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Accuracy and Outcomes of Freehand Thoracic Pedicle Screw Placement using Qi's Technique

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Abstract:

Objective: Many authors have proposed a variety of strategies for freehand thoracic pedicle screw (PS) placement based on identifying ideal entry points and trajectories in the transverse and sagittal planes. This study aimed to assess the accuracy and safety of using a landmark proposed by Qi et al., for determining the entry point and trajectory for freehand thoracic PS placement.

Material and Methods: A total of 59 consecutive adult patients who underwent thoracic (T1-T12) PS fixation using Qi's landmark were enrolled in this retrospective study. Demographic and diagnostic information, adverse events, and postoperative pedicle violation grading were all recorded for analysis.

Results: A total of 398 thoracic pedicle screw insertions were analyzed. There were no cases of postoperative neurological deterioration, however two patients required revision surgery to remove a misplaced screws at T6 and T7 due to significant medial wall violation. A total of 360 PSs (90.5%) and 28 PSs (7.0%) were categorized as having high accuracy and low accuracy, respectively. The remaining 10 PSs (2.5%) in the lateral cortex violation group were considered clinically acceptable due to their position in the rib-pedicle unit. The most common location for misplaced screws was the T4 to T8 vertebral region.

Conclusion: In terms of accuracy and safety, our findings support using Qi's technique for freehand thoracic PS placement. The rate of screw misplacement was comparable to that of other techniques. Surgeons should be familiar with the unique anatomy of the mid-thoracic region because it constitutes the most common site of misplaced screws.

Keywords: accuracy, freehand, pedicle screw, thoracic spine

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Introduction

The pedicle screw (PS) has long been used as a standard spinal fixation device for a variety of spinal pathologies because it provides rigid 3-column fixation and is biomechanically superior to wires or hook constructs.[1-3] Every spinal surgeon must have the necessary knowledge and skills to perform pedicle screw placement. When the PS is not properly positioned, it can result in several serious complications such as neurovascular injury, dural tear with cerebrospinal fluid (CSF) leakage, visceral organ injury, or eventual fixation failure.[2,4,5]

Many technological advancements, such as computerized tomography (CT)-guided surgical navigation systems, robotic-assisted systems, 3-D printed drill guide templates, and augmented reality systems are currently available to assist surgeons in improving the accuracy of PS placement.[6-8] However, implementation of such technological tools has several limitations including very high costs, longer time-consumption, and/or not eliminating the risk of PS malposition.[9] Therefore, the conventional freehand PS placement is still an important skill in the armamentarium, and a familiar technique for most spinal surgeons.

Because of the unique anatomical characteristics of the thoracic spine, freehand PS placement in this area is more challenging and requires a longer learning curve than the same process in the lumbar spine.[9] Malposition of a screw in this spinal section could lead to severe neurovascular complications, including most seriously spinal cord injury. Therefore, accuracy is essential in screw placement.[10] Several authors have proposed a variety of techniques of freehand thoracic PS placement by focusing on the location of entry points and trajectories in the transverse and sagittal planes.[4,11,12] However, novice surgeons insufficiently familiar with the finer details of the thoracic spine anatomy may be uncertain in the selection of an appropriate entry points and trajectories. In practice, novice surgeons planning to specialize in spinal surgery should be encouraged to focus on one technique and practice it under the supervision of an experienced surgeon until the technique becomes consistent and accurate.[12] Recently, Qi et al. proposed a new landmark for determining an entry point and trajectory for PS placement.[13] They stated that their quantitative-based method was simple to learn and use. In our department, we have been using Qi's technique for thoracic PS placement since 2016. The purpose of this study was to report on a single institution's experiences with this technique, and support its accuracy and safety.

Material and Methods

This study constituted a retrospective review of medical records and radiologic images. The study protocol was approved by the Institutional Ethics Committee (SUR-2559-04007).

Between January 2016 and April 2021, 59 consecutive adult patients over 18 years old who had undergone any kind of spinal surgery requiring thoracic (T1-T12) PS fixation performed using Qi's technique were enrolled. Patients not having a postoperative CT scan or who had had percutaneous PS placement were excluded from the study. The clinical characteristics of the participants are presented in Table 1. All surgeries were performed by a single surgeon.

A standard midline posterior approach was used for all surgeries. The lamina, facet joints, and the base of the transverse process were first exposed through subperiosteal dissection. Depending on the pathology, PS insertion was performed before or after the primary procedure such as decompression or tumor removal. The "safe" entry point or zone for PS placement in the planned vertebral level was identified in reference to Qi's landmark, which is defined as the most concave point of the spinous-transverse process junction, as this point consistently indicates the medial cortex of the pedicle (Figures 1 and 2). In the transverse plane, the entry point was 5-10 mm laterally from the Qi's landmark, and it overlaps to the superior ridge of the transverse process in the sagittal plane.

The next step was to create a small entry hole by penetrating the cortex with a high-speed drill or a sharp awl. A blunt-ended curved pedicular probe was then gently introduced through the drilled hole into the pedicle and vertebral body, approximately 20 to 30°, 15 to 20° or 5 to

Table 1 Clinical characteristics of the 59 patients who underwnet thoracic PS insertion

Clinical characteristics	
Sex, Male: Female	45:14
Age, mean±S.D. (range), years	45.23±17.32 (18-86)
Follow-up period, mean±S.D. (range), months	24.89±14.80 (2-51)
Diagnosis (n)	
Trauma	32
Primary spinal tumor	4
Metastasis spinal tumor	18
Spondylodiscitis	3
Thoracic disc herniation	2

S.D.=standard deviation, n=number

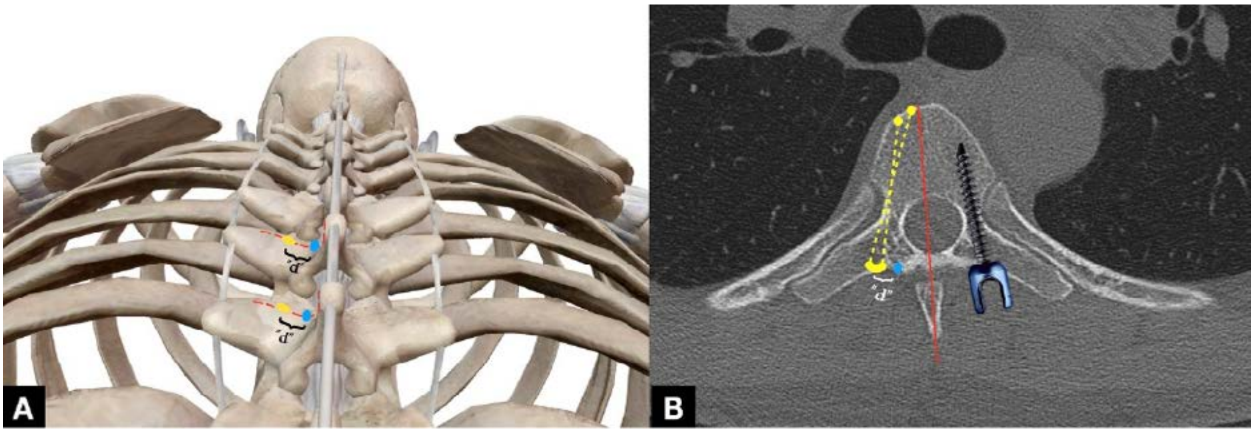

Figure 1 (A) An imaginary line traced from the tip of the spinous process down to the junction of the spinous and transverse processes (red dashes lines), The most concave point is identified as Qi's landmark (blue dots). Then using the distance ("d") from Qi's landmark, the safe entry point or zone (yellow ovals) for PS insertion in the transverse plane could be determined. (B) The trajectories (yellow dashes lines) in the transverse plane are approximately 20-30°, 15-20° and 5-10° towards the midline for vertebral levels T1-2, T3-T4 and T5-T12, respectively. (Image courtesy of visible body[14])

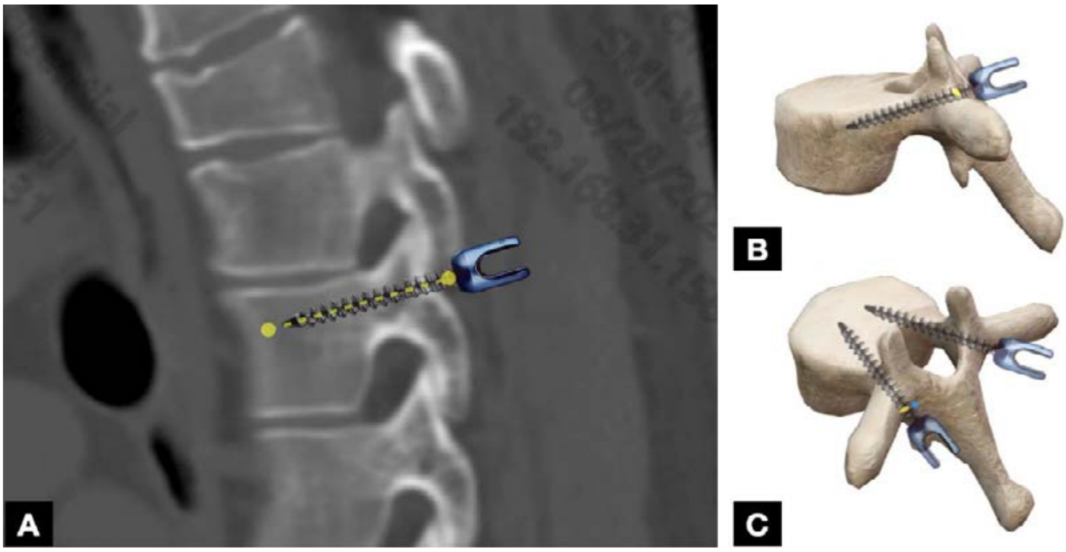

Figure 2 (A–C) The ridge of the transverse process is being used as a reference to locate the safe entry point in the sagittal plane (Table 2), and the sagittal plane trajectories (yellow dashes lines) were controlled using lateral fluoroscopic imaging. The sagittal plane trajectories were approximately 25, 20, 15, 10 and 5° for vertebral levels T1, T2–T6, T7–T10, T11, and T12, respectively. (Image courtesy of visible body[14])

10° towards the midline for vertebral levels T1–2, T3–T4, and T5–T12, respectively, which had been evaluated prior to the surgery with a CT scan. The sagittal plane trajectories were approximately 25°, 20°, 15°, 10° and 5° for vertebral levels T1, T2–T6, T7–T10, T11, and T12, respectively.[10] After reaching the desired depth, a ball-tipped probe was used to determine if the pedicle wall had been violated. The track was redirected when any pedicle violation was identified. A mono- or poly-axial PS was then inserted. We typically used 3.5 to 5.0 mm diameter and 20 to 40 mm-long PSs. Depending on the pre-operative measurements of the planned levels. The procedure was then repeated for all planned vertebral levels. A high-speed drill was used to decorticate the facet joints and transverse processes, and autologous bone chips with or without bone substitutes were deposited in the decorticated bed for spinal fusion.

Demographics, diagnostic data, and adverse events including postoperative neurological deterioration, revision or removal of a screw, surgical site infections and implant failure or loosening of screws were all recorded. Data analysis was performed using Stata version 12.0 (StataCorp, College Station, Texus, USA). All quantitative data are presented in frequencies, percentages, means ± S.Ds., and ranges (min–max).

A thin slice multiplanar CT scan was performed postoperatively in every case to assess the degree of the pedicular wall violation in the transverse plane using Gertzbein and Robbin's grading (Table 2).[15] Grades 1 and 2 were considered to represent 'high' accuracy and grades 3 to 5 as 'low' accuracy of the screw placement. Lateral, superior, or inferior pedicle wall violations of more than 2 mm were also considered as 'low' accuracy and recorded using coronal and sagittal reconstructed CT imaging.

Results

A total of 398 thoracic PSs, placed in 59 consecutive adult patients, were analyzed. No postoperative neurological deteriorations were noted, but due to significant postoperative pain, two patients underwent revision surgery to remove misplaced screws at T6 and T7 (grade 5 pedicle violation). We did not observe any neurological deterioration in these two individuals because they already had paraplegia due to spinal cord injury. Surgical site infection was found in one case. In this study, no implant failures nor screw loosenings were observed.

Table 2 Gertzbein and Robbins's pedicle violation grading

Grade 1: a position without perforation of the wall of the pedicle
Grade 2: perforation of the wall by ≤2 mm
Grade 3: perforation by ≤4 mm
Grade 4: perforation by ≤6 mm
Grade 5: perforation by >6 mm or position outside the pedicle

The number of PSs placed in each thoracic vertebral level is shown in Table 3. A total of 360 PSs (90.5%) and 28 PSs (7.0%) were categorized as having high accuracy and low accuracy, respectively. The remaining 10 PSs (2.5%) in the lateral cortex violation group were considered clinically acceptable due to their position in the rib-pedicle unit. The most common location for misplaced screws in our series was the T4 to T8 vertebral levels, while PS placement in both the upper (T1 to T3) and lower (T9 to T12) thoracic levels had high accuracy (Figure 3).

Discussion

Freehand techniques for thoracic PS placement have been widely used and extensively investigated in both cadaveric and clinical studies because any freehand technique saves time and eliminates the risk of radiation exposure for the surgeon and the remainder of the operating room staff. Many authors have proposed a variety of

Table 3 The number of PS and Gertzbein and Robbins's pedicle violation grading according to each vertebral level.

Level	Total number of PS	Grade 1: n (%)	Grade 2: n (%)	Grade 3: n (%)	Grade 4: n (%)	Grade 5: n (%)	Lateral cortex violation	Superior cortex violation	Inferior cortex violation
T1	12	7 (58.3)	5 (41.7)						
T2	18	12 (66.7)	5 (27.8)					1 (3.5)	
T3	29	21 (72.4)	7 (24.1)	1 (3.5)					
T4	45	32 (71.1)	7 (15.6)	3 (6.7)			2 (4.4)		1 (2.2)
T5	41	25 (61.0)	13 (31.7)	2 (4.9)			1 (2.4)		
T6	45	28 (62.2)	9 (20.0)	2 (4.4)	1 (4.4)	1 (2.2)	2 (4.4)		2 (4.4)
T7	36	19 (52.8)	10 (27.8)	3 (8.3)	1 (2.8)	1 (2.8)	2 (5.6)		
T8	45	22 (48.9)	14 (31.1)	3 (6.7)	1 (2.2)		3 (6.7)		2 (4.4)
T9	54	35 (64.8)	17 (31.5)	2 (3.7)					
T10	31	22 (71.0)	8 (25.8)	1 (3.2)					
T11	23	18 (78.3)	5 (21.7)						
T12	19	15 (79.0)	4 (21.0)						
Total	398	256 (64.3)	104 (26.1)	17 (4.3)	3 (0.8)	2 (0.5)	10 (2.5)	1 (0.3)	5 (1.3)

PS=pedicle screw

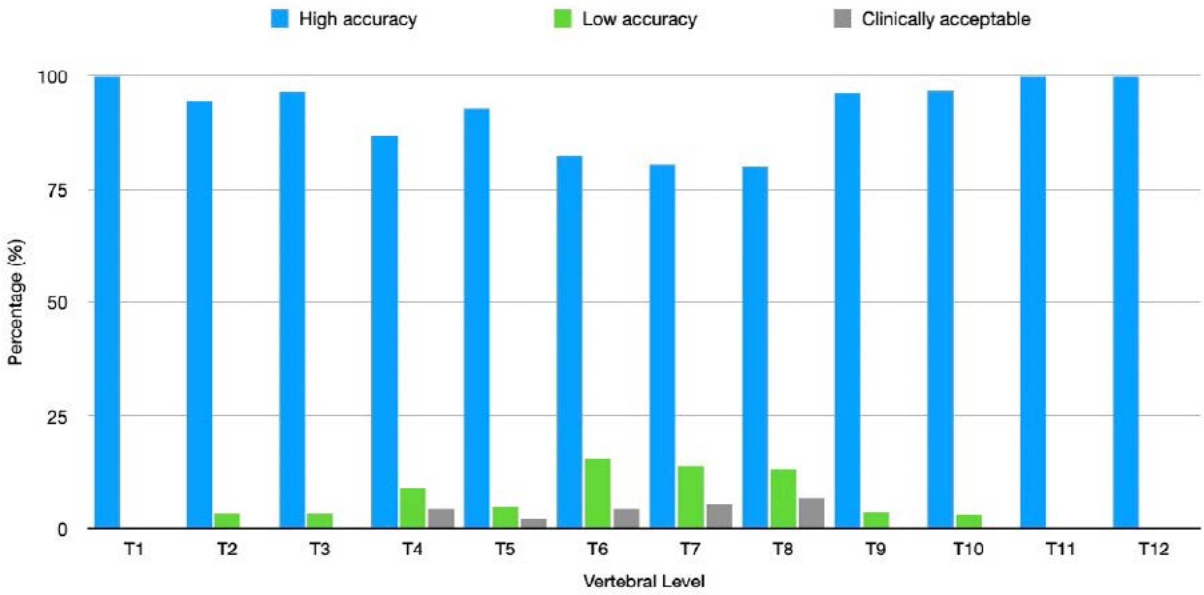

Figure 3 Accuracy of freehand PS placements according to each vertebral level.

freehand strategies based on identifying the ideal entry point and the screw trajectory in the transverse and sagittal planes to meet a challenge of thoracic PS placement. For novice surgeons, remembering and identifying the different landmarks at each thoracic level is the most difficult task. Over several years of experience with almost 60 surgeries, we have found that using the landmark proposed by Qi et al. has the advantages as described following.[13] Determining the optimal position for each thoracic PS entry points was easy, quantitative, and fairly consistent without requiring removing the inferior one-third of the inferior articular facet as in the funnel technique. Additionally, because the Qi's landmark is directly project to the medial wall of the pedicle, staying away from this wall effectively prevents medial wall violation with spinal canal encroachment.

To our knowledge, this is the first study to support the accuracy and safety of freehand thoracic PS placement using Qi's technique. The accuracy rate in our study was found to be high (90.5%) although it was lower than the 96.4% accuracy rate reported in the original study by Qi et al.[13] The overall rate of screw misplacement was only 7.0%, with most of these being medial wall violations (5.5%), and two (0.5%) grade 5 violations requiring revision, one each in T6 and T7.

We found a higher rate of violations of the midthoracic vertebrae, from T4 to T9, than at the upper and lower thoracic levels. These findings were consistent with anatomical studies showing the midthoracic spine (T4 to T9) has a smaller transverse pedicle diameters (4.7 to 6.1 mm) than the upper and lower thoracic spines, which have larger pedicle diameters of 5.6 to 7.9 mm and 6.3 to 7.8 mm, respectively.[1,10] Cho et al. also stated that the spinal canal is shaped like an hourglass, with the narrowest part in the midthoracic spine.[16] Because of these factors, achieving an accurate PS placement in this area is more challenging.[10,15] Apart from the medial wall violations, we found a 2.5% rate of lateral wall violations, which we considered clinically acceptable because there were no post-operative complaints in these cases. The pedicle-ribs complex makes the lateral wall violations safer, except for extremely lateral displacement, which can cause injury to the pleural cavity, major arteries, or even the esophagus. In such cases, several authors have even proposed an extrapedicular approach as an alternative to the conventional PS technique.[17,18] In this study, the patient's outcomes were unaffected despite 0.3% and 1.3% rates of superior and inferior violation, respectively.

In the literature, several different methods of freehand thoracic PS placement have been proposed. Kim et al. reported a 92.0% accuracy rate for freehand thoracic PS placement, but their technique required partial inferior facetectomy to expose the base of the superior articular process, and both the entry point and screw trajectory at each thoracic level appeared to be highly variable and could not be quantified.[20] Modi et al. reported the use of a common entry points for all the thoracic vertebral levels. They defined this ideal entry point as the junction of the outer third and inner two-thirds of the superior articular process. A total of 854 thoracic PSs were placed in their 43 consecutive scoliosis patients. The rates of medial and lateral wall violations were observed to be 10.3% and 21.0%, respectively, with an overall accuracy rate of 93.0%. They did not, however, describe the angles of the transverse and sagittal planes.[21] Fennell et al. and Avila et al. both used the same uniform entry point, which was 3 mm caudal to the transverse-superior articular process (TP-SAP) junction.[22,23] The transverse screw angles were 30° and 20° for the T1-T2 and T3-T12 levels, respectively, and the sagittal plane angle was orthogonal to the dorsal curvature of the spine. With a 96.0% accuracy rate, Fennell et al. found no medial wall violation and only 4.1% minor lateral wall violations. A subsequent study utilizing a computed tomography-based virtual simulation had similar results.[24] Recently, Zhang et al. proposed a new universal entry point and trajectories for all subaxial cervical, thoracic, and lumbosacral spines. For the thoracic spine, they used an entry point 2 mm caudal to the TP-SAP junction, as well as sagittal and transverse planes angles orthogonal to the lamina of each thoracic level. In a total of 219 thoracic PSs placed in non-kyphoscoliosis patients, they identified only one misplaced screw.[25]

In summary, our accuracy rate was comparable to those of other techniques and the incidence of misplaced screws did not exceed that of others (5.8 to 50.0%).[7,15,16,19,26-29] Because this retrospective study was based on the experience of a single surgeon, the findings were not directly comparable to those studies using different surgical techniques. Furthermore, we did not include kyphoscoliosis patients in our analysis, unlike other studies, including the original study by Qi et al. Following a normal learning curve, the surgeon's skills improved over time, resulting in increased PS placement accuracy. Finally, the use of Qi's technique is not practical in cases of a deformed or fractured transverse process. In this circumstance, using a funnel or the extrapedicular technique is recommended.[9,30]

Conclusion

In terms of accuracy and safety, our findings support using Qi's technique for freehand thoracic PS placement. The rate of screw misplacement in our study was comparable to that of other techniques. Due to the unique anatomical characteristics of the midthoracic region, the surgeons should be familiar with the anatomy and procedures to reduce the high rate of misplaced PSs in this region.

Conflict of Interest

None declared.

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