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Complexity of the thoracic spine pedicle anatomy

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Abstract Transpedicular screw fixation provides rigid stabilization of the thoracolumbar spine. For accurate insertion of screws into the pedicles and to avoid pedicle cortex perforations, more precise knowledge of the anatomy of the pedicles is necessary. This study was designed to visualize graphically the surface anatomy and internal architecture of the pedicles of the thoracic spine. Fifteen vertebrae distributed equally among the upper, middle, and lower thoracic regions were used. For the purpose of mapping surface anatomy, each pedicle was cleaned, spray-painted white, and marked with more than 100 fine points. Using an opto-electronic digitizer, three-dimensional coordinates of the marked points and three additonal points, representing a coordiate system, were digitized. A solid modeling computer program was used to create three-dimensional surface images of the pedicle. To obtain cross-sectional information, each pedicle was sectioned with a thin diamond-blade saw to obtain four slices, 1 mm in thcikness and 0.5 mm apart. The pedicle slices were X-rayed and projected onto a digitizer. The internal and external contours were digitized and converted into graphs by a computer. The pedicles exhibited significant variability in their shape and orientation, not only from region to region within the thoracic spine, but also within the same region and even within the same pedicle. These variations are extremely significant in light of current techniques utilized in transpedicular screw fixation in the thoracic spine. Information documenting the three-dimensional complexity of pedicle anatomy should be valuable for surgeons and investigators interested in spinal instrumentation.

Key words Anatomy · Pedicles · Thoracic spine · Pedicle instrumentation · Biomechanics

Introduction

The current use and popularity of transpedicular screw fixation in rigid stabilization of the thoracolumbar spine have been well documented. Many studies have described techniques of pedicle screw fixation [4, 7, 21, 24] as well as the complex anatomy of the pedicle from a variety of perspectives (see below). Controversy continues, however, regarding the benefits and performance of this technique [12]. Unacceptable rates of pedicle cortex perforations have been described in both in vivo and in vitro studies [5, 7, 23]. Clearly, opinions vary regarding the safety and efficacy of transpedicular screws in spinal stabilization, and more information is needed to assess accurately the correct specific approach to the procedure as well as the overall value of pedicle screw fixation.

The anatomy of the pedicle is complex and varies from region to region in the thoracolumbar spine [8, 15, 25]. There is much information in the literature concerning the morphometry of the thoracolumbar spine [15, 20] as well as the specific anatomy of the pedicle (height, width, axis angles, and landmarks) [2, 3, 9–11, 14, 22, 25]. These studies have served as an anatomical foundation for the development of more sophisticated surgical instrumentation.

To our knowledge, however, there is a void in the literature regarding the true complexity of the pedicle as a variable three-dimensional structure. Studies have described the pedicle as ovoid in shape, with relatively constant dimensions for each spinal level [17, 18, 25]. Our experience has shown otherwise. For adequate utilization of a screw that traverses the extent of the pedicle, in light of the pitfalls of such instrumentation, we feel that accurate information about the pedicle as a non-homogeneous, three-dimensional structure is necessary.

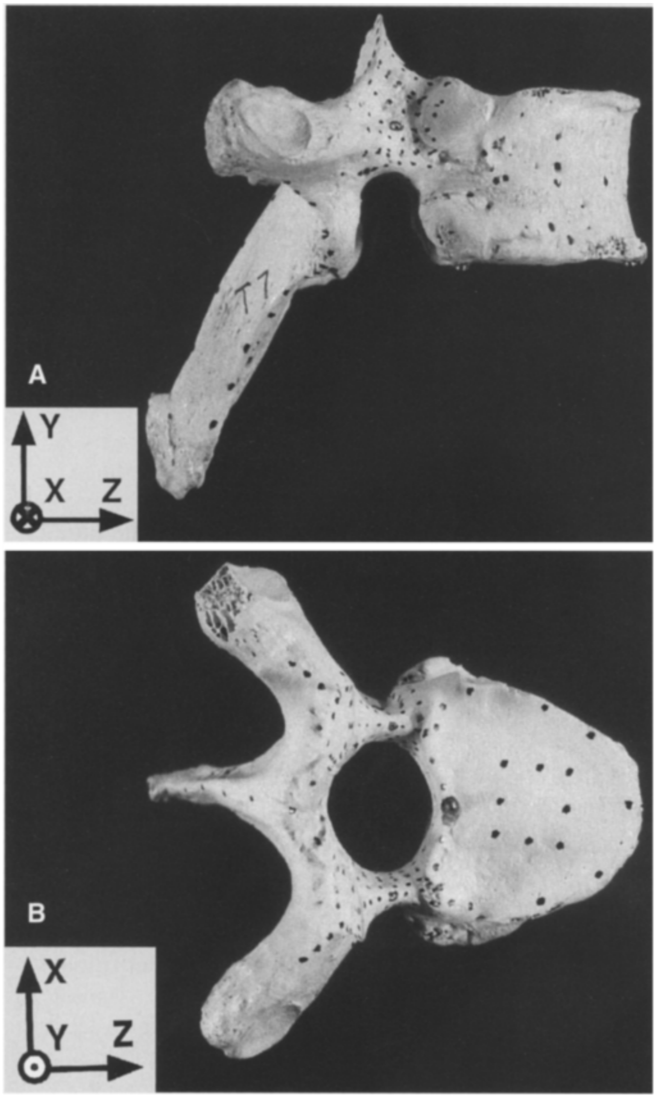

Fig. 1 A, B Photographs of a cleaned vertebra, spray-painted white and marked with more than 100 fine points on its pedicle surface. The points were digitized, documenting the three-dimensional surface of the pedicle. **A** Right-side view; **B** top view

The purpose of this study was to provide an anatomical analysis of the three-dimensional structure of the pedicle. Two methodologies were used: a computer-generated three-dimensional surface model, and a set of cross-sectional contours. Hopefully this graphical study will spark further investigations into instrumentation and surgical approaches in the treatment of the thoracic spine.

Materials and methods

Fifteen isolated thoracic vertebrae were harvested from 13 fresh-frozen, human spinal specimens. The mean age of the spines was 57 years (range 33–82 years), with a male to female ratio of 6:8. Five specimens were chosen from each of the three thoracic transitional zones, as described by Panjabi et al. (upper: five T2; middle three T6 and two T7; and lower: three T10 and two T11) [15]. Specimens with documented abnormalities in bone quality or gross pathology as determined by radiographs were excluded from the study. Each vertebra was dissected out and all soft tissues removed by sharp dissection. The specimens were subsequently immersed in a 1:1 hypochloride bleach solution for 12 h to remove all remaining soft tissue.

Three-dimensional surface model

The cleaned vertebrae were spray-painted with a white flat latex paint for ease of visualization of surface points marked with a fine-tip marker (Fig. 1). The right and left pedicles of each vertebra were marked with a number of points, ranging from 96 in the smaller specimens to 120 in the larger specimens, arranged in a symmetric and even distribution. To establish a standardized coordinate system for the pedicles relative to their vertebral bodies, three small steel balls were glued to the endplates: one on the superior and two on the inferior endplate, in the mid-sagittal plane.

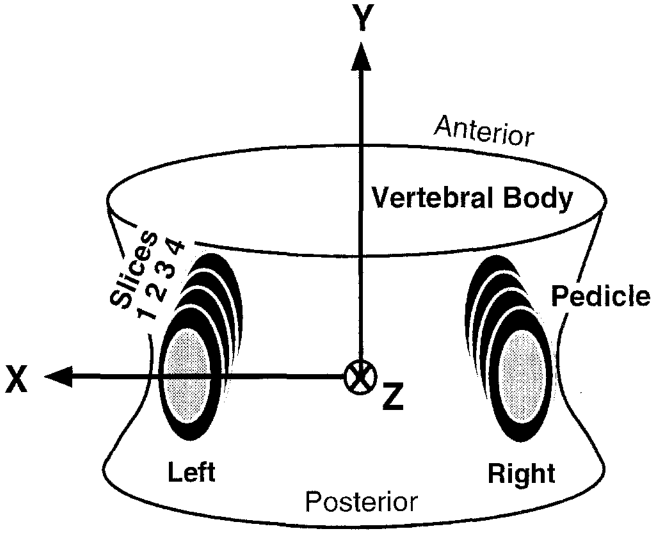

Fig. 2 A schematic representation of a typical vertebra, demonstrating the orientation of the pedicle cross-sections. Slice 1 represents the posterior end of the pedicle at the junction with the inferior articular process, and slice 4 represents the anterior end of the pedicle at the junction with the vertebral body

The two inferior endplate balls were placed at the interesection of the mid-sagittal plane with the anterior-most and posterior-most boundaries of the inferior endplate. Similarly, the superior ball was placed at the posterior-most aspect of the superior endplate. These three "coordinate points" enabled us later to convert all contour data to one standardized coordinate system for inter-specimen comparison.

To digitize the points, a three-dimensional digitizing pointer (Optotrak, Northern Digital, Waterloo, Canada) was used. The specimen was rigidly held in space using a clasp stand. The specimen was oriented to facilitate reaching the whole pedicle with the pointer. The pointer was gently placed on the mark of interest and the point was recorded by a computer upon depression of a foot pedal connected to the Optotrak system. Points were recorded in a systematic fashion around the extent of the pedicle.

The data for each specimen were converted to a standardized three-dimensional coordinate system using the three reference balls, as described above. Special software was written for the coordinate transformation of the array of points on the pedicle into a series of cross sections, and subsequently into a three-dimensional solid model.

Cross-sectional contours

The vertebral specimens were then placed in a specially designed fixation device for rigid attachment to the thin sectioning machine (Hamco Machines, Rochester, N.Y.) such that the 0.5-mm diamond-blade was perpendicular to the axis of one of the pedicles. Although the orientation of the pedicle axis was not quanitified, lateral and transverse radiographs were used to align the pedicle axis in the sectioning machine, so that the cuts were made perpendicular to the pedicle axis. Starting from a point just anterior to the inferior articular facet and progressing anteriorly, 1.0-mm slices were cut. The thin sections were then arranged in anatomical order on a plastic mount, together with a radiographic scale, and X-rayed. The first (no. 1) and last (no. 4) slice were used to describe the anatomical orientation of the slices (Fig. 3). Slice 1 represented the posterior end of the pedicle, at the junction with the inferior articular process, and slice 4 represented the anterior end of the pedicle, at the junction with the vertebral body. The 35-mm photographic slides of the contact radiographs were rear-projected on to a digitizer (magnification × 10) and the internal and external borders of the pedicle were digitized. These coordinate data were then transformed, using specially written software, into smooth cross-sectional surface contours and presented graphically for visualization.

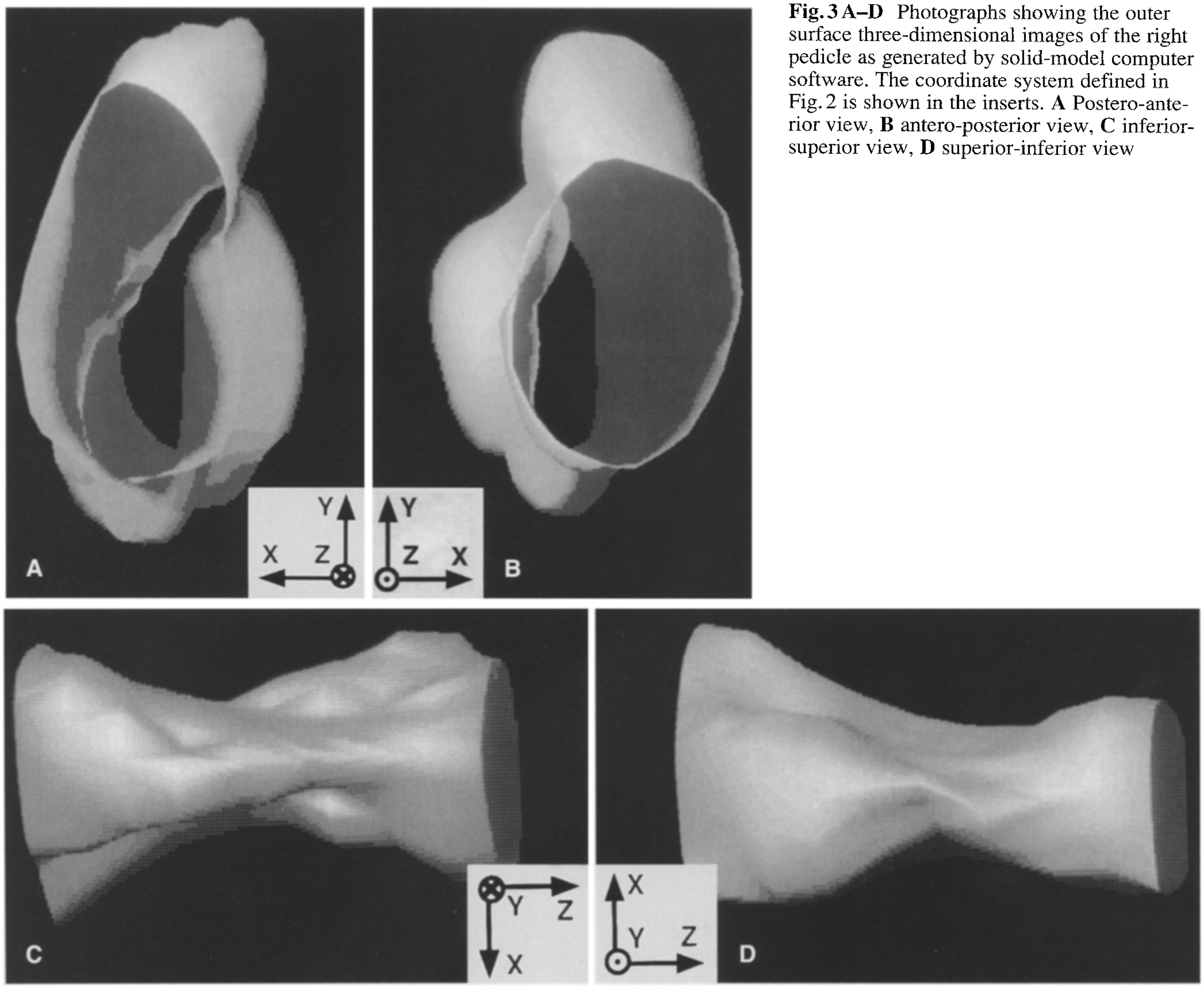

Fig. 3 A–D Photographs showing the outer surface three-dimensional images of the right pedicle as generated by solid-model computer software. The coordinate system defined in Fig. 2 is shown in the inserts. **A** Postero-anterior view, **B** antero-posterior view, **C** inferior-superior view, **D** superior-inferior view

Results

The data for this study are visual in nature, depicting the three-dimensional complexity of the thoracic pedicle.

Three-dimensional surface model

The computer-generated surface model of the pedicles clearly documents the complexity of the shape of the thoracic pedicles (Fig. 3). The cross-sectional shape and size vary along the pedicle axis, and the centers of the cross sections are not aligned along a straight line.

Cross-sectional contours

The external and internal contours of the cross sections of the pedicles are described separately for each of the three regions of the thoracic spine.

Upper thoracic spine

In the upper thoracic spine (Fig. 4), the pedicle (level T2) changes in shape from a teardrop to a kidney shape as the slices progress postero-anteriorly (slice 1 to slice 4). Specimens T2-244, T2-413, and T2-450 all display this progression, with the concavity directed laterally and the medial cortical wall being much thicker than the lateral cortical wall. In specimen T2-207, the superior aspect of the posterior slices is more sharply pointed than in the other specimens, and the anterior slices are more squarely shaped. Specimen T2-402 shows all four slices as being relatively teardrop shaped.

Middle thoracic spine

In the middle thoracic spine (Fig. 5), the pedicle (levels T6 and T7) changes in shape from a tall, narrow teardrop to an "inverted" teardrop (wider convexity at the cuperior pole) as the slices progress postero-anteriorly (slice 1 to slice 4). Variations exist among specimens, yet this pattern is basically seen in all examples. Specimen T6-215 produced only three slices from the left pedicle, due to the length of the pedicle itself. Again, concavity is directed laterally, and the medial cortical wall is substantially thicker than the lateral cortical wall.

Lower thoracic spine

In the lower thoracic spine (Fig. 6), the pedicle (levels T10 and T11) changes in shape in a similar fashion to specimens of levels T6 and T7. All specimens display hetero-

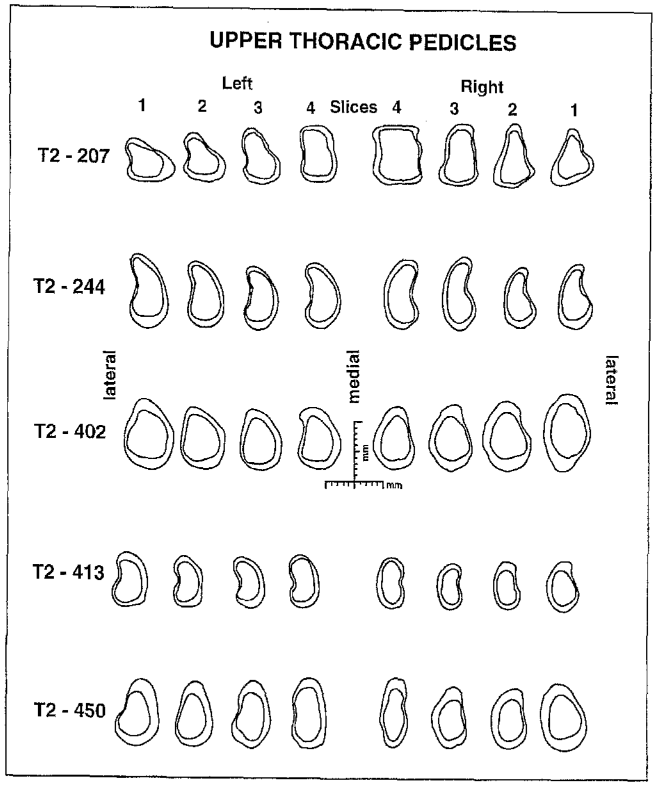

Fig. 4 Upper thoracic pedicles. External and internal contours of the four slices of the left and right pedicles of five vertebrae

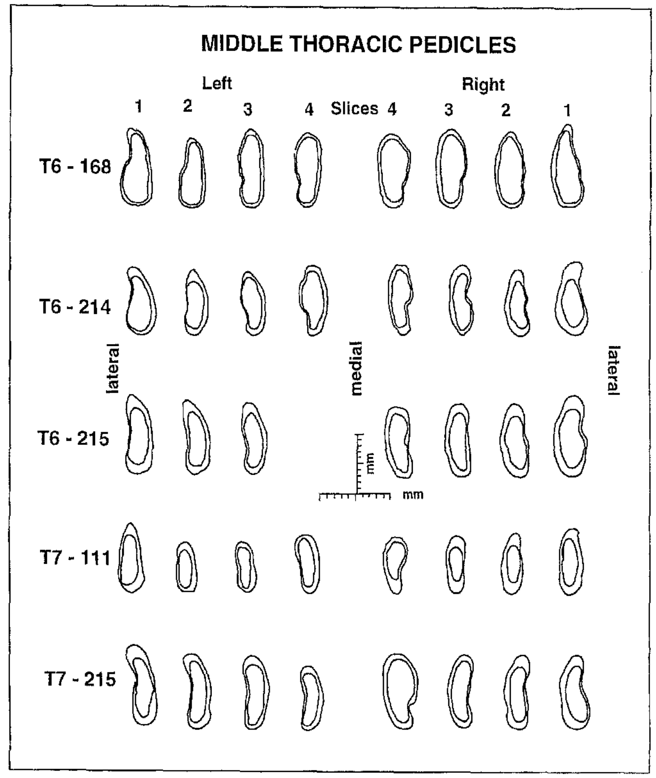

Fig. 5 Middle thoracic pedicles. External and internal contours of the four slices of the left and right pedicles of five vertebrae

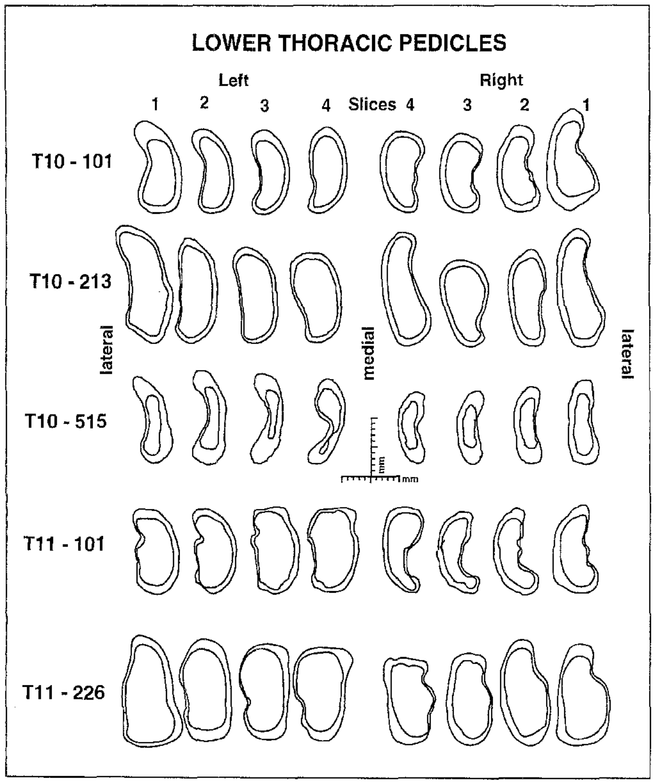

Fig. 6 Lower thoracic pedicles. External and internal contours of the four slices of the left and right pedicles of five vertebrae

geneity in shape near the vertebral body (slices 3 and 4), yet the overall pattern of teardrop to inverted teardrop is seen. Specimen T10-515 is much narrower in the transverse plane, and T11-226 left is markedly wider than the other specimens.

Discussion

In the present anatomical study we have attempted to demonstrate the complex three-dimensional structure of the thoracic pedicle. This was best achieved visually, using sequential cross sections to elaborate the changes in pedicle shape as one moves postero-anteriorly. Among various shapes, we found the majority of the pedicles to be teardrop or kidney shaped, with a laterally directed concavity and a medial convexity. The pedicle exhibited variations in shape and orientation from region to region in the thoracic spine, as well as within the same region and even within the same pedicle. These variations are extremely significant in light of current techniques and equipment utilized in transpedicular screw fixation.

Since early descriptions of the pedicle as a simple cylinder [18, 19], most surgeons have presumably visualized the pedicle as a homogeneous structure with an oval shape. Similarly, anatomical studies have been limited to the description of the height, width, and orientation of the pedicle in the transverse and sagittal planes [3, 9–11, 14, 22, 25]. Although some authors have described the pedicle to be teardrop shaped [10], our study is, to our knowledge, the first systematic, three-dimensional anatomical study of the thoracic pedicle.

The use of the Optotrak three-dimensional opto-electronic camera system enabled us to reconstruct the pedicle surface with high accuracy, as is demonstrated by the three-dimensional image. More difficult was the interpretation of the pedicle cross sections in an analytical manner. It was not possible to quantify the pedicles' complex shapes; we therefore chose to present our data in a qualitative visual manner. The internal structure of these different pedicle specimens, specifically the relationship between the cortical and cancellous bone thicknesses, has been investigated quantitatively in a separate study [8].

The fact that the pedicle structure is significantly more complex than that of a simple cylinder should be of importance for those using pedicle screws for spinal instrumentation. For a kidney-shaped pedicle that curves along its postero-anterior axis, the effective diameter permitting a given screw size is much less than one would expect on the basis of simple measurements of external pedicle width and height. This is especially important for the mid- to lower thoracic spine, where the diameter of the available pedicle screws often exceeds the diameter of the pedicle.

The increasing use of more sophisticated techniques in spinal surgery, e.g., computer-assisted pedicle screw placement as described only recently [1, 13], requires a three-dimensional understanding of the anatomical structures involved. We hope that this study will provide valuable information for surgeons and other investigators interested in spinal instrumentation, and will spark further study into the three-dimensional complexity of the human spine.

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