Decreasing the Pedicle Screw Misplacement Rate in the Thoracic Spine With Robot-guided Navigation

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Study Design: A retrospective chart review.

Objective: The aim of this study was to evaluate the screw accuracy of thoracic pedicle screws placed with a robot-guided navigation system.

Summary of Background Data: Thoracic pedicles are smaller in diameter than lumbar pedicles, making pedicle screw placement difficult. Misplaced pedicle screws may present complications including decreased construct stability, and increased risks of neurological deficits and blood vessel perforation. There is a dearth of knowledge on thoracic pedicle screw accuracy placed with a robot.

Materials and Methods: A retrospective analysis of the robot-assisted placement of thoracic pedicle screws was performed. Preoperative and postoperative computed tomography (CT) scans of the implanted thoracic screws were collected to assess screw placement accuracy, pedicle breadth, and placement deviations. A CT-based Gertzbein and Robbins System was used to classify pedicle screw accuracy in 2 mm increments. A custom image overlay software was used to determine the deviations between the preoperatively planned trajectory of pedicle screws and final placement at screw entry (tail), and tip in addition to the angular deviation.

Results: Seventy-five thoracic pedicle screws were implanted by navigated robotic guidance in 17 patients, only 1.3% (1/75) were repositioned intraoperatively. Average patient age and body mass index were 57.5 years and 25.9 kg/m^2, respectively, with 52.9% female patients. Surgery diagnoses were degenerative disk disease (47.1%) and adjacent segment disease (17.6%). There were zero complications, with no returns to the operating room. According to the CT-based Gertzbein and Robbins pedicle screw breach classification system, 93.3% (70/75) screws were grade A or B, 6.6% (5/75) were grade C, and 0% were grade D or E. The average deviation from the preoperative plan to actual final placement was 1.8 ± 1.3 mm for the screw tip, 1.6 ± 0.9 mm for the tail, and 2.1 ± 1.5 degrees of angulation.

Conclusions: The current investigation found a 93.3% accuracy of pedicle screw placement in the thoracic spine. Navigated robot assistance is a useful system for placing screws in the smaller pedicles of the thoracic spine.

Level of Evidence: Level III—retrospective nonexperimental study.

Key Words: robotic-assisted surgery, thoracic pedicle screw accuracy, Gerzbein-Robins Grading System

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Pedicle screw placement remains the gold standard for posterior fixation in spine surgery. Accurate screw placement is of utmost importance, as misplaced pedicle screws may cause neurological damage, biomechanical instability, and perforation of major blood vessels.[1,2] However, in vivo screw accuracy for the lumbar and thoracic spine using the conventional freehand technique varies from 27.6% to 100% with a median accuracy of 83.6%.[3] With the use of computer-based navigation, the in vivo screw accuracy improves to a range of 72% to 100%.[3] In an effort to ensure accurate pedicle screw placement, robot-guided navigation has been developed in recent years. This robotic technology allows a surgeon to preoperatively plan a pedicle screw trajectory using a preoperative computed tomography (CT) scan. Following intraoperative registration, the robotic arm moves to follow the planned trajectory, where the surgeon can then drill and place the screw using an open or percutaneous approach. Studies have shown that robotic assistance can improve screw accuracy rates in comparison to conventional freehand techniques with shorter intraoperative radiation exposure for the patient.[4–8]

While the accurate placement of pedicle screws has been well established in the lumbar spine,[4–7] in the thoracic spine, screw accuracy rates are lower and inconsistent due to smaller pedicles, lower frequency of pedicle screw placement, neurological and vascular anatomy. The

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in vivo misplacement rate of pedicle screws placed in the thoracic region of the spine can range from 7.15% to 30%.[9–12] Gonzalvo et al[13] found a correlation between the size of the pedicle and misplacement rate of pedicle screws, showing as pedicle breadth decreases, misplacement rate increases. With a pedicle breadth of 5 mm or less, the reported misplacement rate is 33%, this rate decreases to 10.7% with a breadth of 5–7 mm.[13] One previous study has shown improved misplacement rates using robotic assistance in thoracic screw placement, 10% with robotics and 15.2% using freehand technique, however, these rates are still higher than lumbar screw placement (2.3%).[14]

Furthermore, there have been few studies that have reported screw accuracy within the thoracic spine using robotic assistance. While there is consensus that screw placement with navigation is better than the conventional freehand technique in the thoracic spine, the lack of published data with robotic assistance makes it difficult to understand its true value in thoracic pedicle screw placement. Therefore, the aim of this study is to evaluate the accuracy and deviation between the planned and placed trajectory of pedicle screws placed with robotic assistance in the thoracic spine.

MATERIALS AND METHODS

A retrospective, single-surgeon, single-center, institutional review board–exempt review of the 75 thoracic pedicle screws placed with robotic assistance was performed. The authors included any adult patient having undergone posterior thoracic spine fixation with the use of a robot between January 2018 and February 2020. However, any patient with a history of previous fusion or fusion attempts at index levels was excluded from the study. Seventeen patients met the criteria and were selected out of a large cohort of patients (367 subjects with robot-assisted spine surgeries) in the study period. The robotic positioning system (ExcelsiusGPS; Globus Medical Inc., Audubon, PA) studied uses radiologic patient images (preoperative CT, intraoperative CT, or fluoroscopy), in addition to a dynamic reference base and positioning cameras to guide pedicle screw placement in real time. This visualization can help guide the surgeon's planning and approach before and during surgery to improve pedicle screw accuracy.

Surgical Technique: Minimally Invasive Navigated Robot-assisted Surgery

The robotic system used the intraoperative CT registration method to determine the image coordinate system. The intraoperative CT scan was obtained using a portable intraoperative CT (eg, O-arm; Medtronic SNT, Louisville, CO) or a standard CT scan taken at the time of surgery with the patient in surgical prone position. After the CT scan and the spinal levels identified, pedicle screw trajectories were planned and saved for each operating vertebral level. The trajectories were planned on the ExcelsiusGPS planning software to optimize screw diameter, length, and position. Reference frames were installed and fixated to the pelvis. However, for upper thoracic levels, the reference frames were affixed to the spinous processes of vertebrae closer to the surgical field. For example, for T3 instrumentation, the frames were fixed to the spinous processes of T12 and T11. All instruments and arrays with reflective markers were registered with the robot. Respiration was halted temporarily, only during registration, to avoid movement of the spine. A surgeon-controlled foot pedal activated and positioned the robot arm to the planned pedicle trajectory. Stab incisions were made on the skin using a scalpel. Pedicle screws were inserted percutaneously using navigated instruments guided by the robotic arm. Screw insertion started at the farthest levels from the frames and progressed towards them. The sequence of awling, drilling, and then tapping was repeated until all pedicle screws were placed on one side, and then a similar order of steps was taken on the other side. Rods were then placed, and locking caps were set once the rods were reduced in the proper position. Intraoperative CT images were taken to verify screw and rod position. Interbody cages (when used) were inserted manually following the insertion of screws. If needed, through a midline incision, direct decompression and fusion with posterolateral grafting would follow. Surgical incisions were cleaned and closed in the standard fashion. Preoperative and postoperative CT scans were collected, along with complication rates.

Outcome Measures

Pedicle screw malposition, reposition, and return to operating room rates were collected to assess complications. Thoracic pedicle breadth was measured according to the literature[15] from the axial view of each vertebral body, as seen in Figure 1. A CT-based Gertzbein and Robbins classification was used to classify pedicle screw placement; screws were graded A (screw is completely within the pedicle), B (pedicle cortical breach <2 mm), C (pedicle cortical breach <4 mm), D (pedicle cortical breach <6 mm), or E (pedicle cortical breach > 6 mm).[16] The evaluator was blinded to the study. Screws assigned an A or B grade were deemed accurate, while screws with a C, D, or E grade were considered inaccurate, as previously described.[16–19] In addition, quantitative 3-dimensional screw tip, tail, and angulation deviations were determined using preoperative and postoperative CT scans. A custom software, developed by Globus Medical Inc., was used to automatically overlay and fuse the preoperative and postoperative CT images of each patient. Preoperatively planned screw trajectories were compared with actual postoperative screw placement (Figs. 2, 3). Tip deviation was measured between plan and placement at the end of the screw (screw tip), whereas tail deviation was at the head of the screw (screw entry point). Both of these measurements were based on the axial, coronal, and sagittal planes and using the 2-dimensional distance formula to report a translational deviation in mm. Angular deviation is the 3-dimensional angle between the tip-tail vector of the preplanned trajectory and the final placement, measured in degrees. All of these measurements were made by using the software, based on purely mathematical and trigonometric formulas. No measurements were manually performed by a human operator.

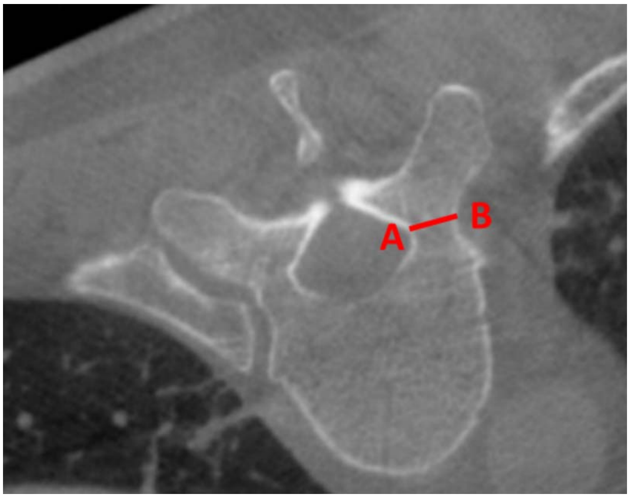

FIGURE 1. Pedicle breadth measured as line AB on the axial view of the preoperative computed tomography scan. full color online

Statistical Analysis

All patient and surgical data, pedicle breadth measurements, and deviations were presented as mean ± SD. For screw accuracy, the number of accurate screws were divided by the number of total screws placed with robotic navigation

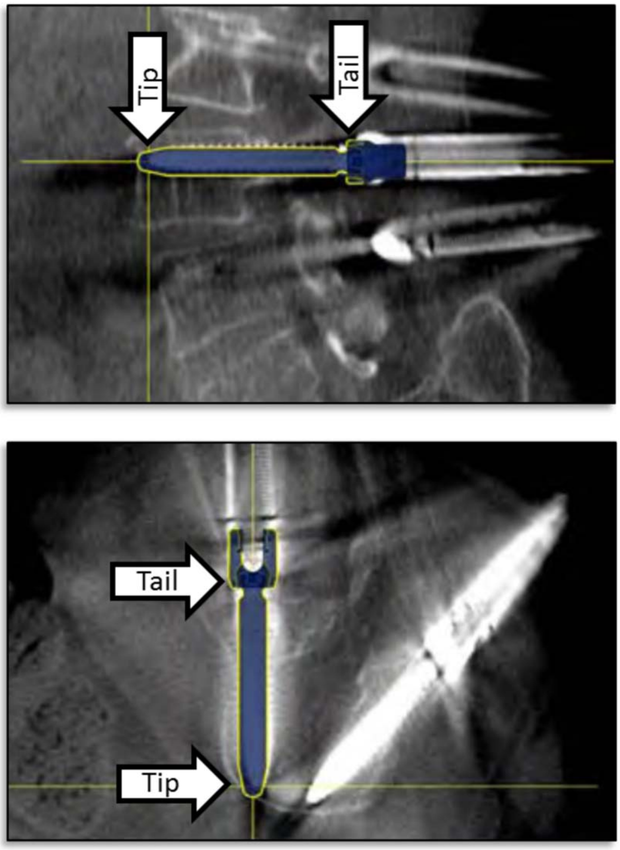

FIGURE 2. Description of the translational (tip and tail) deviation. full color online

to determine percentage accuracy. Correlations between pedicle breadth, screw accuracy, tip, tail, and angular deviations were determined using either the Pearson correlation coefficient or the Spearman rank correlation (SPSS Statistics V. 25; IBM Corp., Armonk, NY). The effect of thoracic level on screw accuracy and deviations was measured using the Mann-Whitney-Wilcoxon test. Significant statistical differences were accepted at *P*-value <0.05 for all analyses.

This case series has been reported in line with the PROCESS Guideline.[20]

RESULTS

Patient Demographics and Surgical Data

Seventy-five thoracic pedicle screws were placed in 17 patients. The average patient age and body mass index was 57.5 ± 17.4 years and 25.9 ± 5.5 kg/m^2, respectively. Of the 17 patients in this study, 52.9% (9/17) were female. Surgery diagnoses were predominantly degenerative disk disease—47.1% (8/17) or adjacent segment disease—17.6% (3/170, Table 1). The main indications for surgery were: myelopathy and spinal canal compression; intractable axial pain; worsening deformity and infection. Various thoracic levels were implanted with pedicle screws with an average pedicle breadth of 4.8 ± 1.5 mm (Table 2). Of the 75 screws, only 1.3% (1/75) were misplaced and repositioned intraoperatively. The mean estimated blood loss was 167.6 ± 142.5 mL. There were zero surgical complications with no returns to the operating room.

Pedicle Screw Accuracy and Deviations

Based on the Gertzbein and Robbins classification, CT-based grading, 93.3% (70/75) of screws were graded A or B, 6.7% (5/75) screws were graded C, and 0% (0/75) screws were graded D or E (Fig. 4). No significant correlation between screw accuracy and pedicle breadth ($P = 0.123$, $\rho = 0.180$) was observed (Fig. 5). There was no significant differences between upper thoracic (T3–T9) and lower thoracic (T10–T12) levels for screw accuracy ($P = 0.631$).

The average deviations from preoperative plan to actual final placement was 1.8 ± 1.3 mm at the tip, 1.6 ± 0.9 mm at the tail, and 2.1 ± 1.5 degrees of angulation. A significant correlation between screw accuracy and tip deviation was observed ($P = 0.031$, $\rho = -0.307$), as screw accuracy decreased, tip deviation increased. In addition, no correlations between screw accuracy and tail deviation or angular deviation were found ($P > 0.054$). There were significant negative correlations between pedicle breadth and tip deviation ($P < 0.001$, $r = -0.430$) as well as between pedicle breadth and angular deviation ($P = 0.037$, $r = -0.241$, Fig. 6). No significant correlation was found between pedicle breadth and tail deviation ($P = 0.654$, Fig. 6). There were no significant differences between upper thoracic (T3–T9) and lower thoracic (T10–T11) levels for tip ($P = 0.310$), tail ($P = 0.182$), or angular ($P = 0.439$) offsets.

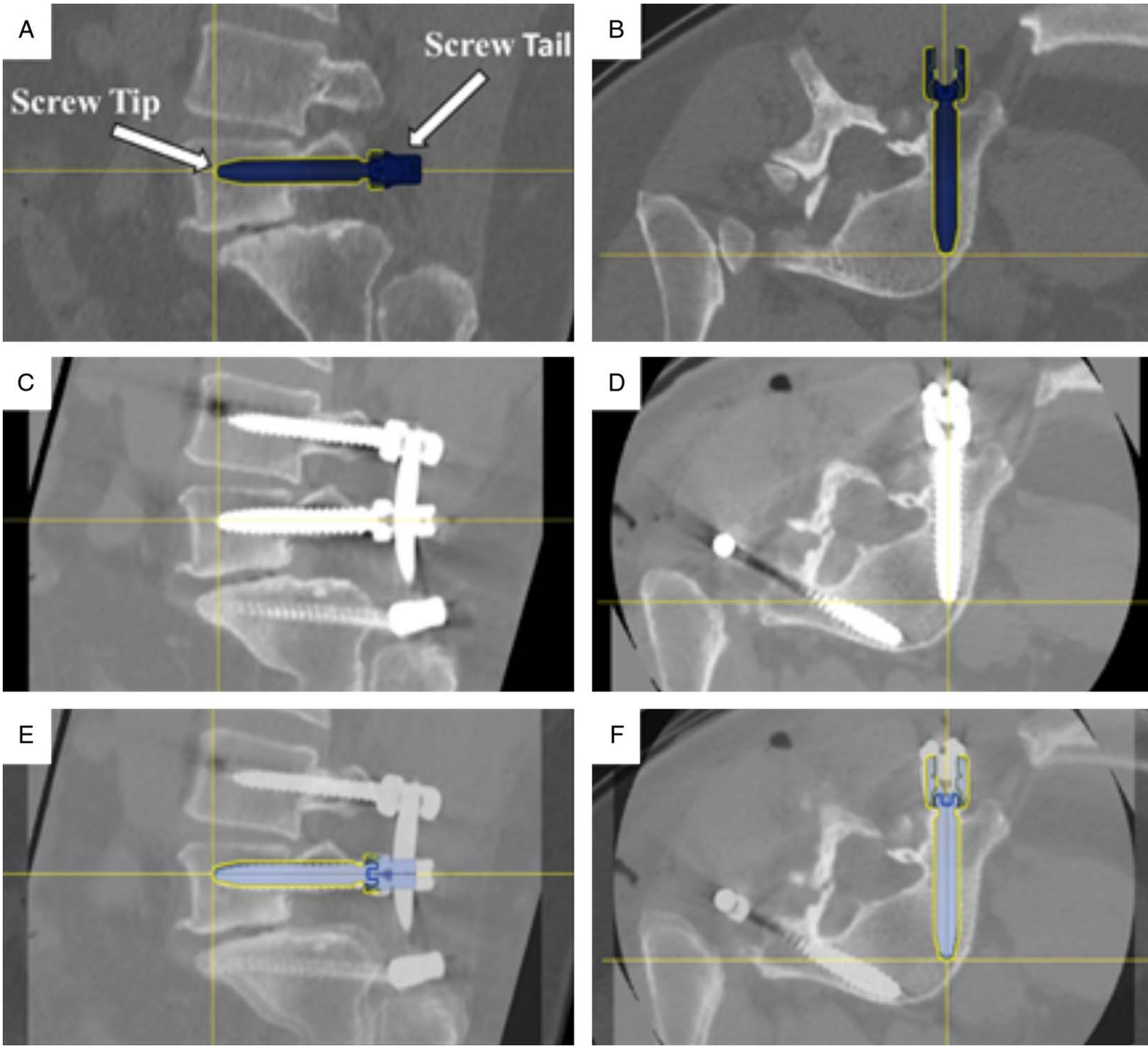

FIGURE 3. Screw tip, tail, and angle deviation assessment. Right L5 screw planning in sagittal (A) and axial (B) planes. Postoperative computed tomography of L5 screw placement in sagittal (C) and axial (D) planes. Image overlay analysis with preoperatively planned trajectory and postoperative screw placement in sagittal (E) and axial (F) planes. The cross-hairs indicate screw tip. full color online

TABLE 1. Baseline Characteristics of the Patient Cohort

Parameters	Overall [n (%)]
No. patients	17
No. screws	75
Sex	
Female	9 (52.9)
Male	8 (47.1)
Age [mean ± SD (range)]	57.5 ± 17.4 (18–83)
Body mass index [mean ± SD (range)]	25.9 ± 5.5 (14.8–38.1)
Diagnosis	
Degenerative disk disease	8 (47.1)
Adjacent segment disease	3 (17.6)
Infection	2 (11.8)
Tumor	2 (11.8)
Fracture	1 (5.9)
Other	1 (5.9)

TABLE 2. Distribution of Level Implanted Within This Study

Parameters	Overall [n (%)]
Levels treated	
T3	4 (5.3)
T4	3 (4.0)
T5	5 (6.7)
T6	4 (5.3)
T7	4 (5.3)
T8	6 (8.0)
T9	12 (16.0)
T10	9 (12.0)
T11	9 (12.0)
T12	19 (25.3)

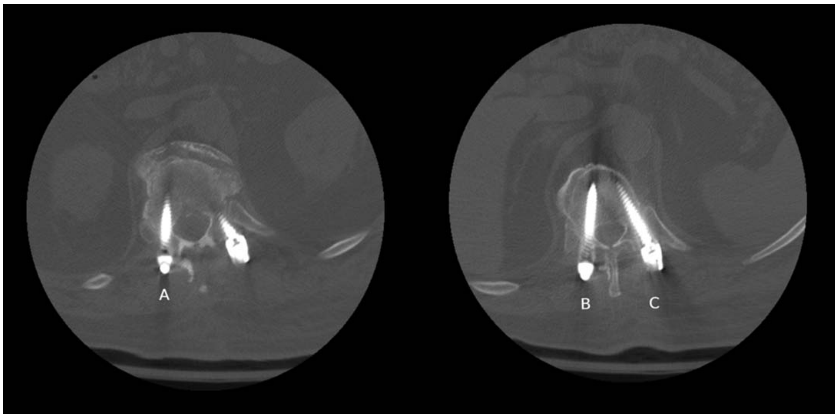

FIGURE 4. Representative computed tomography images of lower thoracic spine showing grades A, B, and C screws.

DISCUSSION

The current investigation found a 93.3% placement accuracy of pedicle screws in the thoracic spine of 17 patients with minimally invasive navigated robotic assistance. Despite no significant correlation between screw accuracy and pedicle breadth, a positive trend was observed (Fig. 5) where screw accuracy increased as pedicle breadth increased. Though not frequently measured in literature, a plan to place deviation of 1.8 mm at the tip and 1.6 mm at the tail was observed with an angular deviation of 2.1 degrees. Tip deviation was found to increase as pedicle breadth and screw accuracy decreased. In addition, the angular deviation increased as pedicle breadth decreased. Interestingly, tail deviation (deviation at screw entry, Fig. 2) did not significantly correlate with either pedicle breadth or screw accuracy.

Screw placement accuracy in the present study was similar to that of 2 other studies, which reported accuracy in the thoracic spine using robotic assistance. van Dijk et al[19] found a 92% accuracy in adult patients with the placement of 33 thoracic pedicle screws, while Macke et al[8] found an accuracy rate of 92.8% in pediatric patients with deformity and placement of 662 thoracic screws. In comparison, the present study found an accuracy rate of 93.3% with placement of 75 screws, which is similar. Pedicle screw placement with navigation has been shown to be more accurate than using the freehand technique, with a mean accuracy of 85.1% versus 63.1%.[3] As expected, robotic assistance screw accuracy is similar to that of navigation, therefore better than the freehand technique. It is important to note that thoracic screw accuracy with robotic assistance has not been thoroughly investigated, unlike lumbar and thoracolumbar screw placement accuracy where there are many studies.[12] Therefore, there is minimal understanding on how robotics can aid in the placement of thoracic screws where anatomy makes it technically challenging. This present study adds to this body of literature to further improve current knowledge.

Thoracic screw placement accuracy in the present study and previous literature is lower than that found within the lumbar spine largely due to the anatomic differences between the 2 regions. Lumbar screw accuracies using robotic assistance are predominantly larger than 95%, with most studies reporting rates between 98% and 99%.[19,21–27] In addition, placing pedicle screws in the thoracic region of the spine has resulted in a higher misplacement rate than when placed in the lumbar spine.[13,28] The lower accuracies and higher misplacement rates are due to a smaller mediolateral diameter and reduced medial inclination in the thoracic pedicle in comparison to the lumbar, leaving less room for error.[29–35] Correlation between pedicle breadth and screw accuracy in the present study did not show significance. However, there was a positive trend showing a relationship, as pedicle breadth increased, screw accuracy increased. In addition, the comparison between upper and lower thoracic levels for screw accuracy resulted in no significant differences, despite pedicle breadth being larger at T10–T12, where the vertebra is transitioning to lumbar vertebral anatomy.

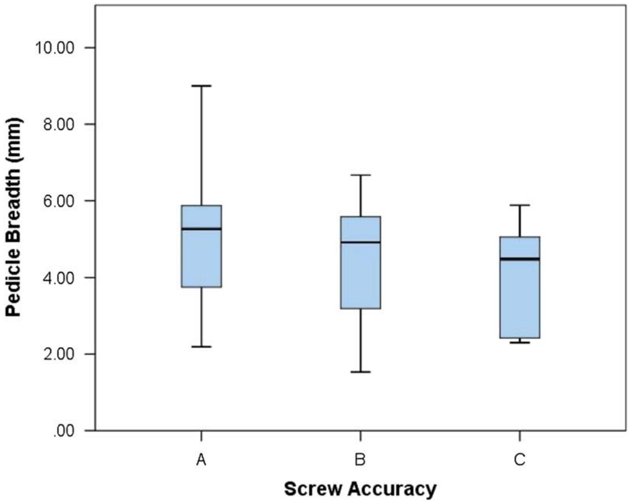

FIGURE 5. Boxplot depicting the correlation between pedicle breadth and screw accuracy based on the Gertzbein and Robbins classification. No significant correlation ($P = 0.123$, $\rho = 0.180$), however, a slight positive trend was observed where pedicle breadth decreases as screw accuracy decreases. full color online

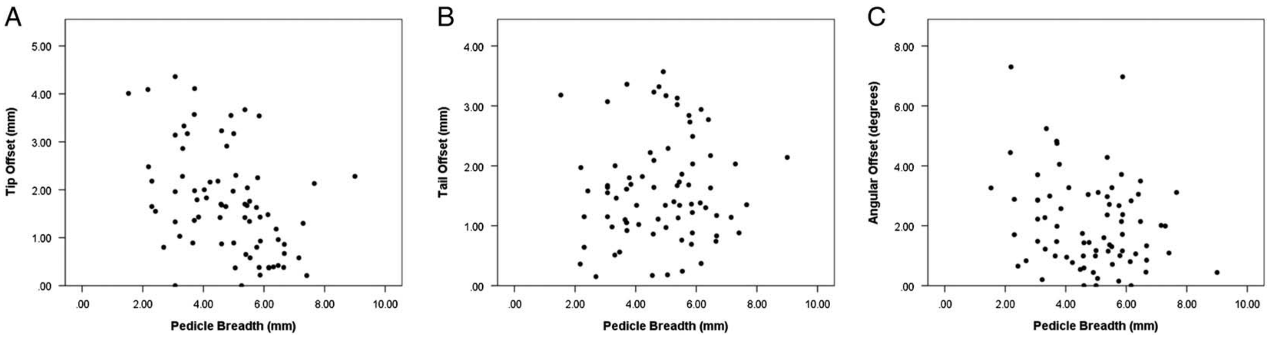

FIGURE 6. Scatter plots showing the correlation between pedicle breadth and tip (A), tail (B), and angular (C) offsets. Offsets are calculated between the preoperatively planned screw trajectory and the final placement. Significant negative correlations were found between pedicle breadth and tip (A) and angular (C) offsets ($P < 0.038$).

The offsets between preoperatively planned trajectory and final placement are scarcely reported in the literature with deviation calculations varying among the studies. The present study is the first to report tip, tail, and angular deviations for thoracic screw placement. Previous studies have measured plan to place deviations for placement of lumbar pedicle screws. The tip (1.8 ± 1.2 mm), tail (1.6 ± 0.9 mm), and angular (2.1 ± 1.5 degrees) deviations in the present study are within the reported range in literature, despite the differences in methods. Devito et al[17] found mean deviations of 1.2 ± 1.49 mm in the axial plane and 1.1 ± 1.15 mm in the sagittal plane where calculations incorporated deviations at entry and exit. These deviations are different than the present study as deviations were calculated separately at screw entry and exit using axial and sagittal measurements. van Dijk and colleagues found screw entry deviation to be 2.0 ± 1.2 mm, where screw entry deviation is similar to the present study's tail deviation. However, both of these studies reported deviation on lumbar only or a combination of thoracic and lumbar pedicle screw placement. The present study reported 3-dimensional angular deviation, however, previous studies have report angular deviations in the axial (2.2 ± 1.7 degrees) and sagittal (2.9 ± 2.4 degrees) planes separately.[19] Previous studies using the ExcelsiusGPS robotic platform reported deviations for lumbar pedicle screws that ranged from 1.7 to 1.9 mm for tip deviation, from 1.8 to 2.3 mm for tail deviation, and from 2.0 to 2.8 degrees for angular deviation,[21–23] which are similar. Despite the differences in measurements, the deviations between preoperatively planned trajectory and final placement of the present study are comparable to the previously mentioned 2 studies.

Correlations between deviations and screw accuracy as well as pedicle breadth were observed in the present study. Screw tip deviation (Fig. 2), negatively correlated with screw accuracy, indicating that as tip deviation increased, screw accuracy decreased. However, both tail (screw entry deviation) and angular deviations (Fig. 2) did not correlate with screw accuracy. van Dijk et al[19] found a significant correlation between screw accuracy and screw entry deviation (similar to tail deviation), whereas accuracy decreased, deviation increased. However, the screw entry deviation was measured predominantly for lumbar pedicle screws. Tip and angular deviations were negatively correlated with pedicle breadth, and there was no correlation with tail deviation. Pedicle screw trajectory may change after initial entry into the pedicle due to anatomic reasons, specifically the size and orientation of the pedicle. This would have more of an effect on the tip and angular deviations than the tail deviation, which measures the deviation at screw entry.

It's important to note the limitation that the present investigation was a single-surgeon, single-site, retrospective study. However, as found with the current lack of literature on thoracic screw accuracy, placement of thoracic screws in adult patients with robotic assistance is not common. In addition, the authors recognize the lower sample size with the number of implanted screws at 75, however, as previously mentioned, robotic placement of thoracic pedicle screws is not as routine as lumbar pedicle screw placement. The method of evaluating screw deviation is limited in the subjective nature of manual image overlay; however, the assessor was blinded to the result of the study. As this was the first ExcelsiusGPS study to report thoracic screw accuracy, intraoperative radiation exposure and operative time was not measured. Therefore, future studies should include multiple sites with larger sample size, radiation exposure, and operative times for full evaluation of a robotic navigation system in the placement of thoracic screws.

CONCLUSIONS

Varying anatomy and surrounding vital organs make accurate placement of pedicle screws in the thoracic spine crucial. The present study found a 93.3% accuracy for pedicle screws placed in the thoracic spine with robotic assistance. In addition, this was the first study to report screw placement deviations between preoperatively planned trajectory and final placement for thoracic pedicle screws. Correlations showed that pedicle breadth may affect screw accuracy, tip, and angular deviation. Based on the findings of this investigation, robot assistance is useful when placing screws in the thoracic spine where challenging anatomy raises the risk of a misplaced screw.

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