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New method for intraoperative determination of proper screw insertion or screw malposition*

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Object. Inadequate imaging techniques may lead to misjudgment of screw positioning when applying transpedicular instrumentation; this can create potential risks of major vessel and nerve damage. In this article the authors present a new method to determine screw malpositioning intraoperatively.

Methods. The authors retrospectively evaluated pre- and postoperative plain radiographs of 97 spinal segments in which screws had been placed in 41 patients suffering from thoracolumbar injury who had previously undergone transpedicular screw fixation. They developed a new mathematical equation with which they determine the distance ratios of two screw tips in the same segment by comparing the distance between the pedicles on preoperative radiographs with those on postoperative radiographs. Subsequently, the results are compared with postoperative computerized tomography findings to determine which screws are in the correct position and which are penetrating the medial or lateral cortex of the pedicle. It was found that the ratio range of correctly placed screw tips was 46 ± 10% (mean ± standard deviation) in the thoracic region and 60 ± 9% in the lumbar region (ranges 43–50% and 57–63%, respectively, 95% confidence intervals). Higher ratios (higher percentages) than these values indicated extreme closeness of screw tips and therefore medial malpositioning. Lower ratios (lower percentages) indicated lateral malpositioning.

Conclusions. This proposed method may provide intraoperative determination of correct screw positioning or malpositioning. This method allows surgeons to replace the malpositioned screw, and, consequently, early resolution of neurovascular injuries is made possible. Additionally, repositioning of the screw correctly will avoid rigidity failure of the fixation device.

Key Words • **pedicle** • **screw fixation** • **screw malposition** • **spine injury**

In the past decade pedicle screw fixation of the thoracolumbar spine has gained greater acceptance as a result of improved instrumentation and clinical efficacy.[5,10,11,15] Nevertheless, a substantial problem remains associated with spinal surgery in that the unexposed spinal anatomy cannot be visualized, and this factor is critical when placing screws into the pedicles.[6,9,12–14,16]

At present, two methods are commonly used to determine intraoperative anatomical orientation of pedicle screw placement: radiography (serial radiography and C-arm fluoroscopy) or computer-assisted systems.[5,7,9,10] Although the high frequency of misplaced screws when using computer-assisted systems has not been documented, several studies have shown that standard intraoperative x-ray guidance is not reliable in assessing pedicle screw placement.[5,7,9,11–13] Intraoperative fluoroscopy and serial radiography only demonstrate the depth of screw penetration but cannot be used to recognize screw malpositioning.[7] Intraoperative radiographic observation of screw tips that have been placed too close or too far from each other might only suggest a possible misplaced screw. Unfortunately, these suspect screws can only be observed to be penetrating the medial or lateral cortex of the pedicle on postoperative CT scans.

In this study we clarified the validity of this observation via a novel mathematical equation. This was based on measurements obtained from pre- and postoperative AP plain radiographs, which demonstrated in which ratios screw tips were close to or distant from each other. The purpose of the study was to identify the ranges in which the screws are correctly placed and, consequently, to clarify this method's effectiveness when used intraoperatively for determining screw malpositioning.

Clinical Material and Methods

Patient Population

This study consisted of 41 patients suffering from thoracolumbar injury who had previously undergone transpedicular screw fixation. There were 17 women and 24 men (mean age 41.2 years, range 19–58 years). There were 21

Abbreviations used in this paper: AP = anteroposterior; CI = confidence interval; CT = computerized tomography; SD = standard deviation.

* See the Letter to the Editor and the Response in this issue in *Neurosurgical Forum*, pp 175–182.

cases of Frankel Grade E function, five of Grade D function, seven of Grade C function, two of Grade B function, and six cases of Frankel Grade A function. Plain radiographs and CT scans were obtained at admission, and magnetic resonance imaging was performed in patients with neurological injury. There were six wedge compressions, 26 burst fractures, and nine fracture dislocations involving T-9 to L-4.

During the operation, the position of the pedicle was estimated using anatomical landmarks. A line was drawn along the lateral aspect of the superior articular facet and a second along the rostrocaudal center of the transverse process, and this became the site for cortical entry.[5,17] The entry point was prepared with a square awl, and the pathway was opened with a pedicular probe. The hole was tapped and then a pedicle tester was used to determine if the pedicle wall had been breached. If this had occurred, the entry point was changed at the same segment or moved one level up or down until the intact pedicle wall was prepared. Finally, the screw was inserted using fingertip pressure only. After each screw had been placed, fluoroscopy was used to confirm the pedicle screw trajectory. Within 24 hours of surgery, AP and lateral radiographs as well as CT scans of the spine were obtained to determine if the hardware had been correctly placed.

In all procedures, the Diapason spinal system (Dimso SA/Stryker Implants, ZI Marticot, France) was used with a thoracic screw 40 mm in length and 5.5 mm wide and a lumbar screw 45 mm in length and 6.7 mm wide.

Description of the Method

Two different measurements were obtained from pre- and postoperative plain radiographs.

First, we measured the distance between the midpoints of the pedicles (A), and then we measured the distance between the screw tips (A′) on the same segment on pre- and postoperative plain radiographs for each screwed segment, respectively (Fig. 1). Normally, $(A - A'/A)$ represents the ratio in which the screw tips are close to or distant from each other, but this equation is only valid if dimensions of the anatomical structures are determined to be the same on pre- and postoperative radiographs. Generally, comparative dimensions are not equal on pre- and postoperative radiographs because the source–object distance differs with each procedure. Therefore, in this formula A′ is a relatively variable value. For this reason, A and A′ are divided by constant B and B′ values (A/B and A′/B′) to create constant values and to avoid the false effect of mismatch between radiographs. Whereas B represents the width of the first distal untreated vertebrae demonstrated on a preoperative radiograph, B′ represents the width of the same distal vertebrae on the postoperative radiograph after the instrumentation has been placed (Fig. 1).

Finally, the equation can be described as: $100 \times [(A/B - A'/B') / A/B] = \%$.

This formula was applied to values obtained from measuring 97 segments in which screws had been placed in 41 patients (49 in the thoracic and 48 in the lumbar region, between T-9 and L-4). We compared these results with postoperative CT findings to determine in which ratios the screws were in the correct position (Group C) or penetrating the medial (Group M) or lateral (Group L) cortex of the pedicle (Fig. 2). We classified the data in these three groups separately for the thoracic and lumbar regions. A 95% CI and mean ± SD were both found for each group, and statistical analysis was performed on data obtained from each group by using the Mann–Whitney U-test and the Student t-test (Table 1).

The efficacy of this proposed method was assessed by intraoperative examination of 16 screw segments in seven patients. During surgery, intraoperative direct radiographs were acquired after full insertion of pedicle screws, before rod placement and distraction. The related distances were measured on pre- and intraoperative radiographs, and we then used this formula to calculate the ratio for the distance between screws in each segment.

TABLE 1

Ratios of correctly and incorrectly positioned pedicle screws as determined on pre- and postoperative radiographs

Screw Position	Mean ± SD (%)	95% CI
thoracic region		
correct	46 ± 10	43–50
medial penetration	89 ± 12	81–97
lateral penetration	13 ± 8	0.005–26
lumbar region		
correct	60 ± 9	57–63
medial penetration	95 ± 18	93–113

Results

In 33 segments the screws were correctly placed, in 12 there was medial penetration, and in four there was lateral penetration between T-9 and T-12. In the lumbar region, in 40 segments the screws were correctly placed, in six there was medial penetration, and in two there was lateral penetration. The overall rate of screw malpositioning was 24.7%.

The ratio range of correctly placed screw tips was 46 ± 10% (mean ± SD) in the patients undergoing thoracic surgery and 60 ± 9% in the patients undergoing lumbar procedures (ranges 43–50% and 57–63%, respectively [95% CI]). Consequently, higher ratios (higher percentages) than the aforementioned values indicated that the screw tips were extremely close and, thus, that medial malpositioning had occurred, whereas lower ratios (lower percentages) indicated that lateral malpositioning had occurred (Table 1).

Results of the Student t-test demonstrated a statistically significant difference between measurements obtained in Groups C and M in the thoracic and lumbar regions ($p < 0.001$), and likewise the Mann–Whitney U-test demonstrated a statistically significant difference between Groups C and L in terms of values obtained in the thoracic region ($p < 0.001$). We excluded two cases in which the screws penetrated the lateral cortex in the lumbar region because two values do not comply with the statistical evaluation.

In seven patients in whom this method was applied intraoperatively, the results were within normal ranges, and correct screw positioning was confirmed on postoperative CT scanning (Table 2).

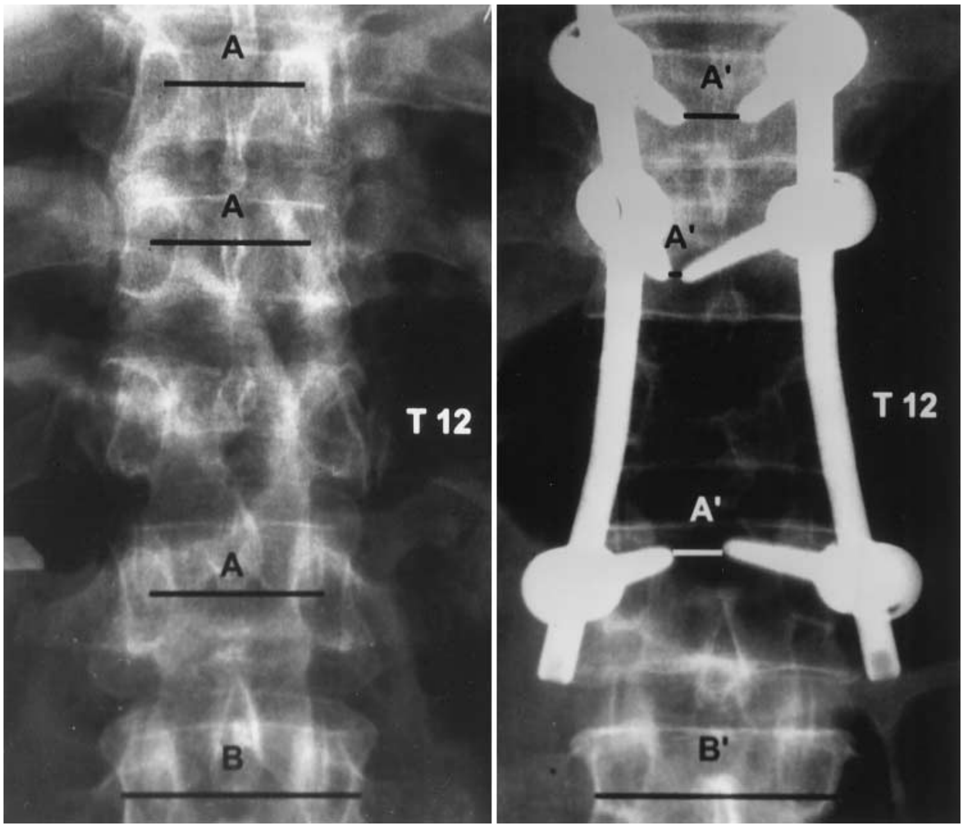

FIG. 1. Radiographic studies. *Left:* Preoperative depiction of A and B distances as seen on the plain radiograph obtained in a patient with T-12 burst fracture (A/B values for T-10 0.5, for T-11 0.68, and for L-1 0.66). *Right:* Postoperative depiction of A′ and B′ distances (A′/B′ values for T-10 0.22, T-11 0.02, and L-1 0.23).

Discussion

Although instrumentation systems have improved over time, the successful placement of pedicle screws still requires surgical skill and experience. The reported incidence of screw misplacement ranges from 28.1 to 39.9% in clinical studies in which the screw positions were verified using intraoperative fluoroscopy.[8,9,14,16] A low incidence of screw malpositioning of 4.3%, under clinical conditions, has also been reported when computer-assisted surgery has been performed.[9]

TABLE 2

Intraoperative values obtained in seven patients who underwent pedicle screw insertion of 16 segments

Level	A/B	A′/B′	Ratio
T-9	0.55	0.13	58%
T-10	0.50	0.22	56%
T-11	0.58	0.24	57%
T-11	0.56	0.32	40%
T-12	0.65	0.31	51%
T-12	0.55	0.24	56%
T-12	0.61	0.26	56%
T-12	0.61	0.21	51%
L-1	0.66	0.23	64%
L-1	0.70	0.29	58%
L-1	0.73	0.25	65%
L-2	0.82	0.30	63%
L-2	0.66	0.25	62%
L-2	0.71	0.21	70%
L-2	0.60	0.23	61%
L-4	0.68	0.24	65%

Despite the inherent risks of inserting transpedicular screws, permanent nerve root injuries related to pedicle screw insertion have occurred less frequently (range 0.1–2.0%) than might be expected.[8] Resolution almost always occurs after the screw is extracted or replaced in such cases.[5,7,11] However, intraoperative vascular or spinal cord injury may cause hazardous complications.[5,6,11,14] There were no neurological or vascular injuries despite a screw malposition rate of 24.7% in our retrospective series, and we did not need to conduct a second operation for screw replacement. This rate of screw malpositioning might be because of pedicle fracture caused by distraction of the hardware or screw–pedicle diameter mismatch, although intraoperatively all screws were thought to have been adequately placed within the pedicle.

Our proposed method allows for intraoperative assessment of the adequacy of screw placement but only after the screws have been placed. Nevertheless, because it leads to early intraoperative determination of screw malpositioning and consequent screw replacement, use of this method may result in early resolution of neurovascular injury and avoidance of late rigidity failure of the fixation device.[8] If intraoperative assessment is not performed, evaluation of the patient's postoperative CT study or neurological condition

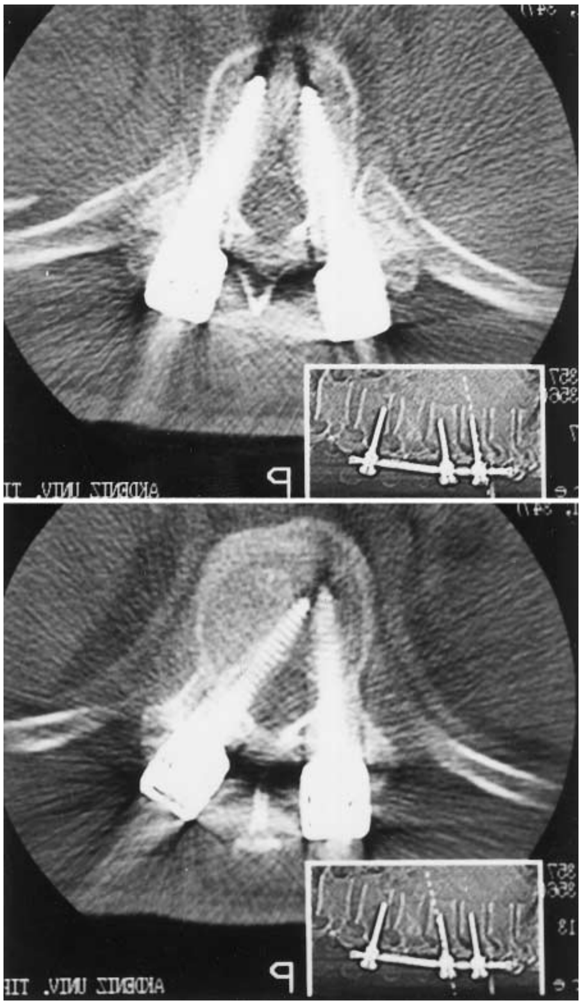

FIG. 2. Postoperative axial CT scans obtained in the same patient after operation. *Upper:* Screws are shown to be in correct position at T-10. *Lower:* Medial malposition of the screw at T-11 can be seen (based on our formula, values for T-10 were 56%, for T-11 97%, and for L-1 64%). The correct position of the screws was also confirmed in L-1 with CT scanning (image not shown).

could determine whether the surgeon must perform a second surgery to replace the pedicle screw, which may cause the patient to suffer a second trauma.[4,5,16] In our prospective study of seven patients, all the screws were also thought to be adequately placed and were found to be within normal ranges; this was confirmed on postoperative CT scans. However, if we had determined intraoperatively that the screw penetrated the medial or lateral cortex of this pedicle, we would not be required to conduct a second operation, as the screw would have already been replaced.

There are some disadvantages to our method. First, it does not provide a real-time determination of screw trajectory. Second, it relies on a mathematical formula obtained from direct radiographs, which might be affected by individual differences in dimensions. This may explain why in our prospective study of seven patients the mean values for three screw segments were found to be slightly below the correct ranges, yet the screws themselves were observed to be correctly positioned on postoperative CT scans. To eliminate the effects of uncontrolled factors arising from patients' anatomical variations, we calculated the 95% CIs to obtain the average parameters. In addition to individual differences, alterations in the height of the source–object distance between preoperative compared with intra- and postoperative plain AP radiographs surely affects the results of the formula. To eliminate these negative effects, we established a ratio between $A - B$ and $A' - B'$. We calculated both B and B′ values on pre- and postoperative radiographs separately, because the width of the same distal vertebrae might be shown to vary between radiographs. In this way, we obtained constant values and avoided possible alterations in measurements, and we then achieved standardized data by the use of A/B and A′/B′ values in the formula.

Moreover, because morphometric measurements of the critical pedicle dimensions (that is, the transverse angle) have been revealed to vary significantly, we used these constant values, calculating the ratios for both the thoracic and lumbar regions separately.[1–3,13] Normally, the transverse angle of the thoracic pedicle axis is smaller than that in the lumbar region, and also it varies between individuals.[1] In our study, the mean value for correct screw insertion in the thoracic region ($46 \pm 10\%$ [SD]) is smaller than that in the lumbar region ($60 \pm 9\%$ [SD]), which correlates with the spatial transverse angulation of the pedicle axis. These results also confirm the fact that screw trajectories found in our retrospective study are symmetrical to fit with the mediolateral angle of the pedicle throughout the thoracolumbar spine. If they had not been symmetrically placed, the screws would have penetrated the pedicle and been classified as Group M or L results.

Care should be taken in positioning the patient while obtaining pre- and intraoperative radiographs, which must be obtained perpendicular to the patient's spine. Because of the cylindrical shape of thoracolumbar vertebrae and also because the bilateral screw depths are equal, screw tips would be seen to rotate parallel with the vertebrae on intraoperative radiographs, and without any major rotation in the patient's position, this would not cause a significant error in the values obtained. The use of this formula in surgery to treat scoliosis or translational injuries, however, is not recommended, as it may yield incorrect results.

Conclusions

Occasionally, it has been observed on postoperative thoracolumbar radiographs that some screws are placed too close or too far apart from each other. This observation might suggest a possible screw malposition, which can be determined using postoperative CT scanning. In our study we clarified the validity of this observation by implementing a novel mathematical equation that measures the differences between the real position of a pedicle screw and its ideal position. It was determined that the correct position of screw tips was in the range of $46 \pm 10\%$ in the thoracic region and $60 \pm 9\%$ in the lumbar region. Larger values than these indicated a medial malpositioned screw and small values a lateral malpositioning. Thus, intraoperative use of this method allows for early replacement of the misplaced screw and consequently early resolution in neurovascular injuries. In addition, screw replacement in the correct way will avoid rigidity failure of the fixation device.

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