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The Effect of Thoracolumbar Pedicle Isthmus on Pedicle Screw Accuracy

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Abstract

Study Design: Retrospective analysis.

Objectives: Aberrant pedicle screws can cause serious neurovascular complications. We propose that a predominant factor of pedicle screw breach is the vertebral anatomy at a given spinal level. We aim to investigate the inverse correlation between breach incidence and vertebral isthmus width.

Methods: The computed tomography scans of patients undergoing thoracolumbar surgery were retrospectively reviewed. Breaches were categorized as minor (<2 mm) or major (>2 mm). Breach incidence was stratified by spinal level. Average isthmus width was then compared to the collected breach incidences. A regression analysis and Pearson's correlation were performed.

Results: A total of 656 pedicle screws were placed in 91 patients with 233 detected breaches. Incidence of major breach was 6.3%. Four patients developed post-operative radiculopathy due to breach. Breach incidence was higher in the thoracic than lumbar spine (Fisher's exact test, $P < .0001$). The 2 spinal levels with the thinnest isthmus width (T4 and T5) were breached most often (73.7% and 73.9%, respectively). The 2 spinal levels with the thickest isthmus width (L4 and L5) were breached least often (20.5% and 11.8%). Breach incidence and isthmus width were shown to have a significant inverse correlation (Pearson's correlation, $R^2 = 0.7$, $P < .0001$).

Conclusions: Thinner vertebral isthmus width increases pedicle screw breach incidence. Image-guided assistance may be most useful where breach incidence is highest and isthmus width is lowest (T2 to T6). Despite high incidence of cortical bone violation, there was little correlation with clinical symptoms. A breach is not automatically a clinical problem, provided the screw is structurally sound and the patient is symptomless.

Keywords
thoracolumbar, pedicle screw, spinal navigation; incidence, regression analysis, tomography, X-ray computed, cortical bone, anatomical landmark, radiculopathy, breach

Background

The use of pedicle screws for posterior spinal fixation has become the mainstay of spinal stabilization for all levels. It provides greater control in sagittal, coronal, and axial planes, allowing for greater stability and increased pull-out strength with fewer fused segments.[1] Despite novel adjunctive technologies to aid pedicle screw placement, the freehand technique remains the most widely accepted, particularly in the lumbar spine.[2] Nonetheless, freehand pedicle screw insertion remains technically challenging, especially given that accurate screw placement depends on variable patient-specific and level-specific anatomic landmarks.[3] Given the proximity to pleura, nerve roots, and the spinal cord itself, aberrant screw placement can lead to serious neurovascular complications, radicular pain, sensory loss, damage to great vessels and breech of the pleural cavity.[4-10] In the thoracic spine, transpedicular screw

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placement is even more difficult due to the complex morphology of thoracic spinal vertebrae, greater proximity to neurovascular and visceral structures and greater variability in anatomic landmarks.[11] The use of computer and image-guided devices to assist thoracic screw insertion has thus gained popularity but is limited by increased operative time, radiation exposure and higher cost.[11-15] In this context, freehand placement is still a widely used technique in the thoracic spine that relies on variable anatomic landmarks for screw placement.[1] An interesting study on adolescent idiopathic scoliosis and freehand pedicle screw placement showed that critical distance from entry point plays a large role in medial pedicle breach, even in the most rotated vertebrae or narrowest pedicle width.[16] However, few studies have investigated the role of pedicle isthmus width and pedicle screw breach in the adult population.

We propose that a predominant factor of pedicle screw breach is due to the inherent vertebral anatomy. While it has been previously suggested that vertebrae morphology can influence breach incidence,[3] there has never been a clear link made between isthmus size, namely the narrowest portion of the pedicle in the mediolateral plane,[17] and the rate of pedicle screw breach among adults. The study aims to investigate the correlation between breach incidence and vertebral isthmus width at all spinal levels.

Methods

We retrospectively reviewed a consecutive series of patients from a spine surgeon's start of practice in an academic center to the start of data collection for this study (April 2010 through February 2016). The criteria for inclusion were as follows: (1) patients must have received pedicle screw placement in the thoracolumbar spine, (2) the pedicle screw insertions must span three or more vertebral levels, and (3) patients must have received both pre- and postoperative computed tomography (CT) scans. This is standard protocol for insertion of spinal instrumentation at the Jewish General Hospital, as the preoperative CT establishes an accurate radiological baseline and the postoperative CT may demonstrate asymptomatic breach or pedicle fracture. Patient demographics, clinical presentation, indications for hardware placement, radiological studies, and operative variables were reviewed for each case. Furthermore, onset of postoperative symptoms including sensorimotor deficit and pain were collected during a minimum 2-year follow-up period. All patient charts and imaging were independently reviewed by both K.R and A.M. This data collection was approved by the Jewish General Hospital Ethics Review Board. All pedicle screws were inserted freehand with fluoroscopic assistance in the form of the OEC 9900 C-arm. The accuracy of each pedicle screw was objectively evaluated by comparing preoperative CT scan with a postoperative CT scan, collected at a slice thickness of 1.25 mm. All pedicle screws placed during previous surgeries were excluded. The presence and extent of cortical breach by any misplaced pedicle screw was determined by review and measurement of the postoperative axial CT scan. Lateral screw malposition was measured between the lateral margin of the screw and the lateral cortex of the pedicle or vertebral body while medial screw malposition was measured between the medial pedicle cortex and the medial margin of the screw. The extent of the breach, namely major or minor, was noted in each case. Following the protocol set by Youkilis et al,[11] we defined a minor breach as a screw that extended less than 2 mm beyond the pedicular cortex, while a major breach was defined as a screw extending over 2 mm. Clinical correlation was not a requirement for presence of breach. Breach incidence was computed by spinal level. An average incidence of breach in the lumbar and thoracic spine was obtained and compared using Fisher's exact test. The average isthmus width by spinal level, reported by Zindrick et al[17] in 1986and demonstrated in Figure 1, was then compared with the collected breach incidences by spinal level through a regression analysis with Pearson's correlation.

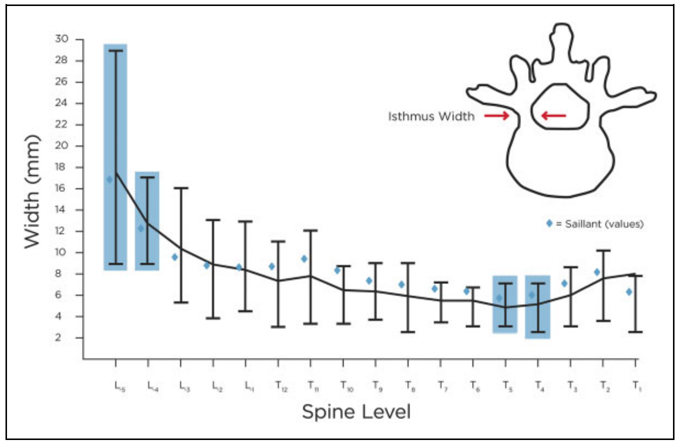

Figure 1. Mean isthmus width by spinal level, as reported by Zindrick et al.[17] Highlighting on L4 and L5 demonstrates the largest average isthmus width while highlighting on T4 and T5 demonstrates the smallest average isthmus width.

Results

A total of 104 patients underwent thoracolumbar surgery at the Jewish General Hospital during the established timeframe. Thirteen of these patients were excluded, as they did not have both pre- and postoperative CT available. Therefore, 91 patients qualified for this study. Mean patient age was 62.9 years, with a range of 19 to 88 and a standard deviation of 13.9. The patients were 58% male and 42% female. The indications for surgery included fracture (5.6%), radiculopathy (18.9%), myelopathy (17.7%), scoliosis (14.4%), stenosis (18.9%), and tumor (24.4%).

Data on pedicle screw placement is given in Table 1. The average incidence of a major breach was 6.3%, with 17.6% of all observed breaches being considered "major." The detectable breaches were 75.5% medial and 24.5% lateral.

Four patients developed a radiculopathy postoperatively that was consistent with the level of a pedicle screw breach. The treating spine surgeon managed these nonoperatively.

Table 1. Number of Thoracolumbar (T2-L5) Pedicle Screws Inserted and Quantity of Major (>2 mm) and Minor (<2 mm) Breach, Stratified by Spinal Level.

Spinal Level	No. of Screws	No. of Total Breach	No. of Major Breaches	No. of Minor Breaches
T2	6	3	1	2
T3	6	4	0	4
T4	19	14	2	12
T5	23	17	6	11
T6	30	20	2	18
T7	31	18	4	14
T8	35	18	4	14
T9	31	17	2	15
T10	33	12	3	9
T11	41	12	2	10
T12	42	17	4	13
L1	40	17	2	15
L2	65	15	1	14
L3	86	22	3	19
L4	83	17	4	13
L5	85	10	1	9
Total	656	233	41	192

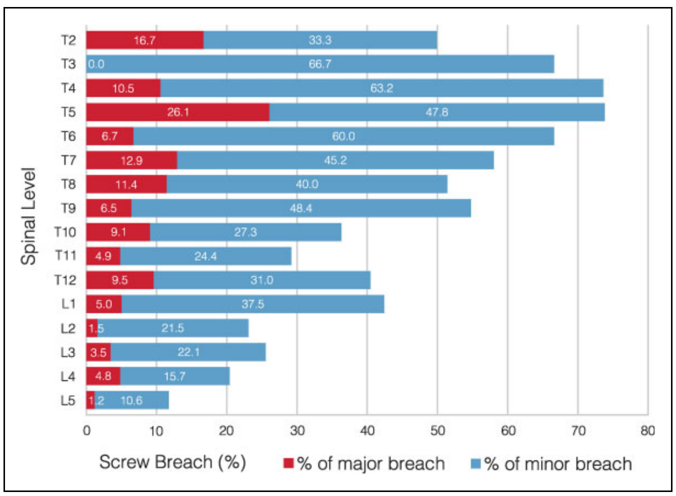

Figure 2. Percent incidence of radiologically detectable pedicle screw breach (>0 mm) by spinal level, stratified by major (>2 mm) or minor (<2 mm) breach.

Three patients warranted surgical revision for postoperative complications: nonunion, compression fracture, and disc herniation, respectively. No surgical revision was due to pedicle screw breach.

The percent incidence of detectable breach (>0 mm) by spinal level is demonstrated in Figure 2. There were 297 screws placed in the thoracic spine with 152 detectable breaches (51.2%), of which 30 were major (10.1%). There were 359 screws placed in the lumbar spine with 81 detectable breaches (22.6%), of which 11 were major (3.1%). The ratio of thoracic to lumbar breach incidence is 2.3 to 1. When stratifying major breaches by spinal level, both the overall breach incidence and the major breach incidence were significantly more frequent in the thoracic spine than in the lumbar spine (Fisher's exact test, $P < .0001$). Moreover, L5 had the lowest incidence of detectable breach at 11.7%, while T5 had the highest incidence of both detectable breach and major breach, with a major breach incidence of 26.1%.

The 2 spinal levels with the thinnest average isthmus width—T4 and T5—had the highest breach incidence (73.7% and 73.9%, respectively). The 2 spinal levels with the thickest average isthmus width—L4 and L5—had the lowest breach incidence (20.5% and 11.8%, respectively). The mean and standard deviation of isthmus width by spinal level, reported by Zindrick et al,[17] was compared with our breach incidence by spinal level. Regression analysis demonstrated that breach incidence and isthmus width have a significant inverse correlation with $R^2 = 0.705$ (Pearson's correlation, $P < .0001$), as described in Figure 3.

Discussion

The study demonstrates the significant inverse correlation between breach incidence and vertebral isthmus width, supporting that the vertebral anatomy inherent to a given spinal level, particularly pedicle diameter, influences pedicle screw accuracy. This seems intuitive, as the narrower the pedicle, the more difficult it is to find the correct trajectory for the screw.

As Zindrick et al[17] previously demonstrated, thoracic vertebrae have a smaller isthmus width than lumbar vertebrae. Furthermore, in morphometric analyses of cadaveric vertebrae, Vaccaro et al showed that thoracic pedicles are more three-dimensionally complex with considerable interpatient and interlevel variation.[18] Geometric studies of vertebral anatomy have also shown that thoracic vertebrae have a much narrower permissible rotational and translational margin of error than lumbar vertebrae.[19] These variations in the thoracic spine make finding anatomical landmarks for pedicle screw placement inherently difficult. Furthermore, intraoperative fluoroscopic quality is inferior in the thoracic spine. Comparatively, the more consistent anatomical landmarks seen in the lumbar spine, coupled with a larger isthmus width, make for more easily identified pedicle screw entry points.[17] The increased difficulty for pedicle screw placement in the thoracic spine is supported by our findings, in that both the overall breach incidence and the major breach incidence were significantly more frequent in the thoracic spine than in the lumbar spine (Fisher's exact test, $P < .0001$). Moreover, the distribution of breach incidence between thoracic and lumbar levels (2.3:1) was similar to a study from Parker et al,[3] which showed a ratio of 2.7 to 1. Given T5 has the smallest mean isthmus width, it has fewer degrees of freedom compared with any other thoracolumbar level. This reinforces our finding that T5 has the highest recorded incidence of major breach at 26%. Furthermore, our regression analysis suggests that isthmus width and breach incidence correlate significantly with $R^2 = 0.705$ (Pearson's correlation, $P < .0001$).

Our results parallel what has been put forth by previous studies—the rates of major breach in our study were within the expected range for the freehand technique. A meta-analysis

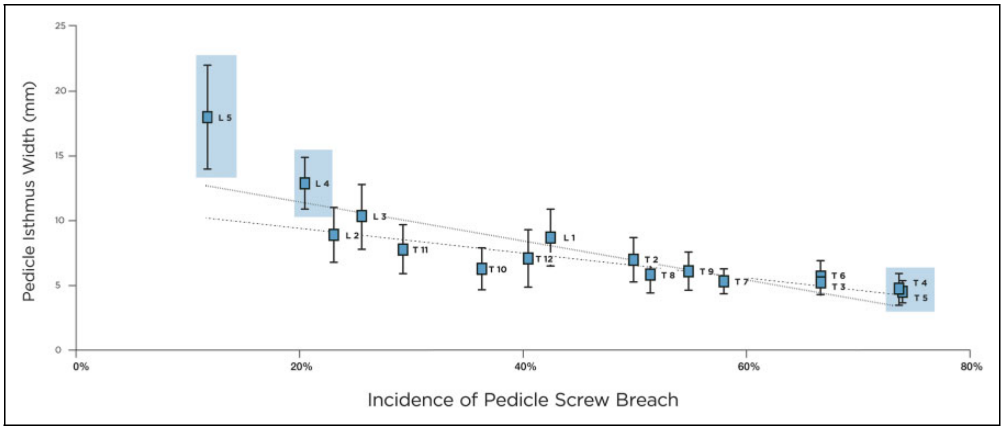

Figure 3. Breach incidence and isthmus width were shown to have a significant inverse correlation with $R^2 = 0.7$ (Pearson's correlation, $P < .0001$). As indicated by highlighting, the 2 spinal levels with the thickest average isthmus width—L4 and L5—had the lowest breach incidence. The 2 spinal levels with the thinnest average isthmus width—T4 and T5—had the highest breach incidence.

done by Kosmopulos et al[20] computed the mean accuracy rate for pedicle screw placement using both freehand and image-guided techniques. Our results show an overall major breach rate of 6.3%, which makes our accuracy rate 93.7%. This is marginally superior to the result obtained from the meta-analysis, which showed a median of 90.7%.[20] However, there are different ways in which one can define pedicle screw accuracy, and this can naturally affect the degree of accuracy recorded. There was a considerable range of reported accuracy values for the free-hand technique in the study by Kosmopulos et al[20]; from 12% in 1 study, to 100% in 11 studies. This highlights the lack of consensus on the appropriate definition of accuracy. The authors identified 35 different ways in which accuracy was determined. While some use the "in versus out" categorization, others define a safe range over which they consider the breach to be significant.[20] This likely stems from work done by Gertzbain et al,[21] where they demonstrated no adverse clinical outcomes for breaches less than 4 mm. This likely contributed to the large range of accuracy values found for pedicle screw placement. The systematic review by Aoude et al[22] concluded that using a breach length of 2 mm to determine significance of a breach was the most widely accepted measure, supported by the protocol set by Youkilis et al.[11] Therefore, we chose to classify breach as more or less than 2 mm.

Ideally, pedicle screw breach is avoided. Serious neurovascular complications can arise from aberrant screw placement,[23-27] including radicular pain, sensory loss ranging from weakness to paralysis, as well as damage to great vessels and the pleural cavity.[7] As such, it is of the utmost importance that surgeons accurately place screws within the confines of the cortex of the vertebral pedicle and minimize breaching. However, if a breach is detected, the need to revise the surgery must be evaluated on a case by case basis. Of all the breaches reported in our study, 4 patients developed a radiculopathy postoperatively relevant to breach. No patient was surgically revised due to pedicle screw breach.

Although the use of breach detection is a helpful benchmark by which one can measure accuracy, the clinical relevance of a given breach needs to be considered as well. If a screw can remain structurally sound and the patient remains asymptomatic, then a breach is not necessarily a problem. The development of a widely accepted, validated breach assessment tool has been suggested but not implemented.[22,28] Floccari et al[29] conducted a survey among spine surgeons who were presented with CT scans of various degrees of breach and asked whether or not they would revise the pedicle screws. Although certain aspects of the breach, such as aortic or dural compromise, made the surgeons more likely to recommend a revision, there was no consensus on what should prompt revision. However, the surgeons agreed not to recommend revision for a breach less than half of the diameter of the screw violating the canal, malposition into a rib, or a small anterior cortical violation far from vessels. Another recent study surveyed spine surgeons from various sites across Canada in order to ascertain their assessment of accuracy of pedicle screw placement.[28] The results suggested that both postoperative clinical findings and radiographic findings were crucial to surgeons' interpretation of aberrant screw positioning. In recognizing this, they developed a scoring system to help classify pedicle screws misplacement and determine the need for revision.[28]

We acknowledge that a potential limitation of this retrospective study is that we are not using the isthmus width collected from the same patients in which we are calculating breach incidence. It is our assumption that the mean and standard deviation calculated by Zindrick et al[17] adequately represents the isthmus width in the general population, and as such the sample size was large enough to appropriately use a surrogate measure for isthmus width. Furthermore, isthmus width is measured in the axial plane. By solely examining axial CTs, the study is limited to analyzing medial and lateral breaches, and therefore cannot comment on the influence of superior and inferior breach. Analysis of coronal or sagittal cuts may also be useful for different breaches not investigated in this article.

A subsequent limitation of this study is that only pedicle isthmus width was studied. Other anatomical features and underlying pathology, such as ankylosing spondylitis, can influence the likelihood of screw breaches and increase difficulty in identifying anatomical landmarks for screw entry. In fact, a study by Cui et al[16] demonstrated that breach was related to the critical distance from screw entry point in adolescent idiopathic scoliosis. Although this may not be applicable to the adult population, this factor and others were not within the scope of this article. Nonetheless, our results demonstrate that thoracic screws merit more attention by surgeons, especially those between T2 and T6. Our results also suggest that measurement of the patient's pedicle isthmus width can be beneficial before the instrumentation of any case.

Conclusions

This study assessed screw placement from a surgeon in an academic center and analyzed breach rate in relation to the pedicle isthmus size. The results demonstrate significant increase in breach rate in the thoracic spine compared to the lumbar spine, directly related to pedicle isthmus width. Although other anatomical landmarks and or pathologies—such as ankylosing spondylitis—can influence breach rates, we believe that the results of this study warrant the attention of spine surgeons. These results indicate that common anatomical variation in pedicle isthmus in all patient, especially the upper thoracic spine, could affect pedicle screw placement accuracy. Although a breach is not automatically a clinical problem, provided the patient remains symptomless, it can play a role in the solidity of the construct and is important to avoid as much as possible. Therefore, we suggest increased attention to screw placement at vertebral levels with smaller isthmus widths (T2-T6), even in the most straightforward of cases.

Declaration of Conflicting Interests

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