

Insertional Torque and Pullout Strength: A Comparison of Robot-Assisted and Manual Pedicle Screw Placement

Hui Zhang, Justin L. Reyes, William K. Crockatt, Alexander Dash, Alexandra C. Dionne, Roy Miller, Oluwadamilade O. Tega, Silvio Torres Betancur, Stephan T. Blaskovics, Thomas R. Gardner, Zeeshan M. Sardar, Lawrence G. Lenke, Ronald A. Lehman, Joseph M. Lombardi
Columbia University in the city of New York
hz2864@cumc.columbia.edu

Disclosures: Hui Zhang (N), Justin L. Reyes (N), William K. Crockatt (N), Alexander Dash (N), Alexandra C. Dionne (N), Roy Miller (N), Oluwadamilade O. Tega (N), Silvio Torres Betancur (N), Stephan T. Blaskovics (N), Thomas R. Gardner (N), Zeeshan M. Sardar (Medtronic plc), Lawrence G. Lenke (Medtronic plc), Ronald A. Lehman (Medtronic plc), Joseph M. Lombardi (Medtronic plc)

INTRODUCTION: Pedicle screw fixation is a common surgical method for correcting spinal deformities. The strength of this fixation is influenced by numerous factors, including the patient's bone health, the screw's design (such as its diameter and thread form), and how the screw is inserted, including the preparation of the pilot-hole and the depth and trajectory of the screw. Additionally, surgeon skill is a critical variable when using the traditional freehand technique. In recent years, robotic guidance systems have emerged to assist with pre-operative planning and ensure accurate screw placement, which is intended to create a stronger biomechanical construct. We conducted this study to compare the fixation strength of freehand and robotic-assisted techniques, using insertional torque and screw pullout force as the primary metrics.

METHODS: Pedicle screws were inserted into seven fresh frozen cadaveric spines (three males and four females, age 70.3 ± 13.0 years, BMI 25.2 ± 4.4 kg/m²) from T2-S2 (Figure 1), with T2 and S2 excluded for some spines if positioned beyond the robot's reach. Screw diameter and length were documented for each level. Two insertion techniques, freehand and robot-assisted (Mazor X, Medtronic), were randomly assigned to either the left or right side of each specimen: four spines with freehand performed on the left side and robot on the right, with the assignment reversed for the remaining three spines. For freehand insertion, the surgeon determined the best insertion orientation based on training and experience, whereas for the robot-assisted method, the robot embedded software program computed the optimal insertion angle from O-arm images. During screw insertion, the surgeon used a screwdriver with a custom-built torque sensor continuously recording insertion torque, differentiating between the 2-mm torque (measured with a 2-mm guide above the bone surface) and the final hubbing torque (screw firmly seated at the bone surface). Subsequent screw pullout testing was performed on a MTS 858 servo-hydraulic tester at rate of 0.05 mm/s (Figure 2). Each vertebra was individually sectioned, potted, and peak screw pullout force recorded. A custom device was used to ensure the pulling force aligned with the screw's axial direction. For bone mineral density evaluation, Hounsfield units (HU) from O-arm images was used to estimate the bone mineral density. A region of interest was selected at S4, and the other two regions (air and muscle) were measured and used as reference for bone HU correction. A 2-way ANOVA was performed using SAS, with insertion technique (freehand, robot) and spinal region (thoracic, lumbar, and sacral) as factors. Repeated measures were performed on 2-mm torque, hubbing torque, and screw pullout force. Tukey's HSD was used for pairwise comparisons with $P < 0.05$ taken as a statistically significant difference.

RESULTS SECTION: Statistical analysis showed that there was a significant main effect of technique ($P < 0.001$) and region ($P < 0.001$) on the 2-mm torque, and there was a significant interaction ($P < 0.05$) between technique and region. Similarly, there was a significant main effect of technique ($P < 0.001$) and region ($P < 0.001$) on hubbing torque, but there was no significant interaction ($P = 0.236$) between technique and region. Pullout force had a significant main effect of region (both $P < 0.001$), but no significant main effect of technique ($P = 0.303$). For 2-mm torque, Figure 3 shows HSD comparisons results at different spine regions with screw inserted by the two techniques. For comparison, the 2-mm torque using the robot-assisted technique was 0.46 ± 0.25 N*m, significantly greater than the 2-mm torque using the manual technique which was 0.37 ± 0.22 N*m ($P < 0.001$). The hubbing torque for robot-assisted method was 1.44 ± 0.64 N*m, greater than the hubbing torque for manual technique which was 1.24 ± 0.59 N*m ($P < 0.001$). The pullout force for the robot-assisted method was $1,226.33 \pm 1,584.89$ N, whereas the pullout force for the manual technique was $1,360.41 \pm 1586.13$ N ($P = 0.236$). The corrected HU at S4 was 301.15 ± 64.43 (range from 234.86 to 397.21).

DISCUSSION: In our study, the robot-assisted technique resulted in greater insertional torque than the manual technique, which suggests a stronger initial screw purchase. However, no significant difference was observed in screw pullout force. This discrepancy highlights an inconsistency in literature, where some studies have found a correlation between insertional torque and pullout force [1], while others have not [2,3]. One potential reason for similar pullout forces is the "hubbing effect," described by Paik et al. [3], where fractures within the pedicle can compromise pullout force. The advanced age of our bone donors and their increased likelihood of osteoporosis may have exacerbated this effect, potentially reducing any pullout force difference between the two techniques. Additionally, the small sample size of the study may have been insufficient to detect a subtle difference in pullout force. Another limitation was the inflated HU of the bone compared to the literature [4], considering the advanced age of the donors and even after attempting to correct for screw-related artifacts using two-point calibration. This indicates that the impact of screw artifacts on HU values of surrounding tissues may be more extensive than previously thought.

SIGNIFICANCE/CLINICAL RELEVANCE: The robot-assisted method achieved higher insertional torque than the manual method, and pullout forces were similar for both. Further specimens are required to increase statistical power and provide a more robust comparison of the two insertion techniques.

REFERENCES: [1] Zdeblick, Thomas A., et al. "Pedicle screw pullout strength: correlation with insertional torque." *Spine* 18.12 (1993): 1673-1676. [2] Inceoglu, Serkan, Lisa Ferrara, and Robert F. McLain. "Pedicle screw fixation strength: pullout versus insertional torque." *The spine journal* 4.5 (2004): 513-518. [3] Paik, Haines, et al. "The biomechanical effect of pedicle screw hubbing on pullout resistance in the thoracic spine." *The Spine Journal* 12.5 (2012): 417-424. [4] Schreiber, Joseph J., Paul A. Anderson, and Wellington K. Hsu. "Use of computed tomography for assessing bone mineral density." *Neurosurgical focus* 37.1 (2014): E4.

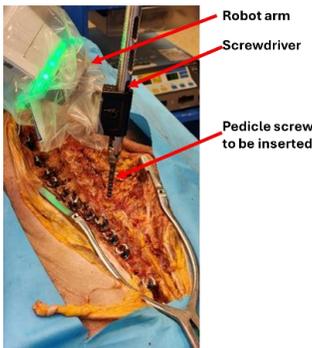


Figure 1. Pedicle screw insertion using robot arm

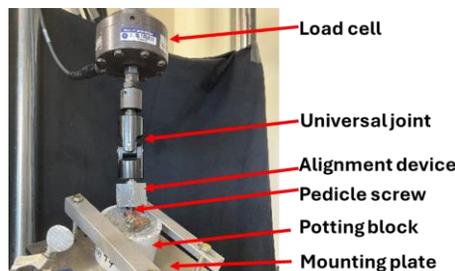


Figure 2. Screw pullout experimental setup

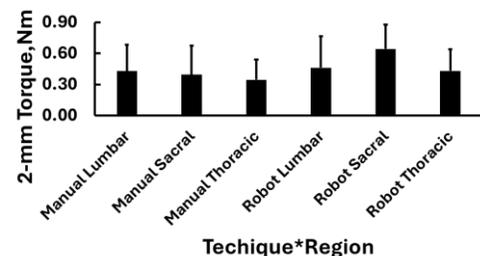


Figure 3. 2-mm torque at different spine regions (thoracic, lumbar, and sacrum) with screws inserted by either manual or robot-assisted techniques