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Can triggered electromyography thresholds assure accurate pedicle screw placements? A systematic review and meta-analysis of diagnostic test accuracy

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HIGHLIGHTS

- Triggered electromyography (t-EMG) by direct pedicle screw stimulation was introduced two decades ago and its efficacy remains disputed.
- The diagnostic accuracy of t-EMG was weak in the condition of overall thresholds.
- Using titanium-alloy pedicle screws, a stimulation threshold of ⩽8 mA in the lumbar spine has high accuracy (sensitivity, 0.82; specificity, 0.97; diagnostic odds ratio (DOR), 147.95) as an indication of possible pedicle screw malpositioning.

ABSTRACT

Objective: Triggered electromyography (t-EMG) for pedicle screw placement was introduced to prevent the misplacement of screws; however, its diagnostic value is still debated. This study aimed to clarify the diagnostic value of t-EMG and to compare thresholds.
Methods: We searched MEDLINE, EMBASE, and the Cochrane Library, and 179 studies were identified. Among them, 11 studies were finally enrolled. The pooled sensitivity, specificity, diagnostic odds ratio (DOR), and summary receiver operating characteristics (SROC) plots were analyzed.
Results: The enrolled studies included 13,948 lumbar and 2070 thoracic screws. The overall summary sensitivity/specificity/DOR values of t-EMG were 0.55/0.97/42.16 in the lumbar spine and 0.41/0.95/14.52 in the thoracic spine, respectively, indicating a weak diagnostic value. However, subgroup analysis by each threshold value showed that the cutoff value of 8 mA in the lumbar spine indicated high sensitivity (0.82), specificity (0.97), and DOR (147.95), thereby showing high diagnostic accuracy of identifying misplaced screws.
Conclusion: The most useful application of t-EMG may be as a warning tool for lumbar pedicle screw malpositioning in the presence of positive stimulation at a threshold of ⩽8 mA.
Significance: t-EMG by screw stimulation may be valuable in the lumbar region at a threshold of ⩽8 mA.

1. Introduction

Pedicle screws are commonly used in thoracic and lumbar spine fixations. The biomechanical superiority of pedicle screws over other spinal fixation methods, along with the increasing comfort level of surgeons with the pedicle screw techniques, has driven the popularity of this technique (Wang et al., 2010). However, spine pedicle screw applications carry potential complications involving the great vessels, the spinal cord, and spinal nerve roots. Clinically, pedicle cortex screw violations have been reported at a rate of 8% (Shi et al., 2003).

The method of using triggered electromyography (t-EMG) after pedicle screw electrical stimulation for placement evaluation was

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developed by Calancie et al. 20 years ago (Calancie et al., 1994a). This method evaluates EMG activity from the lower extremities while electrically stimulating screws below the threshold level. Each pedicle screw is electrically stimulated with an increasing intensity from 5 to 30 mA (duration, 0.2 ms; frequency, 0.8 Hz) (Calancie et al., 1994a; Gavaret et al., 2013). Some prior investigators insisted that pedicle screw testing was the most appropriate available technique and provided rapid and useful intraoperative information regarding screw placements during procedures (Lenke et al., 1995; Shi et al., 2003; Gavaret et al., 2013). By contrast, other studies revealed that the t-EMG technique had low sensitivity in predicting screw malpositioning and asserted that imaging-based modalities remain more appropriate for assessing percutaneous pedicle screw trajectory until more robust and sensitive intraoperative neurophysiologic monitoring methods are devised (Reidy et al., 2001; Wang et al., 2010; de Blas et al., 2012).

Debate has remained not only regarding the efficacy of t-EMG but also regarding its threshold value. One prior study suggested that the threshold stimulus intensity in the lumbar spine is >8 mA if the screw is entirely in the pedicle; 4.0–8.0 mA represents the potential for a pedicle wall defect, and <4.0 mA represents a strong likelihood for a pedicle wall defect with potential for nerve root and dura contact (Lenke et al., 1995). Other investigators suggested appropriate threshold values of 8 mA (Raynor et al., 2007, Alemo and Sayadipour, 2010, Parker et al., 2011), 10 mA (Rodriguez-Olaverri et al., 2008; Gavaret et al., 2013), 10–11 mA (Shi et al., 2003), and 14 mA (Nair, 2013). The lower the stimulation threshold required to evoke a response, the higher the probability of a breach. However, there is little consensus regarding threshold stimulus intensities because these studies are limited by a low incidence of radiographic breaches.

The aim of this study was to estimate the sensitivity and specificity of t-EMG in assuring accurate pedicle screw placement and to compare threshold values with a systematic review and meta-analysis.

2. Materials and methods

2.1. Literature search

We conducted a comprehensive literature search to identify studies that dealt with t-EMG by screw stimulation. The searched databases included MEDLINE, EMBASE, and the Cochrane Library from their inception to April 2014. The keywords and medical subject headings related to the condition and potential treatments were identified prior to initiating the search. The following search strings were used: intraoperative [All Fields] AND (“bone screws” [MeSH Terms] OR “screws” [All Fields] OR “bone screws” [All Fields] OR “pedicle screw” [All Fields]) AND stimulation [All Fields]. We also examined the reference sections of all selected articles to identify other relevant reports. The search was limited to English language studies. Two investigators independently reviewed all of the subjects, abstracts, and the full texts of the articles that were potentially eligible based on the abstract reviews. The eligible trials were then selected according to the inclusion criteria.

2.2. Study eligibility criteria

We selected studies that assessed the diagnostic accuracy of t-EMG. The gold standard was defined as computed tomography (CT) or radiologic studies. We systematically reviewed published studies according to the following criteria: (1) the intervention included a spinal pedicle screw placement in the thoracic and lumbar spine (S1 pedicle screw included); (2) the study reported the electrical stimulation thresholds; and (3) the data were available and provided enough information to assess true-positive (TP), true-negative (TN), false-positive (FP), as well as false-negative (FN) cases. We excluded case–control studies, narrative reviews, letters, editorials, comments, and case series. Studies were excluded if they included cervical pedicle screw or other screw types or if they did not report an electrical stimulation cutoff value. We assessed the quality of the studies by using an outlined component approach for diagnostic accuracy studies using the quality assessment of diagnostic-accuracy studies 2 (QUADAS-2) tool (Whiting et al., 2011).

2.3. Data synthesis and analysis

The data were independently extracted by two reviewers, and any disagreement that arose was discussed and resolved with a consensus. The retrieved data included the following items: study name, year of publication, patient demographics, screw location, stimulation threshold (mA), TP, TN, FP, and FN cases between the t-EMG and CT or other radiologic studies. We used the R: a language and environment for statistical computing (R Foundation for Statistical Computing, Vienna, Austria), and the R-package “mada” for coupled forest plot and summary receiver operating characteristic (SROC) analysis, and Review manager version 5.3 for the QUADAS-2 plots. We analyzed and plotted the pooled and grouped sensitivity, specificity, positive likelihood ratio (LR+), negative likelihood ratio (LR−), and diagnostic odds ratio (DOR) estimates. The DOR of a test is the ratio of the odds of positive test results if the subject has the disease to the odds of positive test results if the subject does not have the disease. The value of a DOR ranges from 0 to infinity, with higher values implying better discriminative test performance.

Forest plots were drawn to show the point estimates in each study in relation to the pooled summary estimates. We used the bivariate logit-normal random-effects meta-analysis model to obtain a summary estimate of sensitivity and specificity and to create SROC curves. The bivariate method includes the logits of sensitivity and specificity in one model and allows for correlation between the two. The logit is the natural logarithm of sensitivity (or specificity) divided by $1 -$ sensitivity (or specificity). As diagnostic test accuracy data are expected to be heterogeneous, we investigated heterogeneity thresholds by adding the following covariates to the model. To perform the meta-analysis for diagnostic test accuracy using all of the available studies in which more than one threshold value was reported in each study, we made 2×2 tables for each stimulation value from the included studies. If there was no event in the groups (i.e., a “zero cell” in the 2×2 table), 0.5 was added to each cell so that the estimated values would not be 0 or infinity and so that the standard error could be calculated.

3. Results

3.1. Search results

A flowchart shows the literature search and the study selection process (Fig. 1). A total of 179 studies were obtained. After the duplicate studies, case reports, and technical notes were excluded, 115 papers were left to screen. Based on the title and abstract, 71 reports were excluded because the topic of the article was not relevant to the objective of the review. Cadaver and animal model studies, as well as studies that lacked threshold descriptions, were excluded after full text reviews. Data from three articles could not be included in the meta-analysis because they did not fit the 2×2 contingency table. Finally, we identified a total of 11 observational studies, which included 13,948 lumbar screws in 2672 patients and 2070 thoracic pedicle screws in 224 patients (Table 1). Among