Improving Pedicle Screw Placement in Spinal Surgery: Acoustical and Torsional Profiling for the Identification of Breached and Non-Breached Screw Scenarios

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Summary

Pedicle screw insertion is challenging, with high rates of misplacement. Surgeons rely on sense perception for accuracy. Inspired by these sensory mechanisms, this study explored acoustical and torsional profiling for breach detection. *In vitro* tests revealed characteristic acoustic and torque changes during breach, providing valuable insights into bone-tool interactions. Monitoring these phenotypic signals could yield superior perception of the surgical field.

Introduction

Back pain affects 619 million people and is the leading cause of disability worldwide [1]. When conservative treatments are not viable, surgical intervention with pedicle screws is necessary. While pedicle screws are championed for their biomechanical performance, the accuracy of their insertion remains a persistent concern, with misplacement rates as high as 42% [2]. Screw breaches pose a serious risk of iatrogenic injury and, although a rare phenomenon, can be fatal [3]. Emerging acoustical and torsional surgical measurement techniques show promise for rapid detection of dangerous breaches and have potential to enhance screw insertion safety for future patients. This study aimed to characterise screw insertion (breach and non-breach) using acoustic emission (AE) when drilling and torque (T) when inserting screws.

Methods

In vitro tests conducted on 66 ovine lumbar vertebrae (L1-L6). Specimens randomly subdivided into three trajectory groups: Normal Insertion (n = 26), Lateral Breach (n = 20) and Medial Breach (n = 20). Pilot holes were bore with an orthopaedic drill and AE captured at 48 kHz by a sound sensor module. Self-tapping pedicle screws (4.5 mm x 32 mm) inserted with a custom rig at 6.0 rpm following predrilled trajectories, whilst torque sampled at 20 Hz. To delineate differences between breached and non-breached trajectories, feature and trajectory analyses were performed on AE and T signals. In feature analysis statistical properties were computed. For AE signals: absolute maximum AE (AE_{max}), number of crossings over a 0.54 V threshold (AE_{counts}), acoustic energy (AE_{energy}) and exposure ($AE_{exposure}$) calculated using Eq. (1) and Eq. (2) respectively. For T signals: maximum T (T_{max}), number of negatives (T_{counts}) and number of approximately zero values (T_{flats}) in derivative vector, and energy (T_{energy}) using Eq. (3).

$$AE_{energy} = \int_{t_0}^{t_1} V(t)^2 \, dt \quad (1) \qquad AE_{exposure} = \int_{t_0}^{t_1} p(t)^2 \, dt \quad (2)$$

$$T_{energy} = \int_{t_0}^{t_1} T(t) \, dt \quad (3)$$

Where, V = AE voltage, t = time, t_0 = initial time, t_1 = final time, p = AE pressure and T = torque (T). Data were stratified by group. All factors subjected to separate, one-way ANOVA analyses, followed by Tukey-Kramer or Dunn-Bonferroni post-hoc tests. In trajectory analysis, statistical parametric mapping (SPM- 1D ANOVA) was used to examine profile differences in AE (enveloped) signals and T signals between breached and non-breached trajectories (Figure 1).

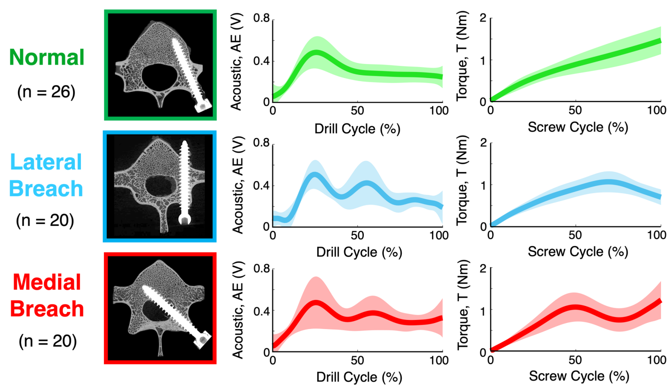

Figure 1: Acoustical and Torsional Insertion Profiles.

Results and Discussion

Significant differences in AE and T features were observed between trajectories (Figure 2). Similarly, SPM showed significant decreases in T profiles during both lateral ($p<0.02$) and medial ($p<0.005$) breach relative to normal insertion. Non-significant differences in AE profiles were observed.

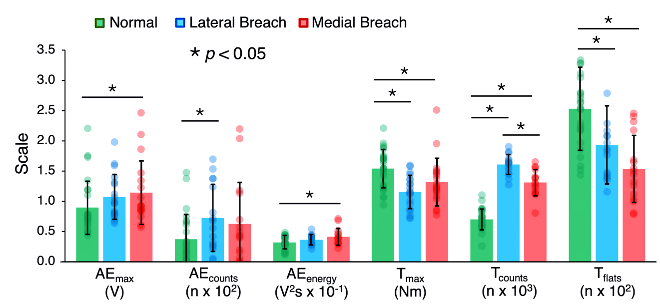

Figure 2: Mean ± SD of Acoustic and Torque Significant Features.

Conclusions

Acoustical and torsional responses are significantly different in breached and non-breached screw insertion scenarios. Real-time monitoring of these signals could aid in breach avoidance and improve pedicle screw placement accuracy.

References

[1] World Health Organization. (2020). *LBP Report & Data.*
[2] Gautschi et al. (2011). *Neurosurg Focus, **31**: E8.*
[3] Fu et al. (2023). *Front Surg.* **10**: 1187801.