Eur Spine J (2011) 20:869–874
DOI 10.1007/s00586-010-1653-x

ORIGINAL ARTICLE

Triggered electromyography for placement of thoracic pedicle screws: is it reliable?

Amer F. Samdani · Mark Tantorski · Patrick J. Cahill · Ashish Ranade · Stephen Koch · David H. Clements · Randal R. Betz · Jahangir Asghar

Received: 15 February 2010 / Revised: 3 September 2010 / Accepted: 5 December 2010 / Published online: 18 December 2010

Abstract Reliable electromyography (EMG) thresholds for detecting medial breaches in the thoracic spine are lacking, and there is a paucity of reports evaluating this modality in patients with adolescent idiopathic scoliosis (AIS). This retrospective analysis evaluates the ability of triggered EMG to detect medial breaches with thoracic pedicle screws in patients with AIS. We reviewed 50 patients (937 pedicle screws) undergoing posterior spinal fusion (PSF) with intraoperative EMG testing. Postoperative CT scans were used for breach identification, and EMG values were analyzed. There were 47 medial breaches noted with a mean threshold stimulus of 10.2 mA (milliamperes). Only 8/47 breaches stimulated at 2–6 mA. Thirteen of the forty-seven screws tested at an EMG value ≤6 mA and/or a decrease of ≥65% compared with intraosseously placed screws. The sensitivity and positive predictive value for EMG was 0.28 and 0.21. A subanalysis of T10–T12 screws identified six of seven medial breaches. Using guidelines from the current literature, EMG does not appear to be reliable in detecting medial breaches from T2 to T9 but may have some utility from T10 to T12.

Keywords Triggered electromyography · Pedicle screws · Thoracic · Adolescent idiopathic scoliosis · Posterior spinal fusion

A. F. Samdani (✉) · P. J. Cahill · R. R. Betz · J. Asghar
Shriners Hospitals for Children,
3551 N Broad Street, Philadelphia, PA 19140, USA
e-mail: asamdani@shrinenet.org

M. Tantorski
Philadelphia College of Osteopathic Medicine,
4170 City Avenue, Philadelphia, PA 19130, USA

A. Ranade
Department of Orthopaedic Surgery, Smt. Kashibai Navale Medical College & Hospital, Narhe, Pune 411051, India

S. Koch
Temple University School of Medicine,
3500 North Broad Street, Philadelphia, PA 19140, USA

D. H. Clements
Cooper Bone and Joint Institute, 3 Cooper Plaza,
Suite 411, Camden, NJ 08103, USA

Introduction

The use of pedicle screws in the thoracic spine has become common for the surgical management of spinal pathologies including tumor [1, 2], trauma [3, 4], and deformity [2, 5, 6]. Advantages of thoracic pedicles over hook-hybrid constructs include three-column fixation, lower pseudarthrosis rates, better coronal and axial correction, and lower revision rates [6–8]. Precise placement of thoracic pedicle screws, particularly in the deformed spine, can pose a unique challenge. Reported breach rates vary widely in the literature, with a low of 1.6% reported by Suk et al. [9]. However, others have reported breach rates from 10 to 58% [10–12]. The variability observed may be due to the method used to detect breaches, with plain X-rays likely underestimating the breach rate [1, 12–14]. Complications from misplaced screws include neurologic injury, dural laceration, esophageal impingement, and vascular sequelae [15, 16]. With respect to the latter, two recent reports document delayed aortic injury following placement of pedicle screws [17, 18].

The surgeon relies on various modalities for the accurate placement of thoracic pedicle screws. These include the use of the ball tip feeler to detect breaches, intraoperative fluoroscopy and radiographs, laminotomies, and EMG. Palpating breaches with the ball tip may not detect all cortical

perforations, even with increasing surgical experience [19]. Careful inspection of intraoperative fluoroscopy and plain X-rays can detect some breaches [20]. Intraoperative navigation-assisted pedicle screw placement increases the accuracy of placement of thoracic pedicle screws, although these systems are not yet widely used [21, 22].

EMG threshold testing is another modality used by surgeons to accurately place thoracic pedicle screws [23, 24]. The premise of EMG testing is based on a characteristic level of electrical resistance with an intact pedicle. The efficacy of EMG in the lumbar spine is well described [13, 25–29]. EMG testing of thoracic pedicle screws has had mixed results [14, 23, 30–32]. The purpose of our study is to determine the utility of EMG in detecting medial breaches in the deformed thoracic spine.

Materials and methods

After obtaining IRB approval, we retrospectively identified 50 consecutive patients with AIS who had undergone a PSF with thoracic pedicle screws with intraoperative EMG and a postoperative CT scan. There were 41 females and 9 males ranging in age from 10 to 20 years with a mean of 14.3 years. The patient charts were reviewed for age, major Cobb angle, number and location of thoracic pedicle screws, EMG value obtained for each screw, and postoperative CT scan to determine breach.

Placement of thoracic pedicle screws

All the screws were placed by an experienced spine surgeon or a fellow under the direct supervision of an attending surgeon. In general, the attending surgeon placed left-sided screws and the spine fellow placed right-sided screws. Pedicle screws were placed by the free hand technique as described by Kim et al. [33]. At the time of this study we were routinely instrumenting greater than 80% of levels with pedicle screws. Since that time, for appropriately selected curves we have decreased our implant density.

Neuromonitoring and EMG

Neuromonitoring was utilized in all cases and included somatosensory-evoked potentials (SSEPs), transcranial motor-evoked potentials (tcMEPs), and EMG testing. Current was delivered via a handheld probe and returned via a needle placed one to two levels proximal in the ipsilateral tissue—paraspinal muscle placement was typical. Stimulation was monophasic constant current pulses of 0.20 ms pulse width generated at a rate of 4.1 Hz. Recordings were logged in the routine manner—time-locked compound muscle action potentials (CMAPs) captured in a EMG mode. Filters were 10 Hz in the high pass and 3 kHz in the low pass. Traces were 100 ms in total duration and 50 μV/div in voltage display sensitivity. Our equipment allowed for the time base and display sensitivity to be adjusted as needed.

Well-separated electrode placements were chosen to provide good sensitivity while maintaining a simple two-channel montage. These were a single intercostal pair, left referenced to right, aligned just inferior to the nipple line on the lateral aspect of the trunk placed to avoid padding whenever possible; and a single abdominis rectus pair, left reference to right, left caudal and lateral and right rostral and lateral to the navel (2–4 cm typical in each dimension).

Time-locked compound muscle action potentials were observed as the stimulus was increased. Current was limited to no more than 30 mA. Decreasing and increasing the stimulus around the initially observed threshold confirmed repeatability. Compound muscle action potentials observed in the intercostal channels were sharper peaked. If very early response latency was initially seen (<5 ms typically) stimulus was increased until a later peak was observed (5–10 ms typical). The latter threshold was recorded. The early latency response correlated best with paraspinal muscle twitch confirmed by the surgeon. Compound muscle action potentials of the abdominis muscles were of longer latency and period—certainly distinct from the intercostal responses.

Threshold responses were obtained and recorded for all screws placed. Using the criteria set forth by Raynor et al. [24] and Rodriguez-Olaverri et al. [23], screws demonstrating threshold values $\leq$6 mA and/or values $\geq$65% decreased from the mean of other screws were removed and the track was thoroughly explored. The screw was redirected and retested.

The probe was a 3-mm Letz Ball Electrode (Utah Medical Products, Inc.) in a Prass Monopolar Handle (Medtronic-Xomed). The most commonly used current return needle was a JO-5 style needle (Viasys Healthcare). The Xltek Protektor (Xltek, a division of Natus) was used for stimulation and recording. Recording electrodes were standard stainless steel 12 mm needle electrodes (Medtronic-Xomed). Variability in EMG recordings is not uncommon secondary to a host of factors including body temperature, blood pressure, and anesthetic. To minimize this variability, we attempted to keep the temperature in a range between 36 and 38°C and blood pressure with mean arterial pressures between 65 and 85 mmHg, and we limited the use of gas inhalants.

Postoperative CT and evaluation of breach

Patients underwent a postoperative CT scan with 3-mm slices in bone windows. At the time of this study, we

routinely obtained a postoperative CT as part of our standard of care. The CT scans were evaluated by two experienced spine surgeons and rated according to the criteria set forth by Kim et al. [20], in which a screw is deemed 'In' if the central axis of the screw is within the cortices of the pedicle and 'Out' if the axis is outside the pedicle walls. Sensitivity and positive predictive value were calculated using breach criteria set forth by Raynor et al. [24] and Rodriguez-Olaverri et al. [23]. Mean EMG values for intracortical, medially breached, and laterally breached screws were compared using ANOVA.

Results

Patient demographics and overall breach rate

Of the 50 patients, there were 41 females and 9 males. Mean age was 14.3 years with a Cobb angle of 58° (range 45–105°). There were 937 screws placed from T2 to T12 (Fig. 1), of which 114 (12.2%) were found to be breached on postoperative CT scan. Forty-seven (5.0%) screws had violated the cortex medially. There were 67 (7.2%) screws that were shown to have breached the lateral cortex. In this cohort, no patient experienced a postoperative neurologic deficit, although two patients demonstrated intraoperative changes in spinal cord monitoring. Both of these were declines in motor-evoked potentials of greater than 50% which occurred after the pedicle screws had been placed. The changes were attributed to a decrease in blood pressure in one patient which was corrected by increasing the mean arterial pressure. In the other patient, the changes occurred after the deformity was corrected; removal of rods with a lesser correction returned the signals to baseline.

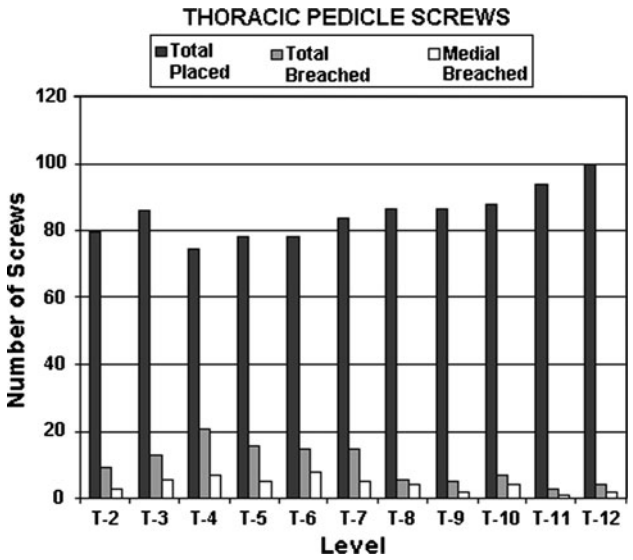

Fig. 1 The histogram shows the total number ($n = 937$) of thoracic pedicle screws placed by vertebral level of the thoracic spine. Total breaches ($n = 114$) are also depicted by thoracic level. Finally, medial breaches ($n = 47$) are illustrated with respect to level of violation

EMG threshold values

There were 823 (88.8%) intracortical screws placed (Table 1). The mean threshold for theses screws was 13.6 mA (3–35 mA). The lateral breach group sustained an average threshold value of 15.6 mA (5–35 mA). The average threshold for medially breached group was 10.2 mA (2–28 mA), $P < 0.05$.

Medially breached screws

The 47 medially breached screws were analyzed and showed only 8 (17%) screws stimulated ≤6 mA; 23 (49%) screws stimulated between 6 and 10 mA; and 16 (34%) stimulated at a level >10 mA. The medial breach group was further studied based on a decrease in threshold level ≥65% of the mean threshold value from the intraosseous screws for a particular patient. Only 10/47 (21.3%) of the medially misplaced screws as confirmed with CT scan demonstrated this decrease. Similarly, 13 of the 47 (28%) medially misplaced screws tested at an EMG value ≤6 mA and/or ≥65% of intraosseously placed screws (Table 2). The sensitivity and positive predictive value for detection of medial screw breach in the thoracic spine with a threshold of ≤6 mA and/or a decrease of ≥65% was only 0.28 and 0.21, respectively.

T10–T12 pedicle screws

We conducted a subanalysis of the T10–T12 pedicle screws (Table 3). From a total of 282 pedicle screws, there were seven medial breaches and using the criteria of ≤6 mA and/or decrease of ≥65%, six breaches were

Table 1 Threshold stimulus for screws placed

Screw placement	No. of screws	Percentage of screws	Threshold (mA)
Intraosseous	823	88.8	13.6
Lateral breach	67	7.2	15.6
Medial breach	47	5.0	10.2

Table 2 Classification of medially breached screws by EMG values

Threshold (mA)	≤6	>6–10	>10	≤6 and/or ≥65% decrease
Number of screws	8 (17%)	23 (49%)	16 (34%)	13 (28%)

Table 3 T10–T12 pedicle screws: EMG detects medial breaches

Levels	Total screws	Medial breaches	≤6 mA	≤6 and/or ≥65% decrease
T10–T12	282	7	4 (57%)	6 (86%)

detected. Thus, EMG may have some utility in detecting medial breaches in the lower thoracic spine.

Discussion

Our results demonstrate that EMG only detected 28% of thoracic medial breaches as confirmed by postoperative CT. Thirty-four percent of medial breaches stimulated at threshold values greater than 10 mA. However, for thoracic pedicle screws from T10 to T12, 86% of medial breaches were identified with the use of EMG. One potential reason for EMG not being reliable from T2 to T9 is that the intercostal muscles are small and may not elicit reliable responses. T0–T12 test the rectus abdominis which is a larger muscle than the intercostals and hence the improved detection. Intraoperatively, the spine surgeon should utilize EMG with caution when evaluating for medial pedicle screw breaches.

Several studies have evaluated the utility of EMG for the detection of thoracic pedicle screw breach, with inconsistent results. Reidy et al. [14] evaluated placement of 95 thoracic screws using EMG. Using 7 mA as a threshold, the sensitivity and specificity of EMG were 0.50 and 0.83, respectively, for eight unrecognized breaches as shown on postoperative CT scan. Although this study involved an adult population and evaluated significantly fewer screws, it highlights the concern that no demonstrable pattern for thresholds for cortical violation exists. In 2003, Shi et al. [32] performed a similar study involving a heterogeneous population with postoperative CT scan also used for confirmation. Using 11 mA as the target threshold, only 3 of 6 violations stimulated at or below this value. All appeared to have acceptable placement on intraoperative fluoroscopy. The positive predictive value of EMG was only 50%.

Raynor et al. [24] specifically assessed EMG for detection of medial breaches in the thoracic spine. The study evaluated the placement of 677 pedicle screws in a group with a mean age of 25 years and with multiple diagnoses. The levels evaluated were from T6 to T12 with direct palpation and radiography used as the means for confirmation of a breach. Twenty-seven screws stimulated at a threshold less than 6 mA. Of these, six were found to have breached medially, and their decrease from the mean intact thresholds was found to be 69% and accounted for 100% of the medial breaches. They concluded that thresholds below 6 mA coupled with a decrease in mean threshold values to greater than or equal to 60–65% of the mean should alert the surgeon to the possibility of a medial breach. Our study differs from theirs in several aspects. First, we utilized postoperative CT to detect medial breaches, and the vast majority of our medial breaches (72%) were not detected utilizing their criteria. Second, it is possible that a significant number of medial breaches were not detected by intraoperative radiography and their not being included in the analysis biased the data. More recently, Rodriguez-Olaverri et al. [23] investigated the utility of EMG for detecting cortical perforation from T3 to T6. A total of 311 screws were assessed, and postoperative CT scan was used for confirmation of breach. Eleven screws showed medial cortical breach, all of which stimulated under 10 mA (6 at 6 mA or below) and had decreases of 60–65% from the mean. They concluded that cortical violation is highly unlikely in patients whose stimulation thresholds fall between 6 and 20 mA with values 60–65% decreased from the mean. Our results differ from their findings possibly because of their overall numbers being smaller than the present study (total screws 311 vs. 937, medial breaches 11 vs. 47).

There are several limitations to the present study. It is a retrospective analysis utilizing postoperative CT as an outcome measure. Several investigators have documented the inconsistency of reading postoperative CT, particularly with stainless steel screws [34, 35]. We attempted to minimize this by utilizing the method of Kim et al. [20], which categorizes a screw as either 'In' or 'Out' rather than attempting to quantify millimeters of breach. Lead placement and neuromonitoring can vary between patients. Our neuromonitoring team consists of four highly experienced technicians. Last, although we have a standardized anesthetic protocol for patients with AIS undergoing a PSF, some variation can occur depending on the clinical situation.

In addition to EMG, other methods have been advocated for detecting a breach. It has been shown that probing pedicle screw tracts is a valid technique for detecting a breach, especially as the surgeon gains experience [19]. Intraoperative radiographs also remain a viable option for evaluation of medial cortex violation. Kim et al. [20] reported a sensitivity of 0.87, specificity of 0.97, and an accuracy of 0.98 using this method when compared with postoperative CT scan. Computer-assisted navigation (CAN) for pedicle screw placement has received attention in recent years. Kotani et al. [21] evaluated the accuracy of this technique and found a perforation rate of 1.8 and 11% for CAN and intraoperative fluoroscopy, respectively, as compared with postoperative CT scan. Rajasekaran et al. [22] have shown similar results with a 2% breach rate for CAN compared with 23% for the intraoperative

fluoroscopy group. Results for this modality appear promising; however, the issues of cost, space, and operational efficiency remain. A novel technique for EMG monitoring has also been recently described. The use of pulse–train stimulation of pedicle tracks for detection of medial malpositioning of screws in the thoracic spine [30]. Eighteen of 19 medial defects were identified with this method. Although absolute thresholds have not been established, it does appear to show improvement over the current techniques with screw stimulation. Future consideration for CAN and pulse-train stimulation may prove beneficial for evaluation of breached pedicle screws; however, additional studies are necessary.

Conclusion

EMG does not appear to be a reliable means for detection of medial cortical breaches when placing pedicle screws in the thoracic spine of patients with AIS. Stimulated threshold levels reported in the literature did not consistently identify medial cortical violations in our population. There may be some utility for EMG monitoring, specifically from T10 to T12. It is recommended that the spine surgeon palpate through a small laminotomy, if feasible, when a medial breach is suspected on intraoperative fluoroscopy or radiographs. The surgeon should consider removing and re palpating suspected laterally breached screws.

Conflict of interest None.

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