whether the cortical violation is partial or total rather than the length (mm) of the perforation.

Each individual screw to the corresponding pedicle was assessed and classified in both the medial and sagittal planes as follows: normally placed in the medial plane; medial cortical perforation (MCP) grade 1, partially medialized; MCP grade 2, totally perforating the medial pedicular cortex; lateral cortical perforation (LCP) grade 1, partially lateralized but anchored in the vertebral body; LCP grade 2, abutting the outer cortex of the vertebral body and not anchored in the vertebral body; normally placed in the sagittal plane; perforating the inferior underlying neural foramen (INF); or perforating the superior underlying neural foramen (SUP). Additionally, screws classified as MCP grade 1 or MCP grade 2 in the axial plane and as perforating the INF or the SUP in the sagittal plane were considered “at risk for nerve injury” (ARNI), as these screws are closer to neural elements. Screws classified as normally placed and screws classified as LCP, although recognized as misplaced, were considered “no risk for nerve injury” (NRNI).

Bias control

The total intravenous technique (TIVA) was used to induce anesthesia in the AIS surgeries, and medications that usually do not interfere with intraoperative neurophysiological monitoring (propofol and remifentanil) were administered. All AIS corrections included in this study were performed by the same surgical team, using the same techniques for surgery and electromyography evaluation. All CT scans were evaluated by the same observer (BMG).

Statistical analysis

Continuous variables are presented as the mean and standard deviation, and categorical data are presented as absolute and relative frequencies. A descriptive analysis of the positioning of all screws was performed. To evaluate the diagnostic accuracy of EMG for predicting screws ARNI, we excluded all screws inserted above T6, as those pedicles have lower reliability for EMG acquisition [16]. A single patient contributed multiple sampling units (screws) to the analysis, resulting in a hierarchical structure of the generated data, with subjects as the primary sampling units and individual screws as the secondary sampling units. The association between the EMG threshold recorded intraoperatively and postoperative screw status, considering the risk for nerve injury, was investigated using generalized estimating equations (GEEs). Only medial cortical perforation of the screw (MCP grade 1 or MCP grade 2) was considered a positive outcome (ARNI) in the axial plane, while both superior or inferior deviation of the screw were considered positive outcomes in the sagittal plane. These statistical models are similar to logistic regression models but take into account the hierarchical structure of the data.

The diagnostic accuracy of EMG for predicting screw malposition was investigated using a receiver operating characteristic (ROC) curve. The curve represents a plot of the sensitivity and specificity at progressive cutoffs of a diagnostic test measured on a continuous scale. Therefore, the area under the curve (AUC) is a measure of the ability of EMG to discriminate between screws ARNI and screws NRNI. Estimates of diagnostic accuracy, including sensitivity (Sn), specificity (Sp), negative predictive value (NPV) and positive predictive value (PPV), were calculated for cutoffs at every 5 mA and are presented with their 95% confidence intervals (95%CI). All statistical analyses were performed using the statistical package STATAÒ 14 (StataCorp, TX/EUA). Associations with p<.05 (two-sided) were considered significant.

Results

In the study period, 16 patients underwent surgical treatment for AIS and were included in this study. Most (12 or 75%) were female, and the average age was 16.6 years (varying from 11 to 26 years). The patients were followed-up for at least three months, and no patient had neurological complaints, experienced irradiated pain to dermatomes or exhibited any observed change in the physical exam indicating nerve injury.

Among the 16 patients, a total of 281 pedicles were analyzed for screw position according to the Abul-Kasim et al. [15] criteria, as shown in Table 1. In the axial plane, 195 screws were in the ideal position (69.4%). There was lateral cortical perforation in 41 cases of which 25 (8.9%) were classified as LCP1, and 16 (5.7%), as LCP2. Medial cortical perforation was found in 45 cases (27 [9.6%] were MCP1, and 18 [6.4%] were MCP2). In the sagittal plane, 226 pedicle screws were in the ideal position (80.4%), while 48 (17.1%) violated the inferior foramen (FP1 INF), and 7 (2.5%), the superior foramen (FP1 SUP). Considering axial and sagittal planes together, 59.1% (166/281) of all screws had no cortical perforation (lateral, medial or superior or inferior foramens), representing ideal positions, while 40.9% (115/281) of screws showed at least one degree of cortical perforation (Table 2).

Table 1 Summary of the positions of the pedicle screws in the axial and sagittal planes for each patient and the total pedicles analyzed

Axial plane

Patient	LCP 2		LCP 1		LCP 0/MCP 0		MCP 1		MCP 2		Total
	n	%	n	%	n	%	n	%	n	%	
1	4	15.4	0,	0.0	17	65.4	3	11.5	2	7.7	26
2	0	0.0	2	10.5	14	73.7	3	15.8	0	0.0	19
3	1	6.7	1	6.7	13	86.7	0	0.0	0	0.0	15
4	0	0.0	1	6.2	9	56.2	3	18.8	3	18.8	16
5	0	0.0	2	9.1	15	68.2	3	13.6	2	9.1	22
6	0	0.0	0	0.0	10	55.6	6	33.3	2	11.1	18
7	1	6.2	2	12.5	10	62.5	1	6.2	2	12.5	16
8	1	5.0	3	15.0	13	65.0	1	5.0	2	10.0	20
9	1	8.3	2	16.7	8	66.7	1	8.3	0	0.0	12
10	2	11.1	1	5.6	12	66.7	2	11.1	1	5.6	18
11	1	5.6	3	16.7	12	66.7	1	5.6	1	5.6	18
12	2	11.1	2	11.1	11	61.1	2	11.1	1	5.6	18
13	0	0.0	2	10.5	14	73.7	1	5.3	2	10.5	19
14	3	16.7	3	16.7	12	66.7	0	0.0	0	0.0	18
15	0	0.0	1	7.1	13	92.9	0	0.0	0	0.0	14
16	0	0.0	0	0.0	12	100.0	0	0.0	0	0.0	12
Total	**16**	**5.7**	**25**	**8.9**	**195**	**69.4**	**27**	**9.6**	**18**	**6.4**	**281**

Sagittal plane

Patient	FP 1 (inf.)		FP 0		FP 1 (sup.)		Total
	n	%	n	%	n	%	
1	0	0,0	26	100.0	0	0.0	26
2	1	5.3	17	89.5	1	5.3	19
3	4	26.7	11	73.3	0	0.0	15
4	6	37.5	10	62.5	0	0.0	16
5	1	4.5	18	81.8	3	13.6	22
6	9	50.0	9	50.0	0	0.0	18
7	4	25.0	12	75.0	0	0.0	16
8	0	0.0	18	90.0	2	10.0	20
9	0	0.0	12	100.0	0	0.0	12
10	5	27.8	13	72.2	0	0.0	18
11	8	44.4	10	55.6	0	0.0	18
12	6	33.3	12	66.7	0	0.0	18

13	2	10.5	17	89.5	0	0.0	19
14	0	0.0	18	100.0	0	0.0	18
15	1	7.1	13	92.9	0	0.0	14
16	1	8.3	10	83.3	1	8.3	12
Total	**48**	**17.1**	**226**	**80.4**	**7**	**2.5**	**281**

Table 2 Summary of the ideal screw positioning in the sagittal and axial planes and inadequate positioning in any of the planes

Patient	**FP 0 and LCP 0/MCP 0**		**FP or LCP/MCP≠0**		**Total**
	n	%	n	%	
1	17	65.4	9	34.6	26
2	13	68.4	6	31.6	19
3	10	66.7	5	33.3	15
4	7	43.8	9	56.2	16
5	14	63.6	8	36.4	22
6	6	33.3	12	66.7	18
7	6	37.5	10	62.5	16
8	13	65.0	7	35.0	20
9	8	66.7	4	33.3	12
10	9	50.0	9	50.0	18
11	8	44.4	10	55.6	18
12	8	44.4	10	55.6	18
13	13	68.4	6	31.6	19
14	12	66.7	6	33.3	18
15	12	85.7	2	14.3	14
16	10	83.3	2	16.7	12
Total	**166**	**59.1**	**115**	**40.9**	**281**

Below T6, 226 pedicles were considered in the EMG accuracy study (Table 3). In the axial plane, 204 (90.3%) screws were considered NRNI, of which 136 (60.2%) were ideally positioned and 68 (30.1%) had LCP, and 22 (9.7%) screws were considered ARNI with MCP. In the sagittal plane, 183 (81%) pedicle screws were considered NRNI, while 43 (19%) violated the inferior foramen (FP1 INF) or the superior foramen (FP1 SUP) and were considered ARNI.

Table 3 Pedicle screws considered in the EMG accuracy diagnostic study

	N	%	
Total	*226*	*100.00*	
Axial Plane			
LCP0	36	15.9	NRNI - 204 (90.3%)
LCP1	19	8.4	
LCP2	13	5.8	
MCP0	136	60.2	
MCP1	16	7.1	ARNI - 22 (9.7%)
MCP2	6	2.6	
Sagittal Plane			
FP0	183	81	NRNI - 183 (81%)
FP1 (SUP)	38	16.8	ARNI - 43 (19%)
FP1 (INF)	5	2.2	

We observed a statistically significant association between EMG responses at lower intensities and the positioning of screws associated with risk for nerve injury. Overall, a 1-mA decrease in the EMG threshold was associated with a 12% increase in the odds of the screw position ARNI (OR=1.12; 95% CI=1.06-1.18; p<.001). In the axial and sagittal planes, the ORs were 1.09 (95% CI=1.03-1.16; p=.005) and 1.12 (95%CI=1.04-1.2; p=.004), respectively.

However, the ROC curves showed that EMG had a poor to moderate ability to discriminate between screws ARNI and NRNI. The AUCs for the axial, sagittal and combined planes were .65 (95% CI=.57-.74), .63 (95% CI=.51-.75) and .65 (95% CI=.55-.75), respectively. Table 4 shows the performance estimates of EMG for predicting screws positioned ARNI in our sample. At every threshold cutoff evaluated, the PPV of EMG for predicting screws ARNI was very low; the highest PPV was 18% with a threshold cutoff of 25 mA. The PPV was always slightly higher for predicting screws ARNI in the sagittal plane than in the axial plane. In contrast, there was a moderate to high NPV (78%-93%) for every cutoff analyzed (Table 4).

Table 4 EMG accuracy as a diagnostic criterion considering different threshold cutoffs

EMG Threshold Cutoff	OVERALL	AXIAL	SAGITAL
10	Sn: 18% (9-30%) Sp: 100% (98-100%) NPV: 78% (72-83%) **PPV: 10% (5-17%)**	Sn: 14% (3-35%) Sp: 97% (93-99%) NPV: 90% (86-94%) **PPV: 3% (1-8%)**	Sn: 21% (10-36%) Sp: 99% (97-100%) NPV: 83% (78-88%) **PPV: 9% (4-16%)**
15	Sn: 38% (25-51%) Sp: 85% (78-90%) NPV: 80% (73-86%) **PPV: 15% (10-22%)**	Sn: 32% (14-55%) Sp: 80% (74-86%) NPV: 91% (86-95%) **PPV: 5% (2-10%)**	Sn: 42% (27-58%) Sp: 84% (78-89%) NPV: 86% (80-90%) **PPV: 13% (8-20%)**
20	Sn: 48% (35-62%) Sp: 72% (65-79%) NPV: 81% (74-87%) **PPV: 16% (11-23%)**	Sn: 50% (28-72%) Sp: 69% (62-75%) NPV: 93% (87-96%) **PPV: 7% (3-11%)**	Sn: 49% (33-65%) Sp: 71% (64-77%) NPV: 86% (79-91%) **PPV: 13% (8-18%)**
25	Sn: 70% (56-81%) Sp: 48% (40-55%) NPV: 83% (74-90%) **PPV: 18% (13-23%)**	Sn: 68% (45-86%) Sp: 45% (38-52%) NPV: 93% (86-97%) **PPV: 7% (4-11%)**	Sn: 67% (51-81%) Sp: 46% (39-53%) NPV: 86% (77-92%) **PPV: 13% (9-18%)**

Discussion

AIS is a complex three-dimensional deformity associated with rotation and structural abnormalities of the vertebrae, making treatment technically challenging. Implants for pedicle fixation have been widely used in surgical treatments of the thoracic and lumbar spine, with better results in arthrodesis rate, correction power and early mobilization of the patient compared with fixation systems that employ hooks or mixed systems [17, 18] . Neurological complications due to incorrect positioning of pedicle screws is rare, comprising 0.9% of cases as described in the literature [19, 20]. In this study, we analyzed the occurrence of pedicle screw misplacement in a specific pathology, AIS. Additionally, we evaluated the accuracy of EMG as a diagnostic tool to predict screws ARNI in AIS surgery.

Pedicle screw misplacement is detected in 3% to 44% of cases in the literature [20], and in this study, the rate was 40.9%. Screws with LCP are associated with risk of vascular or visceral damage [2, 9, 21, 22]. In the present series, 14.6% of screws had LCP, in line with the literature [2, 21, 22], and no cases were associated with complications. For MCP, misplacement rates of 1.4% to 14% have been reported in the literature [2, 9, 22], reaching 28% in one series [23]. In the present study, 16% of screws had MCP according to postoperative CT. There are limited data in the literature describing the misplacement of pedicle screws in the sagittal plane with superior or inferior cortical perforation.

Intraoperative neurophysiology evaluation can allow the early detection and correction of possible lesions during spinal surgery. Such techniques include the evaluation of motor evoked potentials, somatosensory evoked potentials and EMG [10, 11]. The role of the EMG stimulus in the early identification of pedicle cortical perforation has been established for lumbar pedicles. Thresholds below 4 or 5 mA are suggestive of perforation [10], while thresholds above 15 mA indicate correct positioning of screws [24]. However, the correlation between EMG thresholds and screw positioning in thoracic pedicles has not yet been well established.

In evaluating the accuracy of EMG as an intraoperative diagnostic method to detect misplaced screws ARNI, there was a statistically significant association between EMG responses and the positioning of screws associated with risk for nerve injury. A decreased EMG threshold was associated with an increased odds of screw position ARNI among thoracic and lumbar screws. The association between EMG threshold and screw misplacement in thoracic pedicles was recently shown using pulse-train stimulation [25]. The previous study only evaluated the association between EMG stimulation and screw position in the axial plane with MCP, while the present study evaluated both the axial and sagittal planes.

Despite the association found between EMG and the position of screws, the ability of EMG to intraoperatively discriminate between screws ARNI and NRNI was poor to moderate. NPV and PPV are the most meaningful measures of diagnostic accuracy in terms of making clinical decisions based on a test result. NPV expresses the probability of not having the condition under study given a negative test outcome, and PPV expresses the probability of having the condition given a positive test outcome. EMG showed a very low PPV (<18%) at every threshold cutoff evaluated, meaning that less than 1 out of 5 screws that test positive (achieving an electrical response at a threshold lower than the cutoff) would actually be positioned ARNI.

Considering the risk for neurological deficit or stenosis of the spinal canal if a screw breaches the medial wall during thoracic pedicle screw instrumentation in AIS surgery, the consequences of a false-negative result of a diagnostic test for screw malposition can be severe [25]. Therefore, it is imperative that the diagnostic test detect true positives and minimize false negatives, as represented by a high NPV. The present study revealed a moderate to high NPV of EMG as diagnostic test for every cutoff analyzed, and thus, EMG may be considered an accurate test to minimize false-negative screws ARNI.

Conclusions

Despite the association found between intraoperative EMG monitoring and the position of pedicle screws in patients with AIS, EMG exhibited poor accuracy as a diagnostic test for predicting screws ARNI. However, EMG was shown to be effective for minimizing false-negative screws ARNI.

List Of Abbreviations

EMG - Electromyography

AIS - Adolescent idiopathic scoliosis

CT – Computer Tomography

ARNI - At risk for nerve injury

NRNI - No risk for nerve injury

ROC - Receiver operating characteristic

MCP - medial cortical perforation

LCP - Lateral cortical perforation

INF - Inferior underlying neural foramen

SUP - Superior underlying neural foramen

TIVA - Total intravenous technique (TIVA)

Declarations

Ethics approval and consent to participate

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Consent for publication

Not Applicable

Availability of data and material

Not Applicable

Competing interests

All Authors declare that they have no conflict of interest.

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Authors' contributions

CEGB – Writing + design

BMG – Writing

BNB – Statistics

FEP – Colecting Data

CEO – Colecting Data + writing + design

RRP – Writing + design

RRF – Neuro and ENMG writing and Design

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