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Thoracic Pedicle Screws

Comparison of Start Points and Trajectories

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Study Design. Experimental design using cadaveric computerized tomography (CT) scans and a computer-assisted image guidance system to compare various thoracic pedicle screw start points and trajectories.

Objective. To compare described thoracic pedicle screw start points and trajectories to determine which allows strictly intrapedicular screw placement with the most margin of error.

Summary of Background Data. Thoracic pedicle screws are being used in a variety of spinal conditions to include fracture, tumor, and deformity. Optimal thoracic pedicle screw start points have received increasing attention in the literature. Optimal thoracic pedicle trajectory is still undetermined.

Methods. Using fine cut CT scans of 3 cadaveric male specimens (aged 65–70 years) loaded onto a computer-assisted image guidance system, 966 pedicle screws, were virtually inserted. The effective pedicle diameter (EPD) and maximum insertional arc (MIA) was assessed using 3 different trajectories and start points: (1) straight ahead, (2) straight forward, and (3) anatomic. EPD was measured by placing a maximum-sized virtual screw, using a specific trajectory, without cortical violation of the pedicle and/or the vertebral body. The MIA was assessed by measurement of the angle formed by the most superiorly and inferiorly directed 0.1-mm virtual screw through a given start point without violation of the pedicle cortex and obtaining at least 50% vertebral body purchase.

Results. Mean EPD in the sagittal plane was 7.6 ± 0.3 (SEM) mm for the straight forward trajectory and 9.1 ± 0.3 (SEM) mm for the anatomic trajectory, a 20% increase ($P < 0.0005$). Mean EPD in the axial plane was 4.1 ± 0.2 (SEM) mm for the straight ahead trajectory and 5.0 ± 0.2 (SEM) mm for the anatomic trajectory, a 22% increase ($P < 0.0005$). EPD was found to be statistically different based on the trajectory used for placement in both the axial and sagittal planes in the upper (T1–T4), middle (T5–T8), and lower (T9–T12) thoracic spine. Mean MIA in the sagittal plane was 18.7 ± 1.1 (SEM) for straight ahead start points, 25.8° ± 0.8° (SEM) for straight forward start points, and 30.2° ± 0.8° (SEM) for anatomic start points, a 38% increase ($P < 0.0005$) in MIA compared with straight ahead and a 17% increase ($P < 0.0005$) in MIA compared with straight forward. Mean MIA in the axial plane was 17.8° ± 0.6° (SEM) for straight ahead and anatomic start points, and 18.6° ± 0.6° (SEM) for straight forward start points. This difference was not statistically significant ($P = 0.086$). MIA was found to be statistically different based on start points used in the sagittal, but not the axial plane, in the upper, middle, and lower thoracic spine.

Conclusion. EPD and MIA are trajectory (EPD) and start point (MIA) dependent. In the axial plane, anatomic EPD was greater than straight ahead EPD. In the sagittal plane, anatomic EPD was greater than straight forward EPD. Using anatomic start points in the sagittal plane, a greater MIA is achievable. These data suggest that in the diminutive thoracic pedicle or when a larger screw is needed, an anatomic trajectory using anatomic start points may allow a larger bone channel for intrapedicular placement of instrumentation.

Key words: pedicle screw, thoracic spine, trajectory, start points, image-guided surgery. **Spine 2008;33: 2675–2681**

Pedicle screw fixation is a widely used method of spinal instrumentation for a variety of conditions to include deformity (scoliosis and kyphosis), fracture, and tumor.[1–8] Transpedicular instrumentation allows for 3-dimensional fixation with a more rigid construct, while permitting a shorter fusion length and less loss of correction.[6,9,10] Pedicle screw instrumentation has been shown to be clinically and biomechanically superior to hook-rod constructs.[3,6,11–16] Although pedicle instrumentation has been used in the lumbar spine for decades, its use in the thoracic spine has become increasingly popular in recent years.[17–21]

Concerns regarding the use of pedicle screw instrumentation in the thoracic spine relate to anatomic constraints and documented complications.[22] Vaccaro *et al* demonstrated the vital vascular and neurologic structures at risk during thoracic pedicle screw instrumentation.[23,24] Ugur *et al* found the mean distance from the dural sac to the medial pedicle cortex to range from 0.0 to 1.4 mm.[25] The thoracic nerve roots are reported to vary from 0.8 to 6.0 mm from the inferior pedicle cortex.[25] The pedicles in the thoracic region are also significantly smaller and more variable in size than those found in the lumbar region.[23,25] Transverse pedicle diameters in the thoracic spine are reported to range from

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4.5 to 7.8 mm, whereas sagittal pedicle isthmus widths can vary from 7.0 to 20.0 mm.[23,26] Thus, the anatomy of the thoracic pedicle is complex and variable throughout the different regions of the thoracic spine.[27–30]

Various thoracic pedicle screw start points have been described in the literature.[6,24,31,32] Roy-Camille advocated a point of entry for screw insertion at the intersection between the midline of the facet joint and the midline of the tranverse process. Using cadeveric specimens, Ebraheim *et al* examined the projection point of the pedicle axis.[33] This was defined as the projection of the pedicle axis onto the posterior osseous elements of T1 through T12. The pedicle axis projection point was found to be 7 to 8 mm medial to the lateral edge of the superior facet and 3 to 4 mm superior to the midline of the transverse process at T1 to T2. From T3 to T12, the pedicle axis projection point was 4 to 5 mm medial to the lateral margin of the facet, and 5 to 8 mm superior to the midline of the transverse process. Magerl recommended a start point on the lower thoracic vertebrae specific to the junction of the lateral margin of the facet, and the midline of the transverse process.[34]

Authors have described different trajectories for thoracic pedicle screw placement. Roy-Camille *et al* described a screw orientation perpendicular to the posterior plane of the facet. Magerl advocated placing the screw at a 10° to 20° angle to the plane of the pedicle-transverse process.[34]

Comparisons between methods of pedicle screw insertion in the thoracic spine has received little attention in the literature.[35] In the present study, the authors compared various thoracic pedicle screw start points and trajectories to evaluate which would allow the largest osseous channel and greatest insertional arc for screw placement.

■ Materials and Methods

Computed tomography (CT) scans of 3 male thoracic spines (aged 65, 65, and 70 years, respectively) were used in this study. Mean CT scan slice thickness was 1.08 mm (range, 1.0–1.25 mm). The CT scans had no radiographic evidence of osseous fracture, metabolic bone disease, or deformity. All CT scan data were loaded onto a Stealth Station platform with MACH 4 (Medtronic Surgical Navagation Technologies, Louisville, CO) software allowing 3-dimensional (3-dimensional) reconstructive capability and the placement of virtual pedicle screws. A total of 966 virtual thoracic pedicle screws were oriented on the 3-dimensional CT images from the 3 study specimens (3 specimens × 12 thoracic levels × bilateral screw placement × 3 different screw trajectories). This technology allowed a precise analysis of spinal anatomy during repeated measurement of screw start points and screw trajectory using maximum-sized virtual screws placed within the same thoracic pedicle. Once a given pedicle was "instrumented" with a virtual thoracic screw, the relevant data were recorded followed by deletion of the on-screen information. Then, a new start point or trajectory was used and the procedure repeated. These methods allowed for a repeated measurement of intrapedicular screw placement among the CT scans from different specimens.

The effective pedicle diameter (EPD) is the maximum pedicle diameter in either the sagittal or axial plane that will allow for a fully contained transpedicular placement of a thoracic screw without cortical penetration. This measurement was performed by placing the largest possible virtual screw using the Stealth Station platform. Three screw trajectories were compared. These trajectories included: (1) the anatomic trajectory,[17] (2) the straight forward trajectory[36] and (3) the straight ahead trajectory.[37,38] In the sagittal and coronal planes, 2 of these screw trajectories are identical. Thus there is only 1 EPD per pedicle for comparison. The total pedicle area available for instrumen-

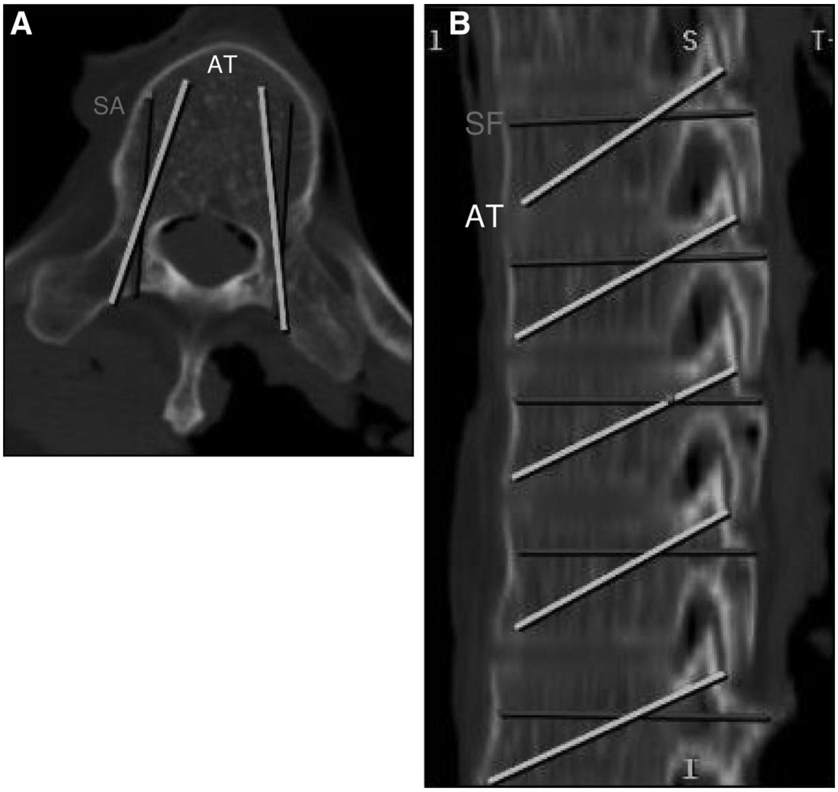

Figure 1. Thoracic pedicle screw trajectories on axial (**A**), and sagittal (**B**) CT slices. The anatomic trajectory is in white; the straight forward/straight ahead trajectory is in gray.

tation was calculated by multiplying the measured sagittal EPD and axial EPD.

The anatomic trajectory is defined by the axis of the pedicle (Figure 1). Morphometric data has shown that the angulation of the pedicle in the axial plane progressively increases as one moves cephalad in the thoracic spine. On average, the thoracic pedicles diverge 2° at T12 and then converge to an average of 17° at T4.[39] In the sagittal plane, the pedicle axis averages 22° of caudad inclination but can range from 17.5° to 27.3° with the most inclination occurring in the midthoracic spine.[33,40] Using the anatomic technique, the sagittal plane trajectory aims for the junction of the anterior-inferior cortex of the vertebral body, which is generally perpendicular to the plane of the superior articular facet.

The straight forward trajectory follows the pedicle axis in the axial plane and parallels the superior endplate of the vertebral body in the sagittal plane.[35] In the sagittal plane, the path of this trajectory generally falls perpendicular to the lamina. The straight ahead trajectory described by Roy-Camille[36,37] parallels the superior endplate in the sagittal plane, and in the axial plane parallels the midsagittal line.

Maximal insertional arc (MIA) is defined as the angle formed by the most cephalad and caudad-directed lines (using 0.1-mm virtual screws) through a specific start point without cortical perforation of the pedicle and passing at least 50% across the vertebral body (Figure 2). The choice of 50% vertebral body purchase was made based on data by Zindrick *et al* who found no difference in pull-out strength between "50%" and "to cortex" depth of insertion of pedicle screws.[11] The start points used for this data set included anatomic,[17] straight forward,[35] and straight ahead (Roy-Camille)[36,37] positions. Figure 3 illustrates the 3 different start points for all thoracic levels. As the anatomic and straight ahead start points are identical in the axial plane, only 1 comparison (anatomic *vs.* straight forward) was made in this plane.

Statistical Analysis

The primary response variable was the EPD (in mm) and was determined in 2 planes (sagittal and axial). The secondary response variable was the MIA (in degrees) and was also made in 2 planes (sagittal and axial). The last response variable was the maximal pedicle area allowable for strictly intrapedicular screw placement (mm^2) using a specified trajectory. EPD and MIA measurements were compared using repeated measures analysis of variance. Area comparisons were determined using the paired *t* test. Significance was defined as $P = 0.05$. Statistical analyses were performed using SPSS, version 11.0 (Chicago, IL).

■ Results

EPD and Area

EPD and area allowable for screw placement varied depending on the trajectory used (Figure 4). For all thoracic levels (anatomic > straight forward), a 1.5 ± 0.5-(SEM)-mm mean difference is seen in the sagittal plane ($P < 0.0005$). A 0.9 ± 0.1-(SEM)-mm mean difference (anatomic > straight ahead) is seen in the axial plane ($P < 0.0005$). Using the anatomic trajectory results in 20% and 22% greater EPD in the sagittal and axial planes, respectively. Data for all thoracic levels is seen in Table 1.

The differences in EPD and the area allowable for screw placement for each trajectory were found to be statistically significant in all regions in both the axial and sagittal planes. In the upper thoracic spine (T1–T4), a 0.7 ± 0.2-(SEM)-mm mean difference (anatomic > straight forward) was seen in the sagittal plane ($P = 0.002$). A 1.3 ± 0.2-(SEM)-mm mean difference (anatomic > straight ahead) was documented in the axial plane ($P < 0.0005$). In the middle thoracic region (T5–T8), a 1.7 ± 0.2-(SEM)-mm mean difference (anatomic > straight forward) was seen in the sagittal plane ($P < 0.0005$). A 0.8 ± 0.1-(SEM)-mm mean difference (anatomic > straight ahead) was noted in the axial plane ($P < 0.0005$). In the lower thoracic spine (T9–T12), a 1.9 ± 0.3-(SEM)-mm mean difference (anatomic > straight forward) is seen in the sagittal plane ($P < 0.0005$). A 0.8 ± 0.2-(SEM)-mm mean difference (anatomic > straight ahead) is seen in the axial plane ($P < 0.0005$). EPD by thoracic region is seen in Figure 5.

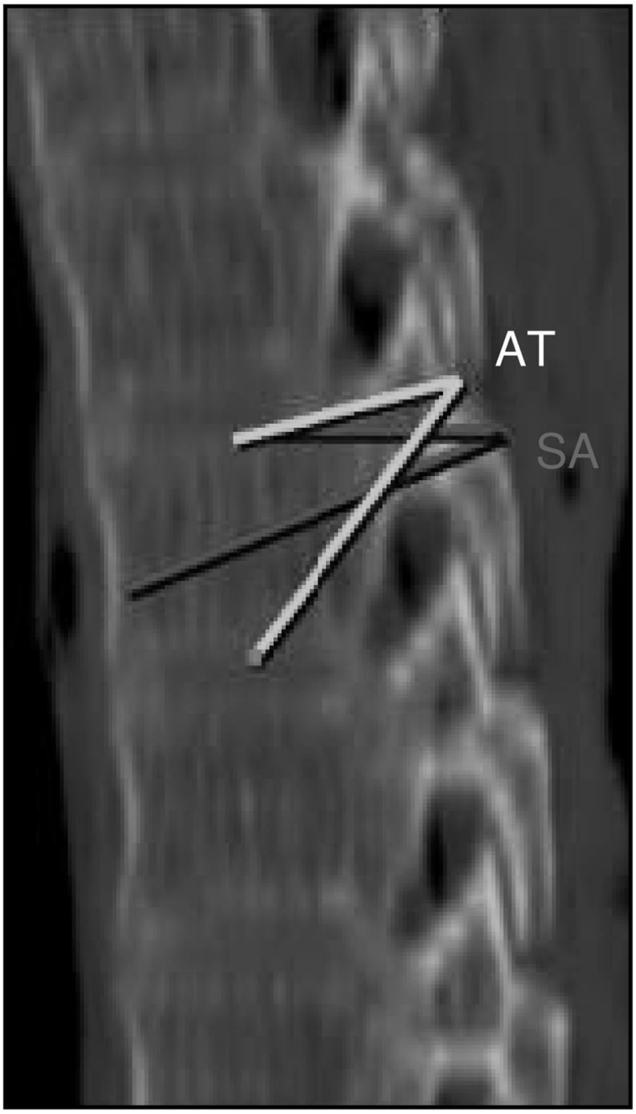

Figure 2. Maximal insertional arc (MIA) using the anatomic (white) and straight ahead (gray) start points. The MIA is defined as the angle formed by the most medial and lateral lines on axial images or, the most cephalad and caudad lines on the sagittal images through a defined thoracic pedicle and passing across at least 50% of the vertebral body.

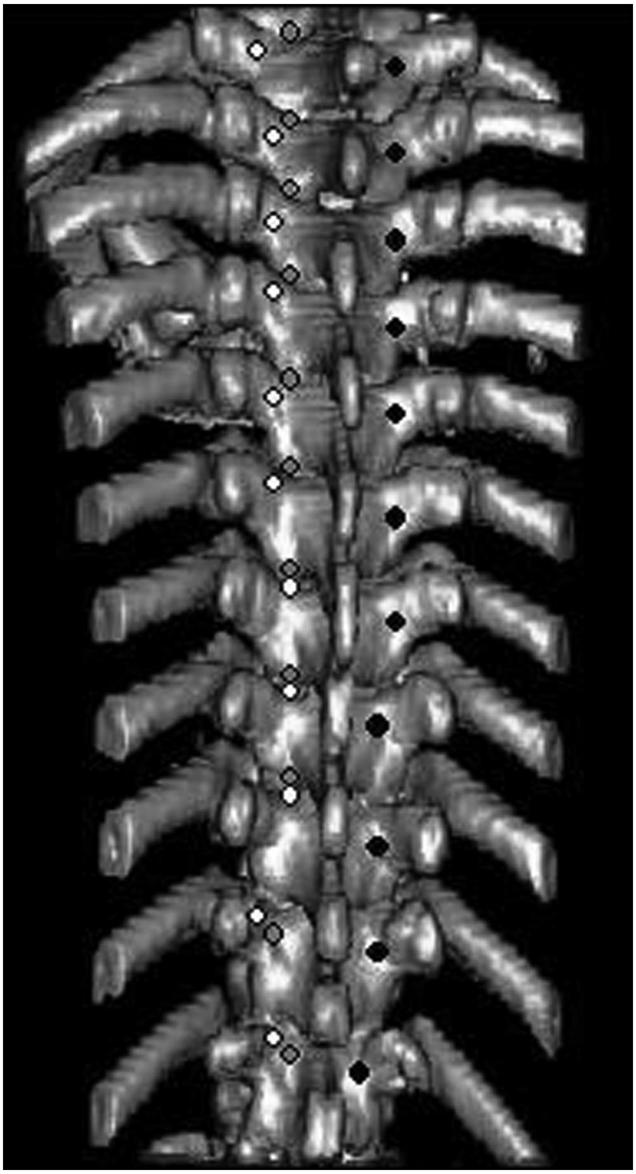

Figure 3. Thoracic pedicle screw start points on the dorsum of a computer-generated 3-dimensional spine model. Straight forward (gray) start points and anatomic (white) start points are represented on the left. Straight ahead (Roy-Camille) start points are represented on the right in black.

Maximal Insertional Arc

The MIA varied in both the sagittal and axial planes and was dependent on which start points were used. For all thoracic regions, a mean difference of 4.4° ± 0.9° (SEM) (anatomic > straight forward) and 7.1° ± 0.8° (SEM) (anatomic > straight ahead) was seen in the sagittal plane ($P < 0.0005$ anatomic *vs.* straight forward, $P < 0.0005$ anatomic *vs.* straight ahead). In the axial plane, a mean difference of 0.9° ± 0.5° (SEM) (straight forward > straight ahead/anatomic) was seen ($P = 0.086$). Data for all thoracic levels is seen in Table 2. Using anatomic start points in the sagittal plane, a 17% increase in MIA compared with straight forward start points, and a 38% increase in MIA compared with straight ahead start points resulted.

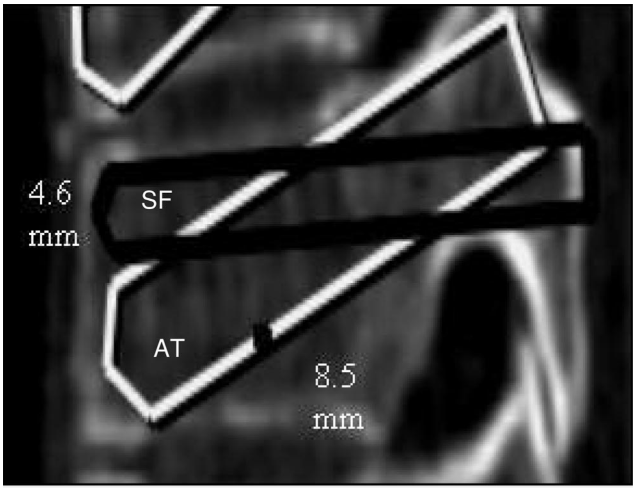

Figure 4. EPD as seen on a sagittal CT slice for the anatomic trajectory (white) and for the straight forward/straight ahead trajectory (gray).

In the upper thoracic spine (T1–T4), a mean difference of 9.9° ± 1.7° (SEM) (anatomic > straight ahead) was seen in the sagittal plane ($P < 0.0005$). A mean difference of 8.2° ± 1.7° (SEM) (anatomic > straight forward) was seen in the sagittal plane ($P < 0.0005$). In the axial plane, a mean difference of 2.0° ± 1.0° (SEM) (straight forward > straight ahead/anatomic) was seen ($P = 0.071$). Figure 6 depicts the regional MIA differences between start points in the sagittal and axial planes.

In the middle thoracic spine (T5–T8), a mean difference of 15.6° ± 1.1° (SEM) (anatomic > straight ahead) was seen in the sagittal plane ($P < 0.0005$). A mean difference of 5.8° ± 1.1° (SEM) (anatomic > straight forward) was seen in the sagittal plane ($P < 0.0005$). In the axial plane, a mean difference of 0.4° ± 0.5° (SEM) (straight forward > straight ahead/anatomic) was seen ($P = 0.426$).

In the lower thoracic spine (T9–T12), a mean difference of 9.0° ± 2.0° (SEM) (anatomic > straight ahead) was seen in the sagittal plane ($P < 0.0005$). A mean difference of 0.3° ± 1.2° (SEM) (straight forward > anatomic) was seen in the sagittal plane ($P = 0.861$). In the axial plane, a difference of 0.4° ± 1.0° (SEM) (straight forward > straight ahead/anatomic) was seen ($P = 0.963$).

■ Discussion

Thoracic pedicle screws provide superior fixation compared with other spinal anchoring devices.[14] They also

Table 1. Table of Thoracic Spine (T1–T12) Effective Pedicle Diameter by Trajectory

	Sagittal*		Axial*	
	Straight Ahead (cm)	Anatomic (cm)	Straight Ahead (cm)	Anatomic (cm)
Mean	7.6	9.1	4.1	5.0
Median	7.0	9.3	3.9	4.9
Standard Error of Mean	0.3	0.3	0.2	0.2

*Statistically significant difference between means-sagittal $P < 0.0005$, axial $P < 0.0005$.

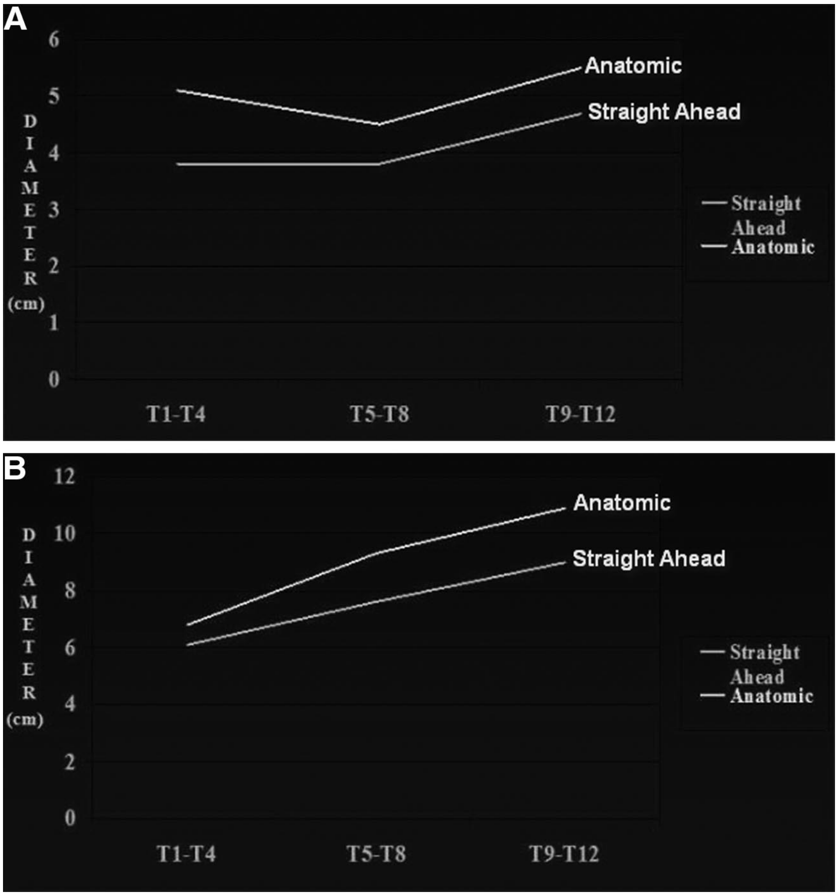

Figure 5. Sagittal (**A**) and axial (**B**) pedicle diameter by trajectory for all thoracic levels T1–T12.

provide for enhanced correction of scoliotic and kyphotic deformities.[12,13] To date, clinical concern has appropriately focused on the safe application of these screws. Studies have emerged detailing the clinical efficacy and safety of thoracic pedicle screw placement.[41–45] As various techniques for thoracic transpedicular screw placement have been devised, the quantitative advantages of each technique relative to screw trajectory and insertional start point has yet to be defined.

Optimal thoracic pedicle screw placement occurs when the screw remains completely within the confines of the outer pedicle cortex. Acceptable screw placement, however, has been defined as a screw position with less than 2 mm of medial cortical violation and up to 6 mm of lateral violation (with the screw actually extending into the costovertebral articulation).[17] Factors influencing the accuracy of screw placement includes: patient size, the region of the thoracic spine, and the presence of scoliotic deformity.[17,18] These factors may affect the size and morphology of the bony pedicle channel.

The results of the present study indicate that the trajectory of a thoracic screw significantly influences the size of the bony pedicle channel available for instrumentation. The anatomic trajectory (with a 22° caudad sagittal inclination) demonstrated a consistently larger (20%) bony channel in the axial and sagittal planes throughout all regions of the thoracic spine.

To our knowledge, the concept of a maximal insertional arc for the placement of thoracic pedicle screws has received little attention in the peer-reviewed spinal literature. We believe that the maximal insertional arc reflects the clinical intraoperative tolerance for accu-

Table 2. Table of MIA by Start Points for All Thoracic Levels, T1–T12

	Sagittal*			Axial†		
	Roy-Camille	Straight Ahead	Anatomic	Roy-Camille	Straight Ahead	Anatomic
Mean	18.7°	25.8°	30.2°	17.8°	18.6°	Same start point as RC
Median	17.0°	25.0°	31.0°	18.0°	18.0°	Same start point as RC
Standard Error of Mean	1.1°	0.8°	0.8°	0.6°	0.6°	Same start point as RC

*Statistically significant difference between means-sagittal RC *vs.* anatomic $P < 0.0005$, RC *vs.* SA $P < 0.0005$, SA *vs.* anatomic $P < 0.0005$.
†Not statistically significant-axial RC *vs.* SA $P = 0.086$.

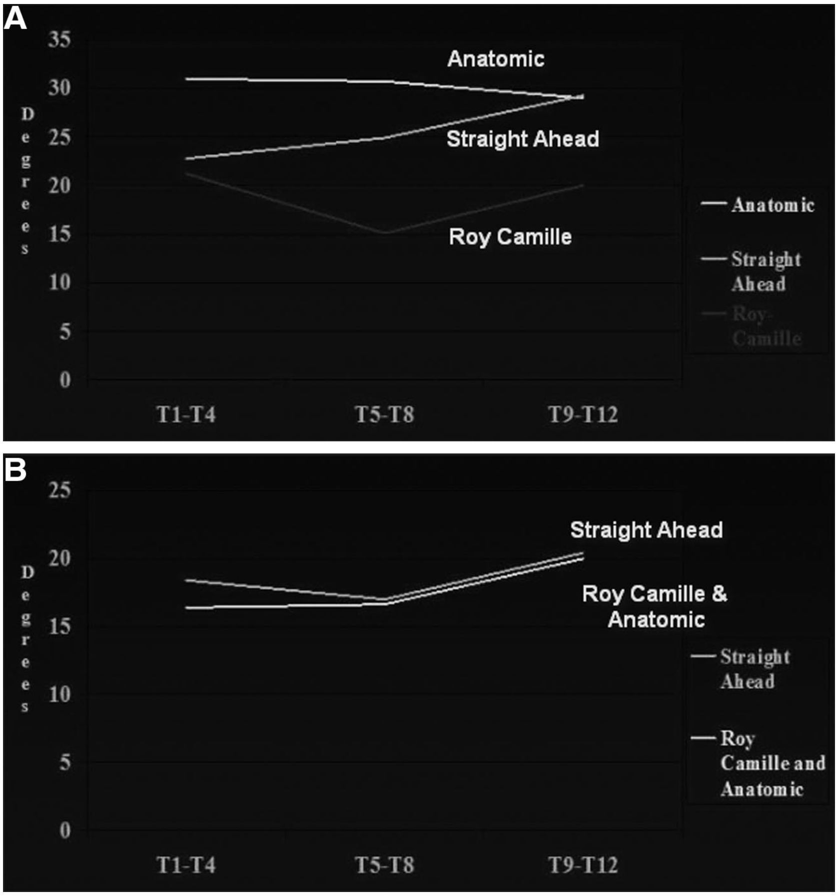

Figure 6. MIA for all thoracic levels in the sagittal plane (**A**) and axial plane (**B**) for various thoracic pedicle screw start points.

rate screw placement as experienced by the surgeon. The isthmus of the thoracic pedicle is the constraining point through which a thoracic screw is navigated. Our clinical experience and cadaveric assessment has shown that on the average, the thoracic pedicle isthmus is located only 15 mm anterior to the dorsal cortical surface of the superior articular facet. Thus, the passage of a screw through the pedicle isthmus occurs early in the process of transpedicular screw placement. The maximum insertional arc is a quantitative measure of screw constraint at the pedicle isthmus and reflects the tolerance for an acceptable screw placement by the surgeon. Again, the anatomic trajectory demonstrates a statistically significant increase in maximal insertional arc throughout all regions of the thoracic spine compared with other screw insertion methods.

The successful placement of thoracic pedicle screws is a multifactorial process. Our study aims to reconcile the various thoracic screw trajectories and start points described in the literature with the anatomic limitations of placing pedicle screws in the thoracic spine. The biomechanics of different trajectories have previously been studied and should also factor into the decision of which trajectory should be used.[46] The present study demonstrates that the maximum effective pedicle diameter and insertional arc are obtained using the anatomic trajectory and start point for any given thoracic level.

■ Key Points

- For all thoracic levels the anatomic trajectory yields a 20% larger effective pedicle diameter in the sagittal plane; a 1.5 ± 0.5-(SEM)-mm mean difference (anatomic > straight forward) is seen in effective pedicle diameter in the sagittal plane ($P < 0.0005$).
- For all thoracic levels the anatomic trajectory yields a 20% larger EPD in the axial plane; a 0.9 ± 0.1-(SEM)-mm mean difference (anatomic > straight ahead) is seen in effective pedicle diameter in the axial plane ($P < 0.0005$).
- For all thoracic levels, a mean difference in maximal insertional angle of 4.4° ± 0.9° (SEM) (anatomic > straight forward) and 7.1° ± 0.8° (SEM) (anatomic > straight ahead) was seen in the sagittal plane ($P < 0.0005$ anatomic *vs.* straight forward, $P < 0.0005$ anatomic *vs.* straight ahead).

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