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# Effectiveness of EMG use in pedicle screw placement for thoracic spinal deformities

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## ABSTRACT

**Study design:** Systematic review.

**Objective:** To determine the effectiveness of using electromyography (EMG) during intraoperative pedicle screw placement in patients with thoracic deformity.

**Methods:** A systematic review of the English-language literature was undertaken for articles published between 1970 and July 2011. For our first question, we identified all articles that were designed to evaluate the diagnostic test characteristics (ie, measures of validity such as sensitivity, specificity, positive predictive value [PPV], negative predictive value [NPV]) of EMG for thoracic deformities in adolescent and adult patients. For our second question, we attempted to identify all articles that reported complication rates (pedicle wall breach or new neurological event) after pedicle screw placement in the same population comparing patients who did and did not undergo intraoperative EMG. Articles were excluded if they did not report or give raw data to calculate at least one of the four primary diagnostic test characteristics: sensitivity, specificity, PPV, or NPV for study question one. Articles were excluded if they did not have a “no EMG” control group for study question two. Other exclusions were reviews, editorials, case reports, non-English written studies, and animal studies. We rated the overall body of evidence with respect to each key question using a modified Grades of Recommendation Assessment, Development and Evaluation (GRADE) system for diagnostic and therapeutic studies.

**Results:** The overall strength of evidence evaluating the diagnostic characteristics was low due to inconsistent findings between studies and uncertainty of the impact of false-negatives. The fairly low sensitivity may lead to a high-false negative rate. It is unclear what the impact of false-negatives would be since no neurological injuries were identified in the studies summarized. A higher specificity would suggest a fairly low false-positive rate; however, the rates could be as high as 30%. If sudden changes in treatment are required in the absence of any adverse event, this could be considered a limitation of such testing. The overall strength of evidence for evaluating the efficacy of EMG compared with no EMG was insufficient because of literature shortage on this topic.

**Conclusion:** The overall strength of evidence evaluating the diagnostic characteristics was low due to inconsistent findings between studies and uncertainty of the impact of false-negatives. Given the low sensitivity and potential high rate of false-negatives, pedicle wall breaches may occur, without EMG notification. These undetected breaches may lead to loose or weak screw position which may lead to neurovascular complications during or after a translation-rotation maneuver, especially in rigid deformities. The higher sensitivity would suggest a lower rate of false-positives. We recommend considering the use of intraoperative EMG-monitoring method to help identify potential complications based upon available technology, personal experiences and preferences; however, surgeons should keep in mind that false-positive results may lead to increased surgery time and increased blood loss. The surgeon should not depend solely on EMG since it can also render false-negatives.

## STUDY RATIONALE AND CONTEXT

The correction of spinal deformity is a challenge for the spine surgeon. Although pedicle screw construct has been widely accepted as the choice of instrumentation for the correction of spinal deformities, some surgeons avoid using pedicle screws in the thoracic region for spinal deformities because of the rotation and unique anatomy of the thoracic spine that may lead to neural and vascular injury. Due to the potential risk of injury to neural and vascular structures, different methods (anatomical landmarks, intraoperative monitoring, etc) have been developed to guide the surgeon to increase the accuracy of pedicle screw placement [1]. Intraoperative electromyography (EMG) testing is a method used more frequently in the last decade. However, EMG monitoring is still in progress as is reflected in the variable results reported in the literature [2]. To our knowledge, no systematic review has been performed to evaluate intraoperative EMG for thoracic deformities. The primary purpose of this systematic review was to review the efficacy of intraoperative EMG monitoring in patients with thoracic deformity.

## OBJECTIVES

For adolescent and adult patients undergoing pedicle screw placement for thoracic deformity, what are the diagnostic characteristics (ie, sensitivity, specificity, positive predictive value [PPV], negative predictive value [NPV]) of using EMG to identify misplacement? For adolescent and adult patients undergoing pedicle screw placement for thoracic deformity, does intraoperative EMG reduce the rate of a new or worsening neurological event or pedicle wall breach compared with no EMG?

## MATERIALS AND METHODS

*Study design:* Systematic review.

## SAMPLING

*Search:* PubMed, Cochrane Collaboration Database and bibliographies of key articles.

*Dates searched:* 1970 to July 2011.

*Common inclusion criteria for both questions:* (1) Corrective surgery for deformity; (2) thoracic spine; (3) adults and adolescents; (4) EMG.

*Inclusion criteria for question 1:* (1) Reference standard: pedicle wall breach, violation, perforation, or penetration; new or worsening neurological deficit; (2) sensitivity, specificity, PPV, NPV.

*Inclusion criteria for question 2:* (1) EMG versus no EMG; (2) pedicle wall breach; and (3) new or worsening neurological event.

*Common exclusion criteria for both questions:* (1) >20% of population including non-deformity (stenosis, trauma, fracture, degenerative conditions, tumor, and/or infection); (2) lumbar or cervical spine only; and (3) cadaver or non-human studies.

*Exclusion criteria for question 1:* (1) No reference standard; (2) no report of sensitivity, specificity, PPV, or NPV or lack of raw data to calculate these.

*Exclusion criteria for question 2:* Lack of a no EMG control group.

*Analysis:* (1) Diagnostic characteristics were reported if stated by authors; otherwise, they were calculated if the raw data was available; (2) rate of pedicle wall breach or new neurological events were reported from each manuscript or calculated from raw data; (3) data was pooled among studies and mean rates of pedicle wall breach or new neurological events and diagnostic characteristics were weighted by study sample size.

*Overall strength of evidence:* For evaluating the risk of bias in individual diagnostic studies, we rated the level of evidence using the rating scheme developed by the Oxford Centre for Evidence-based Medicine and used with modification by *The Journal of Bone and Joint Surgery American*. (A more detailed description can be found in the Web Appendix at [www.aospine.org/ebsj](http://www.aospine.org/ebsj).) After individual article evaluation, the overall body of evidence with respect to each key question was determined based on modified precepts outlined by the Grades of Recommendation Assessment, Development and Evaluation (GRADE) system.

## RESULTS

We identified eight studies [1, 3–9] meeting our inclusion criteria for question 1 (**Fig 1**). All studies reported corrective surgery with the use of pedicle screw performed for thoracic deformity. Reported age populations varied as four studies involved adolescents only (n = 179) [4–6, 8] one study involved adults only (n = 7) [3], two studies involved both adolescents and adults (n = 101) [1, 9] and one study did not report age of patients (n = 50) [7]. Studies varied in what they used as a threshold for indicating a high potential for medial pedicle wall breach. Five studies used a threshold level of <6 mA [1,4,5,7,8], one used a level of <7 mA [9]; one used a level of <12 mA [6]; and one used a threshold of <15 mA [3]. There was not enough data available to evaluate diagnostic characteristics by threshold level. Details of each study are presented in **Tables 1 and 2**. We did not identify any studies to answer our second study question evaluating complication rates during pedicle screw placement for thoracic spinal deformity comparing EMG monitoring with no EMG monitoring.

### Rates of pedicle wall breach, medial pedicle wall breach, and new or worsening neurological event

- All eight studies [1, 3–9] reported if there was a pedicle wall breach. The mean pedicle wall breach rate was 11.6% (range, 0–53.4%).
- Seven studies [1, 3, 5, 6, 8, 9] reported if there was a medial pedicle wall breach. The mean medial pedicle wall breach rate was 5.6% (range, 0–16.5%).
- Seven of eight studies [1, 4, 5, 7–9] reported if there was a new or worsening neurological event. None of these studies reported a neurological event (0%).

### Diagnostic characteristics

- All eight studies [1, 3–9] reported the sensitivity of identifying a pedicle wall breach. The weighted mean sensitivity was 55.0% across studies (range, 0–100%).
- Six studies [1, 3, 4–7] reported the specificity. The weighted mean specificity was 82.1% across studies (range, 70.1–100%).
- Five studies [1, 3, 8] reported the PPV. The weighted mean PPV was 36.2% across studies (range, 21–100%).
- Six studies [1, 3, 7] reported the NPV. The weighted mean NPV was 93.9% (range, 75–100%).
- The overall strength of evidence evaluating the diagnostic characteristics was low due to inconsistent findings between studies and uncertainty of the impact of false-negatives (**Table 3**).
- The fairly low sensitivity may lead to a high false-negative rate. It is unclear what the impact of false-negatives would be since no neurological injuries were identified in the studies summarized.

- A higher specificity would suggest a fairly low false-positive rate; however, the rates could be as high as 30%. If sudden changes in treatment are required in the absence of any adverse event, this could be considered a limitation of such testing.
- The overall strength of evidence for evaluating the efficacy of EMG compared with no EMG was insufficient because of literature shortage on this topic (**Table 3**).

## DISCUSSION

- Intraoperative EMG monitoring for detection of pedicle wall violation has been favored over the last decade.
- The success of EMG depends on the electricity conductivity of the intraoperative environment which hinge on various factors. In addition, there is still no consensus on which technique and which muscles to use, especially for the upper thoracic region [6].
- Our review showed that the weighted mean rate of a pedicle wall breach across studies was relatively low (11.6%). The 11.6% includes all four sides of the wall and the tip of the screw, which did not lead to clinically apparent complications in the studies reviewed. More serious medial wall breaches were even more rare (5.6%); however, this is still an alarming rate when considering the devastating complications that could occur as a result of a medial wall breach.
- Our review also showed that the sensitivity and PPV for identifying breaches using intraoperative EMG monitoring were relatively low (weighted means of 55% and 36.2%, respectively).
- The specificity and NPV were higher (82.1% and 93.9%, respectively).
- The overall strength of evidence evaluating the diagnostic characteristics was low due to inconsistent findings between studies and uncertainty of the impact of false-negatives.
- We recommend considering the use of intraoperative EMG-monitoring method based on available resources and personal experiences, but not based upon present-day literature, to help prevent potential complications caused by pedicle wall breaches; however, surgeons should keep in mind that false-positive results may lead to increased surgery time and increased blood loss. The surgeon should not depend solely on EMG since it can also give false-negative results. Other measures of identification should be used.

**Table 1** Study question 1: studies assessing the diagnostic characteristics of EMG use in pedicle screw placement for thoracic deformity.\*

Author, y	Study design	Population	Diagnosis	Treatment	EMG method(s)	Reference standard	Results	Diagnostic characteristics
Donohue et al [3] (2008)	Prospective cohort	N = 7 patients (116 thoracic and L1 screws) Mean age: 49.8 (range, 36–69) y Male: 43%	– 7 scoliosis – 3 also had a significant kyphotic deformity	Corrective surgery: posterior spinal instrumentation and fusion	Monitoring EMG: – Screws were placed in the thoracic spine and monitored from multiple lower-limb muscles by use of a single-pulse stimulus based on a $\leq 15$ mA threshold High-energy pulse trains: – During probing, constant-current, high-frequency 4-pulse stimulus trains were delivered through the ball-tipped probe	Medial pedicle wall breach, confirmed by CT	– 19 (16.4%) of 116 screws breached the pedicle wall – 18/19 had EMG $\leq 15$ mA when tested with ball-tipped probe – 8 (42%) of 19 failed to elicit any lower limb EMG when tested with direct screw stimulation – Probe, mean threshold for medial breaches: $7.9 \pm 4.6$ mA – Screw, mean threshold: $19.8 \pm 5.3$ mA	For probe-based stimulation, based on $\leq 15$ mA threshold: – 18 true-positive – 1 false-negative – 29 false-positive – 68 true-negative – Sensitivity: 94.7% – Specificity: 70.1% – PPV = 38.3% – NPV = 98.6% †Hand calculated  For direct screw stimulation based on $\leq 15$ mA threshold: – 11 true-positive – 8 false-negative – 16 false-positive – 81 true-negative – Sensitivity: 57.9% – Specificity: 83.5% – PPV = 40.7% – NPV = 91.0% *Hand calculated
Duffy et al [4] (2010)	Retrospective cohort analysis	N = 30 patients (329 screws: 195 thoracic and 134 lumbar) Mean age: 14.8 (range, 4–18) y Male: NR	– 2 congenital scoliosis – 4 juvenile scoliosis – 4 neuromuscular scoliosis – 20 adolescent idiopathic scoliosis	Corrective surgery for pediatric deformities	Triggered EMG: – Screws were placed in thoracic and lumbar spine while using electrical stimulation based on a 6 mA threshold	Pedicle breach, confirmed by CT	– Overall accuracy of 93% – Thoracic: 91.3% – Lumbar: 95.5% – With no pedicle breach, overall accuracy was 77.8% – Thoracic: 73.8% – Lumbar: 83.6% – The lowest interobserver reliability of the CT classification was substantially high ( $\kappa = 0.804$ ) – No patient experienced postoperative neurological, vascular or respiratory complications	– If an acceptable screw was defined as intrapedicular or $\leq 2$ mm breach: – Sensitivity: – Thoracic = 11.8% – Lumbar = 67% – Specificity: – Thoracic = 91.2% – Lumbar = 94.5% – NPV: – Thoracic = 0.92 – Lumbar = 0.93 – Negative likelihood ratios – Thoracic = 0.96 – Lumbar = 0.35 – Positive likelihood ratios – Thoracic = 1.4 – Lumbar = 12.5 – If only intrapedicular screws were acceptable: – Sensitivity: – Thoracic = 14.0% – Lumbar = 36.4% – Specificity: – Thoracic = 92.4% – Lumbar = 97.3% – NPV: – Thoracic = 0.75 – Lumbar = 0.89 – This means that 14% of screws deemed intrapedicular by EMG (mA $\geq 6$ ) were not on CT evaluation
Minetal [5] (2011)	Prospective cohort	N = 7 adolescent patients (103 screws –T5-L3: 80 thoracic: – T5: 14 – T6: 8 – T7: 10 – T8: 10 – T9: 9 – T10: 9 – T11: 9 – T12: 11 23 lumbar: – L1: 12 – L2: 5 – L3: 6) Mean age: 12.6 (range, 11–17) y Male: NR	– All adolescent idiopathic scoliosis (AIS)	Deformity correction surgery for AIS	Triggered EMG: – Screws placed from T5 to T12 were recorded from abdominal muscles and assessed based on $< 6$ mA threshold – Screws placed from L1–L3 were recorded from the internal oblique, adductor longus, and vastus medialis muscles	Breached medial pedicle wall as confirmed by CT	– Medial pedicle cortex was intact for 98 (95%) of 103 screws with stimulation thresholds $\geq 6$ mA – 10 screws (9.7%) breached the pedicle cortex, however only 5 were medial – 100% screws were $\geq 6$ mA – No postoperative neurological deficits or neurological pain in any patients	Based on $< 6$ mA threshold: – Sensitivity = 0% – Specificity = 100% – PPV = N/A – NPV = 95.1%

**Table 1 (cont)** Study question 1: studies assessing the diagnostic characteristics of EMG use in pedicle screw placement for thoracic deformity.\*

Author, y	Study design	Population	Diagnosis	Treatment	EMG method(s)	Reference standard	Results	Diagnostic characteristics
Raynor et al [11] (2002)	Prospective cohort study	N = 92 consecutive patients (677 screws T6–T12) Mean age: 2 (range, 6–83) y Male: NR	<ul style="list-style-type: none"> <li>Adolescent idiopathic scoliosis: 50</li> <li>Adult scoliosis: 10</li> <li>Scheuermann's kyphosis/kyphoscoliosis: 8</li> <li>Infantile/juvenile onset scoliosis: 7</li> <li>Flatback/transition syndrome: 6</li> <li>Vertebral fracture: 4</li> <li>Ankylosing spondylitis: 2</li> <li>Hemivertebrae resection: 1</li> <li>Marfan syndrome: 1</li> <li>Osteomyelitis: 1</li> <li>Spinal tumor: 1</li> <li>Syringomyelia: 1</li> </ul>	Corrective surgery using thoracic pedicle screws	Triggered EMG: <ul style="list-style-type: none"> <li>Screws placed from T6–T12 were evaluated using an ascending method of stimulation within the rectus abdominis</li> <li>Resistance to current flow was measured and outcomes were assessed based on a threshold of 6 mA</li> </ul>	Medial wall perforations confirmed by tactile or visual inspection	<p>Group A:</p> <ul style="list-style-type: none"> <li>650 screws (96.0%)</li> <li>Mean: 16.8 mA (range, 6.3–90.0 mA)</li> <li>Accurately placed within the pedicle</li> </ul> <p>Group B:</p> <ul style="list-style-type: none"> <li>21 screws (3.1%)</li> <li>Mean: 5.1 mA (range, 3.9–5.9 mA; SD, 0.5 mA)</li> <li>Mean decrease of 54% (range, 34.7–71.07%; SD, 11.64%) from the mean of all other screws in the same patient</li> <li>All were appropriately placed and had intact pedicle boards</li> <li>All 21 screws were replaced after reexamination</li> </ul> <p>Group C:</p> <ul style="list-style-type: none"> <li>6 screws (0.9%)</li> <li>Mean: 4.2 mA (range, 3.1–5.5 mA; SD, 1.09 mA)</li> <li>Mean decrease of 68.9% (range, 46.1–80.7%; SD, 12.44%) from the mean of all other screws in the same patient</li> <li>Perforated the medial pedicle wall</li> <li>These 6 screws were removed and not replaced</li> <li>No postoperative neurological deficits or complaints of radicular chest wall pain that could indicate thoracic nerve root irritation were reported</li> </ul> <p>Statistically significant (<math>P = .016</math>)</p>	<p>Based on &lt;6 mA threshold:</p> <ul style="list-style-type: none"> <li>6 true-positive</li> <li>0 false-negative</li> <li>21 false-positive</li> <li>650 true-negative</li> <li>Sensitivity: 100%</li> <li>Specificity: 96.9%</li> <li>PPV = 22%</li> <li>NPV = 100%</li> </ul> <p>Hand calculated</p>
Regidor et al [6] (2011)	Prospective cohort	N = 92 consecutive patients (248 screws T2–T6) Mean age: NR Male: NR	Adolescent idiopathic scoliosis (AIS)	Corrective surgery using thoracic screws for AIS	Triggered EMG: <ul style="list-style-type: none"> <li>Screws placed from T2–T6 were evaluated using a single electrode placed at the axillary midline</li> <li>Outcomes were assessed based on a 12 mA threshold</li> </ul>	Violation of the pedicle medial cortex as confirmed by CT scan	<ul style="list-style-type: none"> <li>46 (18.5%) of 248 screws were malpositioned</li> <li>24 (9.7%) breach of pedicle medial cortex</li> <li>6 (2.4%) were located inside the spinal canal</li> <li>5 (2%) were placed too laterally, outside the pedicle</li> <li>11 (4.4%) screws removed during surgery</li> <li>Mean EMG threshold: <ul style="list-style-type: none"> <li>24.44 ± 11.30 mA for well-positioned screws</li> <li>17.98 ± 8.24 mA (<math>P &lt; .01</math>) for screws violating the pedicle medial cortex</li> <li>10.38 ± 3.33 mA (<math>P &lt; .001</math>) for screws inside the spinal canal</li> </ul> </li> <li>Using a 12 mA threshold, <ul style="list-style-type: none"> <li>21 (47.7%) of 44 screws with &lt;12 mA threshold were malpositioned</li> <li>&gt;12 mA screws were correctly positioned in 87.9% of cases</li> </ul> </li> <li>No postoperative neurological deficits or complaints of radicular chest wall pain</li> </ul>	<p>Based on &lt;12 mA threshold:</p> <ul style="list-style-type: none"> <li>21 true-positive</li> <li>25 false-negative</li> <li>20 false-positive</li> <li>182 true-negative</li> <li>Sensitivity: 45.7%</li> <li>Specificity: 90.1%</li> <li>PPV = 51.2%</li> <li>NPV = 87.9%</li> </ul> <p>Hand calculated</p>

**Table 1 (cont)** Study question 1: studies assessing the diagnostic characteristics of EMG use in pedicle screw placement for thoracic deformity.\*

Author, y	Study design	Population	Diagnosis	Treatment	EMG method(s)	Reference standard	Results	Diagnostic characteristics
Rodriguez-Olaverri et al [7] (2008)	Prospective cohort study	N = 50 consecutive patients (31 screws T3–T6) Mean age: NR Male: NR	NR	Corrective surgery using thoracic screws for posterior spinal fusions	Triggered EMG: – Screws placed from T3–T6 were evaluated using an ascending method of stimulation within the intercostals muscles – Resistance to current flow was measured and outcomes were assessed based on a threshold of 6 mA or a 60–65% decrease from the mean	Cortical violations confirmed by CT and tactile inspection	Group A: – 285 screws (91.6%) with threshold values >6.0 mA with a mean of 15.8 (range, 10–20 mA) – CT confirmed proper, complete pedicle insertion Group B: – 6 screws (1.9%) were found to have intact pedicle borders with threshold responses <6.0 mA with a mean of 4.8 (range, 3.7–5.9 mA) – However, CT of these patients showed medial wall violation Group C: – 5 screws (1.6%) had threshold values < 6.0 mA with a mean of 4.1 (range, 3.0–4.5 mA) – Medial wall perforations confirmed by tactile inspection Group D: – 6 screws (1.9%) with threshold values between 6 and 10 mA and a 60–65% decrease from the mean had medial wall violation as confirmed by tactile inspection (mean, 6.2; range, 6–7 mA) Group E: – 5 screws (1.6%) with threshold values between 6 and 10 mA and a 60–65% decrease from the mean (mean, 6.2; range, 6–7) showed no medial wall perforation on tactile inspection – However, postoperative CT scan proved violation of the medial wall Group F: – 4 screws (1.3%) had stimulation thresholds >20 mA, initially suggesting positive results – However, on postoperative CT scan, lateral cortical breakthrough became evident – No reports of thoracic nerve root irritation, no postoperative neurological deficit nor any complaints of radicular chest wall pain were reported	Based on <6 mA threshold: – 11 true-positive – 15 false-negative – 0 false-positive – 285 true-negative – Sensitivity: 42% – Specificity: 100% – PPV = 100% – NPV = 95%  Based on <6 mA threshold or 60–65% decrease from the mean: – 22 true-positive – 4 false-negative – 0 false-positive – 285 true-negative – Sensitivity: 85% – Specificity: 100% – PPV = 100% – NPV = 98.6% Hand calculated  If diagnostic characteristics were calculated using a threshold between 6–20 mA and a 60–65% decrease from the mean, then specificity and sensitivity would both equal 100%
Samdani et al [8] (2011)	Retrospective cohort study	N = 50 consecutive adolescent patients (937 screws T2–T12: estimate based on figure: – T2: 80 – T3: 86 – T4: 74 – T5: 78 – T6: 78 – T7: 84 – T8: 87 – T9: 87 – T10: 89 – T11: 94 – T12: 100) Mean age: 14.3 (range, 10–20) y Male: 18%	– AIS	Corrective surgery involving posterior spinal fusions	Triggered EMG: – Screws placed from T2–T12 were evaluated using stimulation within the intercostal and abdominis rectus muscles – Resistance to current flow measured and outcomes assessed based on a threshold of 6 mA or a ≥65% decrease from the mean	Breach of cortex as confirmed by CT	– 114 (12.2%) of 937 breached the cortex – 47 (5.0%) medial violations – 67 (7.2%) lateral violations – 823 (88.8%) correctly placed – Mean threshold: 13.6 mA (range, 3–35 mA) – Medial breaches: – Mean threshold: 10.2 mA (2–28 mA) – 8 (17%) of 47 stimulated ≤6 mA – 23 (49%) between 6–10 mA – 16 (34%) >10 mA – 10 (21.3%) of 47 had ≥65% decrease from mean – Only 13 (28%) of 47 had ≤6 mA and/or ≥65% decrease – Lateral breaches: – Mean threshold: 15.6 mA (5–35 mA) – Looking at T10–T12 screws: 7/282 medial breach – 6 (85.7%) of 7 had ≤6 mA threshold and/or ≥65% decrease – No postoperative neurological deficits	Based on a ≤6 mA threshold and/or 60–65% decrease from the mean: – Sensitivity = 28% – PPV = 21%
Silverstein and Mermelstein [9] (2010)	Prospective cohort	N = 9 consecutive patients (121 screws) Mean age: 38.1 (range, 15–69) y Male: NR	Severe spinal deformity or instability	Instrumented thoracic fusion and deformity correction	Triggered EMG: – Screws were placed in the thoracic spine with EMG testing of the abdominis rectus and paraspinal muscles	Pedicle breach confirmed by postoperative CT	– No significant breaches found – No postoperative neurological deficits or neurological pain in any patients in this study were reported	Based on a <7 mA threshold: – Sensitivity = 100% – False-positive rate = 6%

\* EMG indicates electromyography; CT, computed tomography; PPV, positive predictive value; NPV, negative predictive value; NR, not reported; and N/A, not available.



**Table 2** Summary of pedicle wall breach rates, new or worsening neurological event, and diagnostic test characteristics.

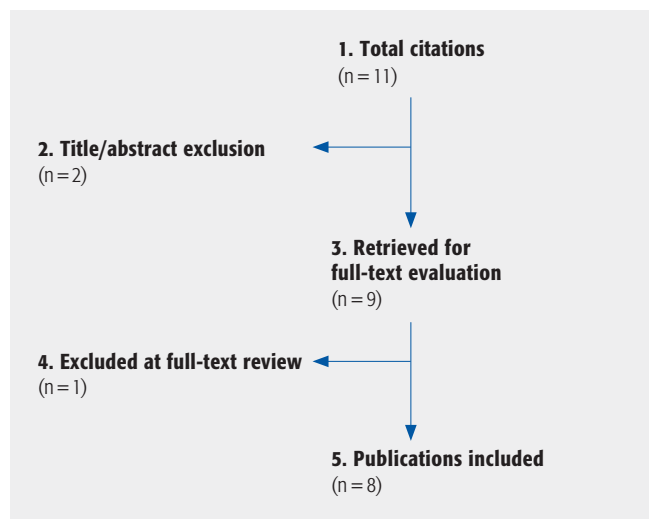
Outcomes	No. of studies	Patients (screws)	EMG	
			Mean, %	Range, %
Pedicle wall breach rate	8 [1–8]	337 (2708)	11.6	0–53.4
Medial pedicle wall breach rate	7 [1, 3–8]	307 (2513)	5.6	0–16.5
New or worsening neurological event	8 [1–8]	330 (2592)	0	0
Sensitivity	8 [1–8]	337 (2708)	55.0	0–100
Specificity	6 [1–6]	278 (1650)	82.1	70.1–100
Positive predictive value	5 [1, 4–7]	291 (2289)	36.2	21–100
Negative predictive value	6 [1–6]	278 (1650)	93.9	75–100

**Table 3** Rating of overall strength of evidence for each key question.\*

<b>Question 1: For adolescent and adult patients undergoing pedicle screw placement for thoracic deformity, what are the diagnostic characteristics (ie, sensitivity, specificity, positive predictive value, negative predictive value) of using electromyography (EMG) to identify misplacement?</b>					
Outcome	Strength of evidence	Conclusions/comments	Baseline	Downgrade	Upgrade
Overall diagnostic characteristics	Low	<p>Mean sensitivity for identifying a pedicle wall breach was relatively low when pooled across studies (55.0%). Further, the findings were inconsistent across studies ranging from 0–100%.</p> <p>Mean specificity was much higher at 82.1% across studies; with some inconsistency ranging from 70–100%.</p> <p>Fairly low sensitivity may lead to a high false-negative rate. It is unclear what the impact of false-negatives would be since no neurological injuries were identified in the studies summarized.</p> <p>Higher specificity would suggest a fairly low false-positive rate; however, the rates could be as high as 30%. If sudden changes in treatment are required in the absence of any adverse event, this could be considered a limitation of such testing.</p>	High	Inconsistency (1) Uncertainty of impact of false (-)	No
<b>Question 2: For adolescent and adult patients undergoing pedicle screw placement for thoracic deformity, does intraoperative EMG reduce the rate of a new or worsening neurological event or pedicle wall breach compared with no EMG?</b>					
Outcome	Strength of evidence	Conclusions/comments	Baseline	Downgrade	Upgrade
Efficacy	Insufficient	There were no studies identified comparing patients who did and did not receive EMG during pedicle screw placement to determine if EMG is more effective at preventing adverse events such as a new neurological event or a pedicle wall breach.	Insufficient level I/II studies	No	No

\* All Agency for Healthcare Research and Quality (AHRQ) “required” and “additional” domains are assessed. Only those that influence the baseline grade are listed in this table.

Baseline strength: risk of bias (including control of confounding) is accounted for in the individual article evaluations. High indicates most articles level I/II; low, most articles level III/IV; downgrade, inconsistency of results (1 or 2); indirectness of evidence (1 or 2); uncertainty about the impact of false-negatives; and no upgrades were considered.

**Fig 1** Results of literature search.

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## EDITORIAL PERSPECTIVE

Not surprisingly this topic raised significant debate among the reviewers on a number of issues. The reviewers agreed that the authors of this systematic review have touched upon a very timely topic and did a fine job of evaluating it.

Certainly the prospect of electrodiagnostic monitoring of pedicle screws during placement has received increasing commercial interest from a number of vendors who have aggressively marketed their technologies as improving patient safety. It therefore seemed appropriate to critically evaluate their claims with the current state of literature.

The overall strength of evidence evaluating the diagnostic characteristics was low due to inconsistency between studies when comparing the following key areas:

- Variations in the technique used for EMG monitoring
- Inconsistency of identifying pedicle breach (visual and/or different types of postoperative CT) – EMG was NOT used to primarily identify pedicle breaches.
- Variations in reference muscles used for monitoring
- Variations in the thresholds utilized to identify pedicle breach which can affect the measurement parameters of diagnostic efficacy such as sensitivity, specificity etc.

The editorial staff believed that we should proceed with publication of this to highlight the present day heterogeneity of EMG-monitoring methods in the literature and to focus on the issue of efficacy versus effectiveness in the application of a relative novel technique. Efficacy would require not only homogeneous methods but also data to support our key question #2: “For adolescent and adult patients undergoing pedicle screw placement for thoracic deformity, does intraoperative EMG reduce the rate of a new or worsening neurological event or pedicle wall breach compared with no EMG?”

We found that heterogeneous methods were a clinical reality for this diagnostic technique. In other words, we had to accept some diagnostic heterogeneity as a flaw but believed we could still apply the findings to making one’s own clinical decision (effectiveness). Therefore it is appropriate to ask this question and report the findings so that the clinician can look at the evidence (as poor as it may be) in one report as opposed to reading multiple individual studies.

Another hot-button topic was how to deal with the wide range of specificities in the individual studies with ranges from 70% to a full 100%. The study that reported 70% [1] would suggest a false-positive rate of 30%. The false-positive rate was less in other studies. Therefore, we did not report an average or an “acceptable rate” based on the literature. The reader will have to decide what is acceptable seeing that the false-positive rates reported in the literature range from 0–30%.

The critical question raised was whether a systematic review study with such low strength of evidence should be published at all. It should be pointed out that as in any formal systematic review, the study questions were set apriori before we explored the literature based on what we believed were clinically relevant and important questions. Finding “no evidence” for a specific question is an important finding. For us this is the question that really needs to be answered and our systematic attempt reveals that there are no studies that have tried, despite several attempts at evaluating sensitivity and specificity in case series. The criteria to publish a systematic review therefore should not be based on overall strength of evidence after the report is completed. Clinical recommendations can even be made on reports that discover “no evidence” especially in case of novel treatment. In addition, a clinical recommendation can be made against a procedure that has high evidence to support it for well-defended reasons (eg. cost, harm, etc).

The real question that needs to be answered is whether using EMG is associated with better outcomes and/or fewer adverse events than no EMG. This can only be done through comparison studies which we have discovered do not exist. That said, the authors hope that ‘no findings’ with respect to this question will motivate our affected specialties to attempt to answer it. Therefore, since there is no record of a systematic review attempting to answer this question in the literature, this review fills a gap, despite the strength of evidence being low. The clinician can use these findings to make their own informed decision more effectively than looking at individual articles.

**Donohue ML, Murtagh-Schaffer C, Basta J, et al (2008) Pulse-train stimulation for detecting medial malpositioning of thoracic pedicle screws. *Spine (Phila Pa 1976)*; 33:E378-385.**