Original Article

Consistent anatomical relationships of pedicle, lamina, and superior articulating process in severe idiopathic scoliosis allow for safe freehand pedicle screw placement: A proof-of-concept technical study

ABSTRACT

Introduction: Transpedicular screw placement has superior pullout strength compared to alternative forms of spinal fusion and is often performed in deformity correction surgery with navigation for optimal accuracy and reliability. Freehand technique for pedicle screws minimizes operation time and radiation exposure without fluoroscopy but is not widely adopted given the challenge of difficult anatomical corridors and accurate placement, especially in idiopathic scoliosis and advanced deformity. We used a computer-generated model to assess a proof-of-concept and anatomical feasibility of a freehand screw technique in severe scoliosis.

Methods: Three-dimensional (3D) reconstructions of vertebra from a sample of two male patients with severe idiopathic scoliosis deformity (1 thoracic and 1 lumbar) with Cobb angles of 100 were used for planned placement of 17 levels of thoracolumbar (6.5 mm × 45 mm) pedicle screws. 3D reconstruction of each vertebra was created and measurements of screw entries and trajectories were reproduced with a 3D slicer software image computing platform.

Results: Accurate transpedicular screw placement is possible with anatomical landmarks based on the 3D reconstructed vertebral levels. A series of 5 figures were assembled to demonstrate sagittal, coronal, and axial planes and key anatomical landmarks and trajectories of thoracic and lumbar freehand pedicle screws in severe idiopathic scoliosis.

Conclusions: Anatomical landmarks for freehand transpedicular screw placement (between pedicle, lamina, and superior articulating process) are constant and reliable in severe idiopathic scoliosis as evidenced by 3D computer modeling. Preoperative computed tomography modeling may assist appropriate screw entry and trajectory based on anatomical landmarks for spine surgeons, and guide freehand technique for screw placement in adolescent idiopathic scoliosis.

Keywords: Adolescent idiopathic scoliosis, freehand technique, pedicle screws, spinal deformity

INTRODUCTION

Transpedicular screws are a mainstay for the stabilization of the thoracolumbar spine and have demonstrated superior pullout strength given biomechanical torque and cortical interface.[1-5] To minimize radiation exposure to the patient, operating room time, and health-care costs, freehand techniques for pedicle screws of thoracic and lumbar levels are well-described.[6,7] Thoracic transpedicular screws are often cited as some of the most challenging levels for freehand pedicular screw placement with the lowest accuracy

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and most frequent breach complications.[8,9] A narrower cortical corridor of the pedicle allows less margin for error with fewer degrees of freedom compared to larger lumbar pedicles.[8] The consequences of misplaced pedicle screws can be severe, resulting in devastating vascular, neurological, or visceral organ injuries.[10-13]

Accurate and reliable freehand transpedicular screw placement is dependent on the recognition of anatomical landmarks and comfortability with spinal topography. Thus, an inherent challenge exists in freehand technique in the pathologic and variable scoliotic spine. Of all spinal pathologies, adolescent idiopathic scoliosis (AIS) represents one of the most difficult for transpedicular screw placement, with lower accuracies when compared to deformity cases for cerebral palsy and muscular dystrophy.[14] Indeed, breach rates range from 2% to 58% in thoracic AIS pedicle screw placement.[15] Descriptions of the thoracic pedicle screw anatomical entry point in the deformed spine are like those of normal anatomy: lateral border of the pars interarticularis, transverse process, and superior articular facet.[16] However, in cases of some severe deformity, pedicles have been noted to be thin and sclerosed, minimizing the chances of successful pedicle screw placement.[17] Other concerns include skeletal maturity patterns after deformity correction and how screw placement may alter proper growth dynamics.[12] Recent studies have, however, shown successful pedicle screw placement in AIS using freehand technique, despite this technique not being regularly incorporated into clinical practice.[17]

The present study features a three-dimensional (3D) model derived from computed tomography (CT) scans of two patients with severe idiopathic thoracic and lumbar scoliosis and Cobb angle of 100°. Entry and trajectories were simulated in the present cadaveric study to depict a reliable, accurate, and reproducible proof-of-concept design for pedicle screws in the patient with AIS. Thoracic 1–12 and lumbar 1–5 were placed with relevant anatomical landmarks depicted with illustration and explanation for entry and trajectory of transpedicular screws. This model intends to build on existing knowledge of pedicle screw placement with freehand technique to ensure confidence and reproducibility in AIS deformity surgery.

METHODS

Patient selection

A sample of two male patients with severe idiopathic scoliosis deformity (1 thoracic and 1 lumbar) with Cobb angles of 100° were used for the planned placement of 17 levels of clinically relevant thoracolumbar 6.5 mm × 45 mm pedicle screws.

Imaging and three-dimensional reconstruction

CT scans were taken with 3D reconstructions of each vertebral level T1-L5. Modeling allowed for reproducible proof-of-concept anatomical landmarks and trajectory for pedicle screws. Specifically, a computer-generated model of thoracolumbar screws was assembled to demonstrate dimensions, entry points, and trajectories of the freehand pedicle screw technique and to assess the feasibility of placement. Relevant anatomy (including facet, transverse process, pedicle, spinous process, and lamina) was delineated to provide perspective and orientation for the screw entry site. Trajectory lines are further created to demonstrate the path of the screw in sagittal and coronal dimensions. 3D slicer image computing platform software was used to create images, marking entry point, trajectory, and angular measurements in the axial, sagittal, coronal, and oblique planes.

RESULTS

Modeling overview and screw placement

A total of 5 figures are assembled to demonstrate sagittal, coronal, and axial planes of thoracic and lumbar levels. Full 6.5 mm × 45 mm screws were within the pedicle without any form of breach, thus 100% accuracy was achieved with screw placement with entry points, cross-sections, and trajectories modeled.

Relevant views for surgical approach

Modeling yielded a reproducible technique for placement and entry point of screws with attention to concave and convex sides at the levels, as shown in Figure 1. The atrophic convex aspect of T7 and L3 is shown to illustrate the diversion of the superior articular process of the facet joint [Figure 2]. Figure 3 highlights the entry point with relevant landmarks of the facet surface and trajectory. Figure 4 shows the entry point in relation to the lateral margin of the facet joint and the expected differences between the concave and convex aspects of the facet joints. The L3 screw trajectory is illustrated with sagittal and axial images with horizontal axis lines demarcated for comparison and guidance [Figure 5].

DISCUSSION

The present analysis depicts anatomical parameters for a reliable freehand pedicle screw simulation of entry, trajectory, and relevant anatomical considerations in the patient with severe thoracic and lumbar AIS. Transpedicular screws allow rigid 3-column fixation with superior pull-out strength and decreased postoperative pseudarthrosis compared to hook or laminar wire traditional techniques.[15,18,19] In addition, transpedicular screws allow for improved deformity correction and pulmonary function in cases of severe deformity, with

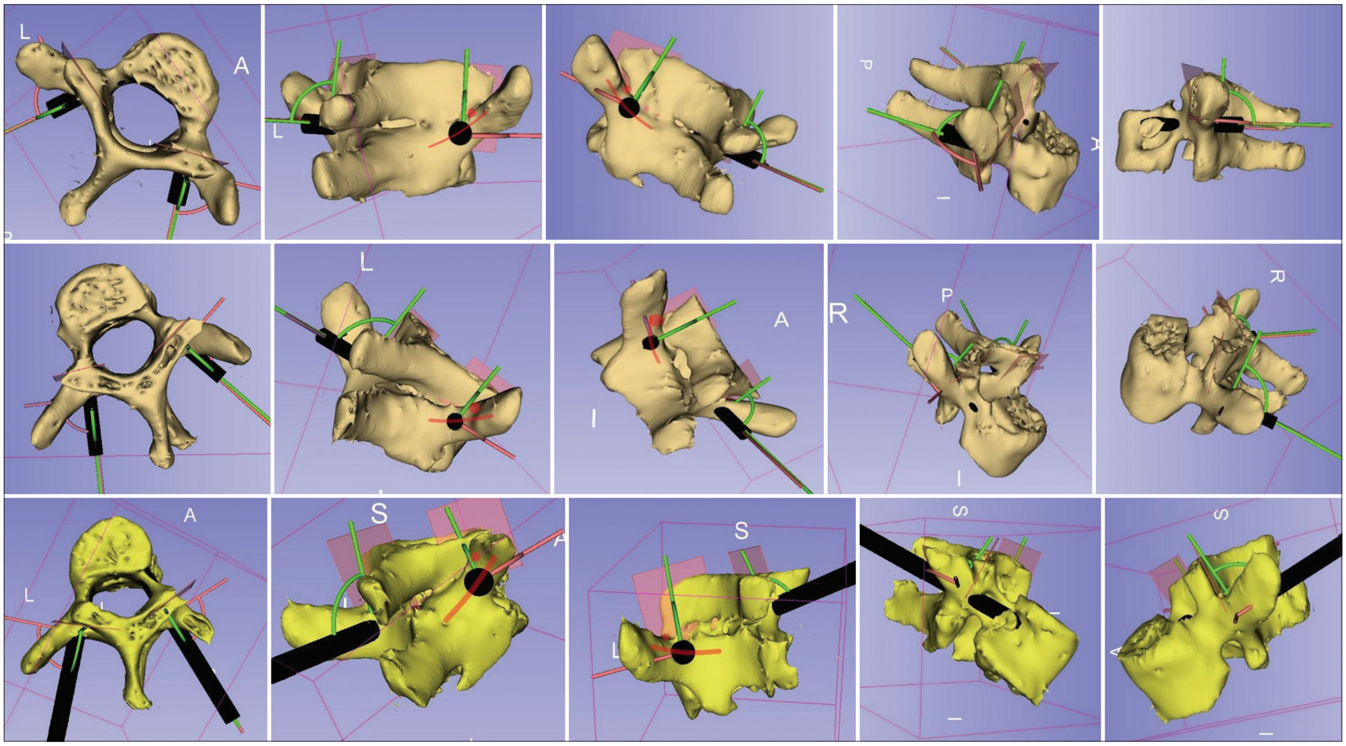

Figure 1: Three rows show different thoracic apical vertebrae (T1-3) in a case of severe idiopathic scoliosis. The left column illustrates the trajectory of the pedicle screw perpendicular to the superior articulating process (SAP). The second and third columns show that the pedicle trajectory (the entry point for pedicle screws) is in line with the lateral margin of the inferior articulating process. The fourth and fifth columns show that the pedicle is almost perpendicular to the SAP in the sagittal plane. The red-shaded rectangle represents the plane of the facet. The red line is perpendicular to the facet joint. Screw entry is medial to the lateral margin of the facet joint and lateral ⅓ of the pars. Green lines are 10° elevated from the horizontal line in the sagittal plane, and the suggested trajectory of the screw. The screws are slightly lateralized in this image

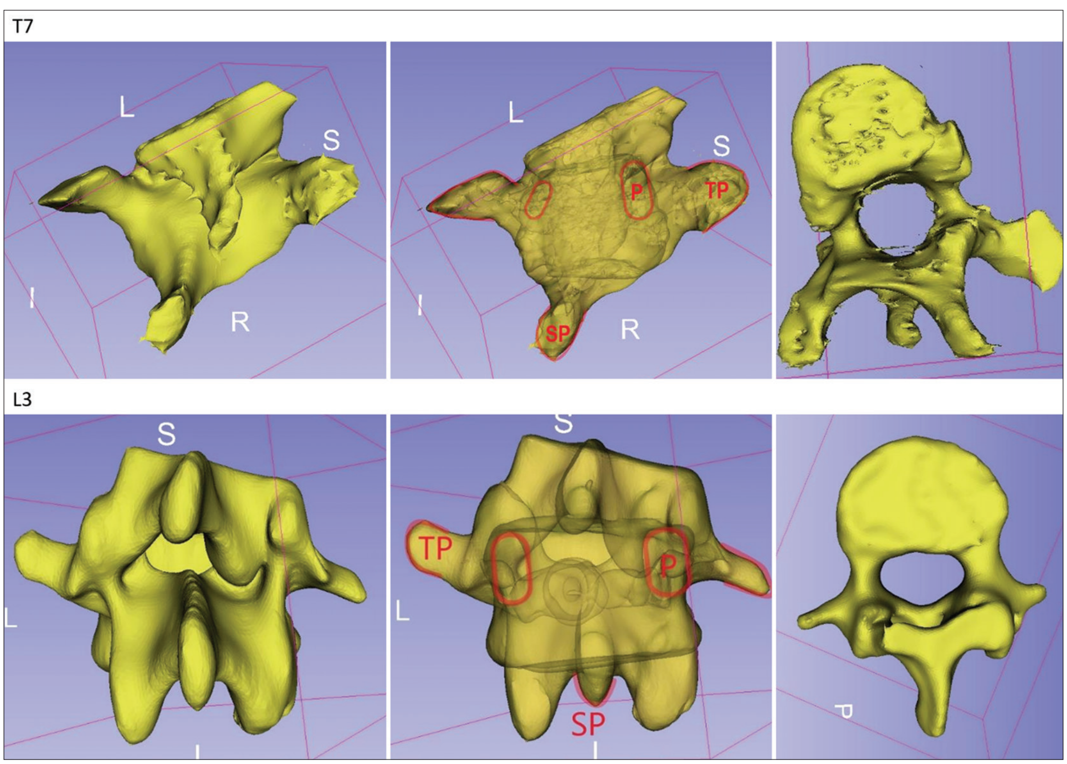

Figure 2: Thoracic screw (T7) and lumbar (L3) anatomy and screw entry point depicted in a case of severe idiopathic scoliosis. Asymmetry is appreciated with a hypertrophic convex aspect and atrophic concave side. The first row shows a mid-thoracic (T7) vertebra and the second row a mid-lumbar (L3) vertebra. Pedicle (p) shown medial to the transverse process (TP). Note the T7 and L3 P and TP are atrophic on the concave side

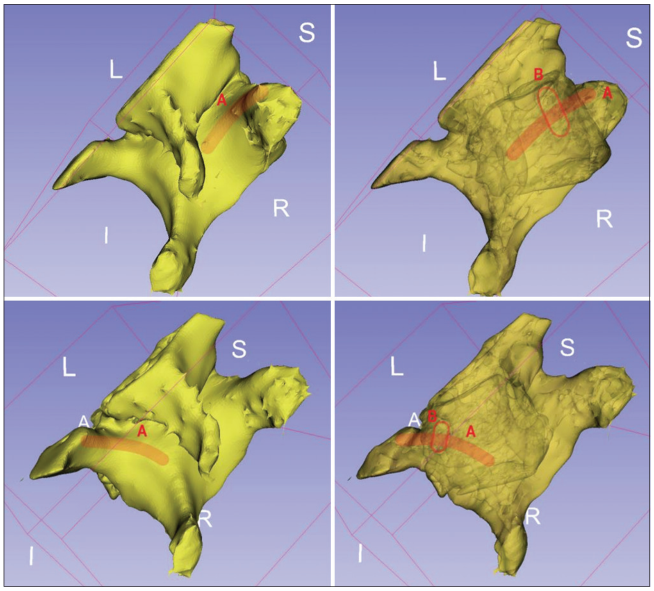

Figure 3: The first image row illustrates the right convex side of a thoracic apical vertebra. The second row shows the left concave side of the same thoracic level. A prominent crest (red, A), which runs along the transverse process into the lamina, is bisected by the center of the pedicle (circled in red and labeled B). Specifically, the entry point for the thoracic screw is along the ridge of lamina that cuts the pedicle at the mid portion. This crest, moreover, can be utilized to access the pedicle

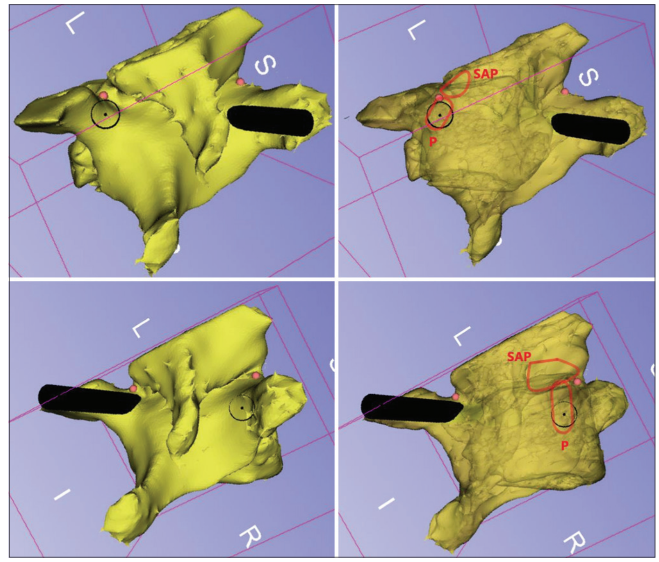

Figure 4: Screw entry point is depicted in relation to the lateral margin of an apical thoracic facet joint (salmon-colored dot). The first row of images shows the right convex side where the center of the pedicle is at the level of the lateral margin of the superior articulating process (SAP). The second row shows the left concave side of the same vertebral level where the center of the pedicle (p) is slightly medial to the lateral margin of the SAP. The size difference of the SAP can be appreciated such that the convex side is smaller compared to the more hypertrophic concave side

possibly fewer levels than comparative techniques.[20] Anatomy is considered highly variable in AIS and poses a risk for neurovascular compromise.[21] However, traditional landmarks with identification of the superior articular process, transverse process, and pars for thoracic levels and the mammillary process landmark for lumbar levels may continue to guide surgeons attempting freehand transpedicular screws in AIS.[16] We demonstrate consistent and reliable anatomical landmarks between the pedicle, lamina, and superior articulating process for transpedicular (6.5 mm × 45 mm) screw placement in severe AIS using CT 3D modeling.

Freehand screw misplacement is more frequently associated with thoracic than lumbar levels and is associated with lateral breaches.[9,15] The lateral region represents a safe zone and often affords fewer clinical injuries in the event of a breach.[22] However, significant lateral cortical violation of the pedicle may result in vascular or visceral injury.[16] Further, <1% of patients have been described to require revision surgeries in freehand pedicle screw placement.[9] Notably, T4 and 6 (each ∼4%) were described to have the highest complication rate.[9] This is consistent with the noted challenge of the thoracic pedicles with shorter diameter pedicles.[23]

The concave side in deformity represents an increased risk of neurological complications and breach compared to the convex side given its proximity to spinal cord position.[21,24,25] In a cohort study of 209 patients receiving thoracic pedicle screw fixation for deformity (81% AIS), concave screws were three times more likely to be misplaced than those in the convex aspect of the vertebral body. Dural tears (1.4% of patients) were all seen during concave pedicle screw placement in the setting of severe scoliotic curves >90°.[26] Pedicle fractures were also observed in 1% of patients all on repeated attempts at screw placement on the concave side. In a prospective study of freehand AIS transpedicular screws, Etemadifar and Jamalaldini demonstrate 86.5% accurate pedicle placement.[15] Of the 13.5% misplaced screws, all were considered Grade 1 or <2 mm of cortical breach deviation. In addition, in a series of 572 patients with freehand placement of thoracic screws–150 of whom were treated for AIS–Kim *et al*. demonstrated efficacy and safety with 6% lateral breach and 1.7% medial breach and no symptomatic consequences across 2 years of follow up.[6] A recent retrospective analysis of 318 patients with AIS with 98% accuracy in the safety zone (graded as 0, 1, or extrapedicular screw placement) without neurological, vascular, or visceral compromise using the free-hand technique.[17] Only 4 of 6358 (0.073%) total screws were revised. Other studies of freehand pedicle screw placement in deformity demonstrate similar accuracy of placement.[27,28] While some studies suggest higher accuracy with navigated pedicle screw placement for AIS,[29,30] freehand technique for thoracolumbar AIS is safe and reliable.[15] In one study of 49 patients receiving freehand versus navigated pedicle screws for moderate AIS, accuracy of pedicle screw placement was equivalent at 96% and the authors reported

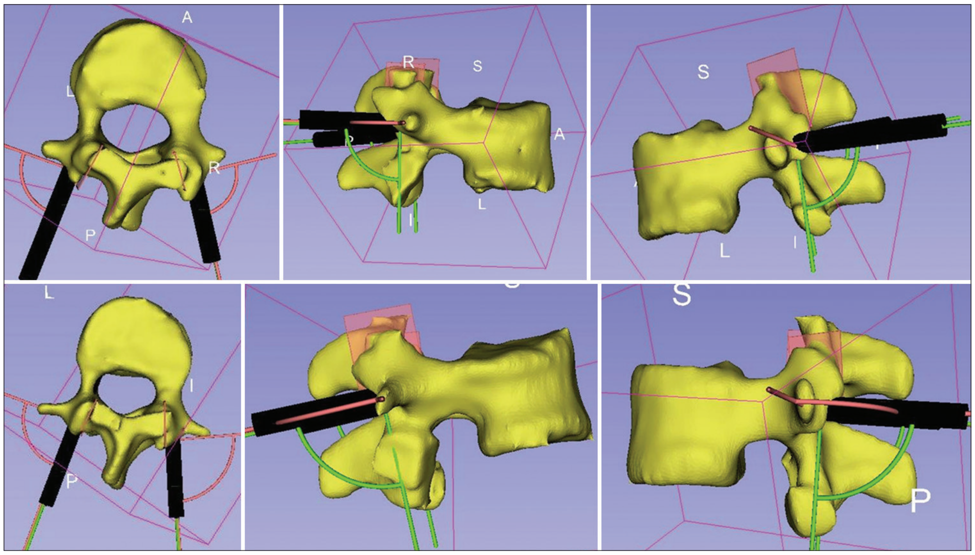

Figure 5: Lumbar apical vertebrae are depicted with screw trajectory with axial, sagittal, coronal views, uniting elements of previous figures for orientation, entry point, and screw trajectory. The first column shows that the pedicle is almost parallel to the superior articulating process. The second and third columns show that the pedicle is perpendicular to a line that connects the entry point with the pars

no benefit to navigated technique.[27] In addition, one meta-analysis showed that improved accuracy with navigated pedicle screw placement in cadaveric or *in vivo* subjects was not shown at thoracic levels.[31]

Achievement of the free-hand pedicle screw in deformity is likely able to reduce operative time, radiation exposure, and overall expenses. Reproducible and reliable freehand screw placement in AIS is possible following consistent anatomical landmarks in the patient with severe AIS.

CONCLUSIONS

Anatomical landmarks for freehand transpedicular (6.5 mm × 45 mm) screw placement (between pedicle, lamina, and superior articulating process) were consistent and technically feasible in severe idiopathic scoliosis as evidenced by 3D computer modeling. Preoperative CT modeling may assist appropriate screw entry and trajectory based on anatomical landmarks for spine surgeons, and guide freehand technique for screw placement in AIS.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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