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Anatomical and radiologic characteristics of isthmus parameters in guiding pedicle screw placement

Paerhati Rexiti[1], Yakufu Abulizi[1], Aikeremujiang Muheremu[2], Shuiquan Wang[1], Maierdan Maimaiti[1], Hailong Guo[1] and Weibin Sheng[1]

Abstract

Objective: To study the clinical application of lumbar isthmus parameters in guiding pedicle screw placement.

Methods: Lumbar isthmus parameters were measured in normal lumbar x-rays and cadaveric specimens from a Chinese Han population. Distance between the medial pedicle border and lateral isthmus border was recorded as a 'D' value and was compared between X-rays and cadavers. Orthopaedic surgeons estimated different distances (2–6 mm) and angles (5–20°), and bias ratios between estimated and real values were compared. Orthopaedic residents placed pedicle screws on cadaveric specimens before and after application of the 'D' value, and screw placement accuracy was compared.

Results: Except for L4 vertebrae, significant differences in the 'D' value were found between 25 cadaveric specimens and x-ray films from 120 patients. Distances and angles estimated by 40 surgeons were significantly different from all real values, except 2 mm distance. Accuracy of pedicle screw placement by six orthopaedic residents was significantly improved by applying the 'D' value.

Conclusions: Surgeon estimates of distance were more accurate than angle estimates. Addition of a 'D' value to conventional parameters may significantly improve pedicle screw placement accuracy in lumbar spine surgery.

[1]Department of Spine Surgery, First Affiliated Hospital of Xinjiang Medical University, Urumqi, Xinjiang, China
[2]Department of Spine Surgery, Sixth Affiliated Hospital of Xinjiang Medical University, Urumqi, Xinjiang, China

Corresponding author:
Weibin Sheng, Department of Spine Surgery, First Affiliated Hospital of Xinjiang Medical University, 137 South Liyushan Road, Xinshi District, Urumqi, Xinjiang, 86830001, China.
Email: wbsheng@vip.sina.com

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Lumbar spine, isthmus, X-ray, pedicle screw, D value

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Introduction

Pedicle screws are widely applied in spinal surgeries, due to superior biomechanical properties compared with preceding constructs, such as pedicle and laminar hook systems.[1] Choosing the appropriate sagittal and transverse screw angle is one of the key elements in safe and effective pedicle screw placement.[2,3] Transverse screw placement angle is often decided depending on the experience of the surgeon, which may be problematic, as inexperienced surgeons could easily misjudge the correct transverse angle, potentially resulting in the pedicle screw breaking through the medial pedicle wall into the spinal canal, causing injury to the spinal cord, nerve roots or coccygeal nerve.[4,5]

In clinical practice, the present authors have found that the straight distance ('D' value) between the tangent of the medial pedicle wall and tangential point of the isthmus is similar among different patients at the same vertebral segment and can be applied as guidance for pedicle screw placement, reducing the need for intraoperative radiation. Thus, the present study was conducted in a Chinese Han population to reveal a pattern for the 'D' value among different patients and different vertebral segments, with the aim of finding an improved way of applying anatomic structures and landmarks to help surgeons find a more accurate screw-placing method, regardless of conventional transverse plane angle.

Patients and methods

Study population and samples

Anteroposterior and lateral X-ray films of the lumbar spine from Chinese Han patients were collected from the radiology centre of the First Affiliated Hospital of Xinjiang Medical University, between September 2015 and September 2016. X-ray films were required to be clear and of high resolution, and from patients without spinal abnormalities, such as fracture, tumour, deformity, lumbar sacralization or sacral lumbarization. Cadaveric specimens of the lumbar spine, also from patients without spinal abnormalities, were provided by the Department of Anatomy, Xinjiang Medical University. The current research was approved by the ethics committee of the First Affiliated Hospital of Xinjiang Medical University. Verbal informed consent was obtained from each patient or patient's legal proxy.

Radiological analysis

Anteroposterior X-rays of lumbar vertebrae (Figure 1a) were used to calculate a 'D' value as follows: Tangential lines (vertical lines with arrow heads) were drawn on the lateral lumbar isthmus margins, vertical to the lamina terminalis, and the distance between the two lines was recorded as S1 (horizontal arrow; Figure 1b). Tangential lines (vertical lines with arrow heads) were drawn on the medial pedicle margins, vertical to the lamina terminalis, and the distance between the two lines was recorded as S2 (horizontal line; Figure 1c). The 'D' value was then calculated using the formula: $D = (S1 - S2)/2$ (Figure 1d). Since the 'D' value is calculated using measurements that span across both sides, it is a mean value that is not affected by vertebral rotation.

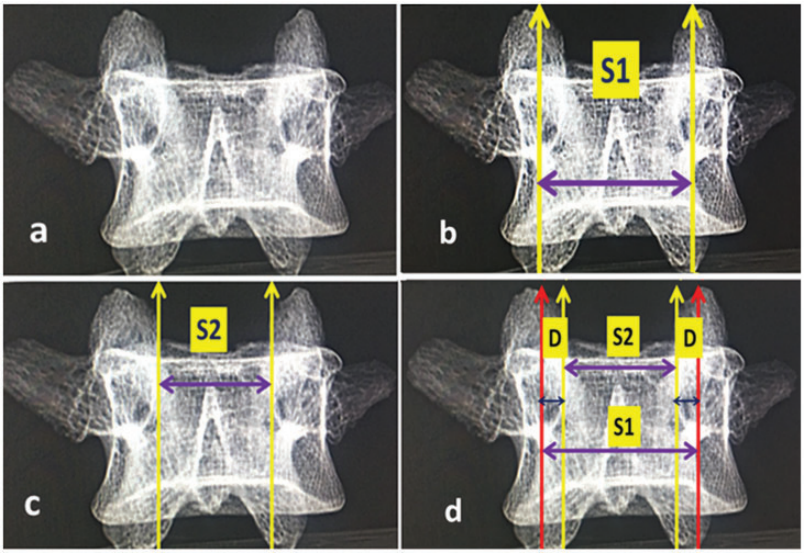

Figure 1. Representative anteroposterior X-rays showing the measurements taken to acquire S1, S2 and D values: (a) no measurement lines; (b) horizontal arrow showing S1 measurement, i.e. distance between the tangent points of the lateral lumbar isthmus margin; (c) horizontal arrow showing S2 measurement; and (d) showing 'D' value as the difference between S1 and S2 divided by two.

Specimen analysis

Cadaveric specimens of the lumbar spine were measured using a similar method to obtain S1 and S2 values and calculate the 'D' value (Figure 2a–c). Specimens were measured using Vernier callipers with an accuracy of 0.02 mm, and Kirschner wires of 1–2 mm diameter (Figure 2d–f).

Accuracy of distance and angle assessment among orthopaedic surgeons

The conventional method to control the pedicle screw angle of abduction in the horizontal plane is to assume the abduction angle to be 5–20° degrees from L1 to L5, and to place the pedicle relying on the personal experience of the surgeon.[6] Thus, orthopaedic surgeons from the Department of Spine Surgery, First Affiliated Hospital of Xinjiang Medical University, were recruited to estimate abduction angles of 5°, 10° and 20° and distances of 2 mm, 4 mm and 6 mm, according to 'D' value results from measuring lumbar X-rays and cadaveric specimens. Surgeons were assessed using a questionnaire regarding distances and angles (Figure 3). Ratio of bias was calculated using the following formula: Ratio of bias (deviation from real value) = ([estimated value – real value]/real value) × 100.

Accuracy of pedicle screw placement

Young orthopaedic surgical residents from the First Affiliated Hospital of Xinjiang Medical University, with no previous experience in spinal surgery, were recruited to perform pedicle screw placement using 6.0 × 45 mm pedicle screws (Tianjin Zhengtian Medical Instrument Co., Ltd., Tianjin, China). The residents were instructed to place the pedicle screws on one side of the lumbar pedicle depending on their previous experience and knowledge of spine surgery, using conventional

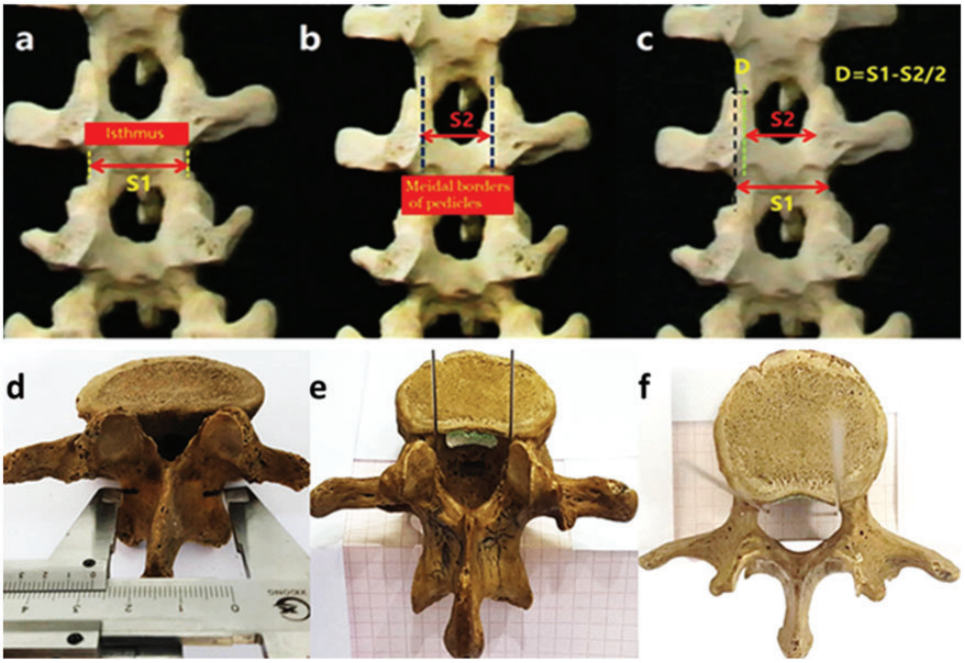

Figure 2. Representative figures of lumbar vertebra showing: (a and d) S1 measurement, i.e. the distance between the tangent points of the lateral lumbar isthmus margin; (b, e and f) S2 measurement, i.e. the distance between the two tangential lines of medial pedicle margin; and (c) the 'D' value calculation.

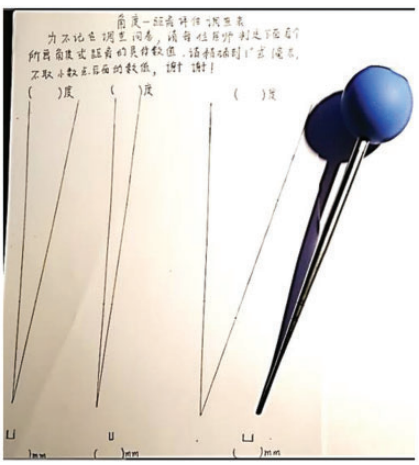

Figure 3. Questionnaire given to orthopaedic surgeons to estimate distances (2 mm, 4 mm and 6 mm) and angles (5°, 10° and 20°). Estimated values were then compared against real values to calculate estimate accuracies.

methods without information regarding the 'D' value. Following placement of all pedicle screws to one side of the spine, residents were provided with mean 'D' values for each vertebra (obtained from radiologic exams and cadaveric specimens) and instructed to place screws on the other side (Figure 4) using the following information: The original angle at the insertion point should not be too big, so that the tip of the pedicle screw does not exceed a line of 1/2 'D' median to the lateral edge of the pedicle; hence the insertion angle of the pedicle screw should be small. Once the pedicle screw has entered the pedicle by approximately 1.5–2 cm, the pedicle screw head starts to enter the vertebral body. The pedicle insertion angle should be a little wider at this time, and the medial edge of the pedicle should not exceed the 'D' value.

Figure 4. A surgical resident placing the pedicle screw on a fresh cadaveric specimen of the lumbar spine.

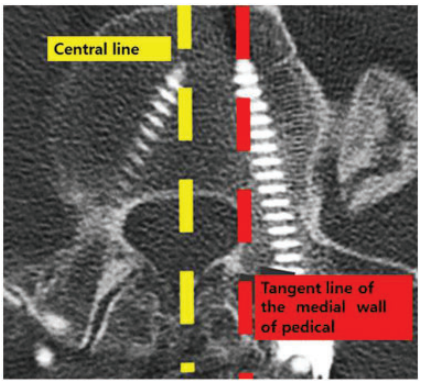

Figure 5. Representative image showing the correct target location for the pedicle screw, at the 1–2 o'clock position of the central line on the right side (tangent line of medial pedicle wall); if the target location is at 12 o'clock (central line) or over it, it may breach the medial pedicle wall.

The target location for the pedicle screw is at the mid line of the spinous process and lateral edge of the isthmus, which is at the 10–11 o'clock position on the left side and 1–2 o'clock position on the right side. If the head of pedicle screw crosses the central line (12 o'clock), it could break through the medial pedicle wall and enter the central canal (Figure 5). Thus, the head of the pedicle screw should be precisely targeted towards different anatomic landmarks or its projection lines during screw placement. This lies roughly in the projection area of the 'D' value (Figure 6).

Accuracy of pedicle screw insertion was evaluated using a Hitachi 500 mA DR X-ray machine (Hitachi, Japan) and Siemens computed tomography (CT) scanner with Picture Archiving and Communication System (PACS) software (Siemens, Germany).

Accuracy of screw placement was scored as described previously:[7] (I) All of the pedicle screw is in the pedicle; (II) $< 50\%$ of the pedicle screw has broken through the pedicle wall; (III) $> 50\%$ of the pedicle screw has broken through the pedicle wall.

Statistical analyses

Data are presented as mean $\pm$ SD or *n* prevalence, and were statistically analysed using SPSS software, version 19.0 (SPSS Inc., Chicago, IL, USA). Independent or paired sample *t*-test and χ^2-test were used to compare between-group differences in parameters. Differences with a *P* value <0.05 were considered to be statistically significant.

Results

Measured vertebral parameters from X-rays

Anteroposterior and lateral X-ray films of the lumbar spine were collected for 362 patients. Of these, radiographic examinations of 120 Chinese Han patients (60 male and 60 female; mean age, 36.21 ± 7.8 years) met the inclusion criteria, and were included in the current study.

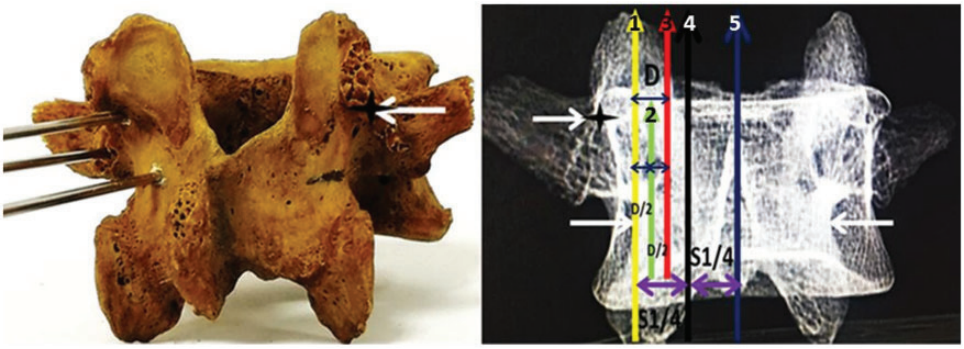

Figure 6. Representative images showing the trajectory of the pedicle screw head lying roughly in the area of the 'D' value: Arrow 5, the central line; Arrow 1, tangent line of the isthmus edge; Arrow 4, central line of arrows 1 and 5; Arrow 3, tangent line of the inner pedicle wall; Arrow 2, central line of arrows 1 and 3.

Table 1. Lumbar isthmus parameters measured on X-ray images from 120 patients without spinal abnormalities.

Lumbar segment	Lumbar isthmus parameter		
	S1	S2	D
L1	26.0 ± 0.59	21.8 ± 0.52	2.13 ± 0.13
L2	26.7 ± 0.61	22.1 ± 0.48	2.30 ± 0.13
L3	29.7 ± 0.82	22.6 ± 0.43	3.58 ± 0.33
L4	32.1 ± 1.13	23.3 ± 0.58	4.42 ± 0.36
L5	41.7 ± 1.45	30.3 ± 0.81	5.73 ± 0.36

Data presented as mean ± SD.
S1, distance between the tangents of the lateral lumbar isthmus margins, vertical to the lamina terminalis; S2, distance between the tangents of the medial pedicle margins, vertical to the lamina terminalis; D, calculated value using the formula D = (S1 − S2)/2.

Values for S1, S2 and 'D' were all shown to increase from the L1 to L5 vertebrae (Table 1). There were statistically significant differences in S1, S2 and 'D' values between male and female patients ($P < 0.001$; Table 2).

Measured vertebral parameters from cadaveric specimens

Parameters were measured on 25 Chinese Han cadaveric specimens of the normal lumbar spine, and values for S1, S2 and 'D' were all shown to increase from the L1 to L5 vertebrae (Table 3). Comparisons between parameters measured by X-ray films and cadaveric specimens found no statistically significant difference in 'D' value at the level of L4, but there were statistically significant differences in S1, S2 and 'D' values at all other vertebral levels, with X-ray-measured values being higher than cadaver-measured values ($P < 0.05$; Table 4).

Estimated versus real angle and distance measurements

Out of 40 orthopaedic surgeons recruited to estimate angles and distances, there was a mean bias of 105.5% concerning estimates of the angle of screw fixation. Over-estimates were all statistically significant ($P < 0.001$) and decreased as angle increased from 5 to 20° (Table 5). In terms of distance estimates, there was a much lower mean bias of 14.33% compared with distance estimates. Estimated 2 mm distance was not significantly different from real 2 mm distance (Table 5), and 2 mm estimates were correct for most surgeons (data not shown).

Table 2. Between-sex comparison of lumbar isthmus parameters measured on X-ray images from 120 patients without spinal abnormalities.

Lumbar segment	Lumbar isthmus parameter	Male ($n = 60$)	Female ($n = 60$)	F	Statistical significance[a]
L1	S1	26.43 ± 0.44	25.60 ± 0.40	0.117	$P < 0.001$
	S2	22.02 ± 0.50	21.51 ± 0.39	2.815	$P < 0.001$
	D	2.21 ± 0.09	2.04 ± 0.11	1.590	$P < 0.001$
L2	S1	27.09 ± 0.46	26.34 ± 0.49	1.086	$P < 0.001$
	S2	22.36 ± 0.47	21.91 ± 0.36	3.025	$P < 0.001$
	D	2.38 ± 0.10	2.22 ± 0.11	1.463	$P < 0.001$
L3	S1	30.18 ± 0.66	29.22 ± 0.66	0.030	$P < 0.001$
	S2	22.73 ± 0.48	22.38 ± 0.28	16.687	$P < 0.001$
	D	3.74 ± 0.28	3.42 ± 0.30	0.233	$P < 0.001$
L4	S1	32.98 ± 0.87	31.39 ± 0.73	4.055	$P < 0.001$
	S2	23.65 ± 0.63	23.03 ± 0.30	33.188	$P < 0.001$
	D	4.66 ± 0.24	4.18 ± 0.30	1.121	$P < 0.001$
L5	S1	42.99 ± 0.78	40.47 ± 0.65	3.704	$P < 0.001$
	S2	30.86 ± 0.59	29.67 ± 0.51	3.032	$P < 0.001$
	D	6.06 ± 0.14	5.40 ± 0.14	0.105	$P < 0.001$

Data presented as mean ± SD.
S1, distance between the tangents of the lateral lumbar isthmus margins, vertical to the lamina terminalis; S2, distance between the tangents of the medial pedicle margins, vertical to the lamina terminalis; D, calculated value using the formula D = (S1 − S2)/2.
[a]Statistically significant between-group differences at $P < 0.05$ (Independent samples *t*-test).

Table 3. Lumbar isthmus parameters measured in 25 cadaveric normal lumbar specimens.

Lumbar Segment	Lumbar isthmus parameter		
	S1	S2	D
L1	25.10 ± 0.25	21.28 ± 0.28	1.92 ± 0.12
L2	25.50 ± 0.38	21.36 ± 0.34	2.06 ± 0.09
L3	29.02 ± 0.49	22.30 ± 0.25	3.36 ± 0.24
L4	31.58 ± 0.61	22.84 ± 0.47	4.38 ± 0.15
L5	40.98 ± 0.83	29.90 ± 0.50	5.54 ± 0.24

Data presented as mean ± SD.
S1, distance between the tangents of the lateral lumbar isthmus margins, vertical to the lamina terminalis; S2, distance between the tangents of the medial pedicle margins, vertical to the lamina terminalis; D, calculated value using the formula D = (S1 − S2)/2.

Accuracy of pedicle screw placement

Six orthopaedic residents were recruited to assess the accuracy of pedicle screw placement in one cadaveric lumbar specimen each, before and after application of the 'D' value. Accuracy of pedicle screw placement was found to be significantly improved ($P < 0.01$) when the 'D' value was used to assist screw placement (86.7% with placement score of I) versus screw placement before the 'D' value was provided to the residents (40% with placement score of I; Figure 7, Table 6).

Discussion

Spine surgeons require novel methods to decrease the duration of intraoperative x-rays, without compromising the accuracy of pedicle screw insertion. While free-hand and funnel techniques have been developed for this purpose, the results are not always satisfactory.[7–9] The 'D' value applied in the present research, which is the straight

Table 4. Comparison between lumbar isthmus parameters measured on X-ray films from 120 patients without spinal abnormalities and in 25 cadaveric normal lumbar specimens.

Lumbar segment	Lumbar isthmus parameter	Sample type		t	Statistical significance
		X-ray film	Cadaveric lumbar specimen		
L1	S1	26.01 ± 0.59	25.1 ± 0.25	12.15	$P < 0.001$
	S2	21.76 ± 0.52	21.3 ± 0.28	6.54	$P < 0.001$
	D	2.13 ± 0.13	1.92 ± 0.12	7.23	$P < 0.001$
L2	S1	26.72 ± 0.61	25.50 ± 0.38	9.58	$P < 0.001$
	S2	22.13 ± 0.48	21.36 ± 0.34	7.72	$P < 0.001$
	D	2.30 ± 0.13	2.05 ± 0.09	9.02	$P < 0.001$
L3	S1	29.70 ± 0.82	29.03 ± 0.49	3.93	$P < 0.001$
	S2	22.55 ± 0.43	22.31 ± 0.25	2.73	$P = 0.007$
	D	3.58 ± 0.33	3.36 ± 0.24	3.17	$P = 0.002$
L4	S1	32.19 ± 1.13	31.58 ± 0.61	3.75	$P < 0.001$
	S2	23.34 ± 0.58	22.84 ± 0.47	4.02	$P < 0.001$
	D	4.42 ± 0.36	4.38 ± 0.15	0.80	NS
L5	S1	41.73 ± 1.45	40.99 ± 0.83	3.42	$P = 0.001$
	S2	30.26 ± 0.81	29.91 ± 0.50	2.75	$P = 0.008$
	D	5.73 ± 0.36	5.54 ± 0.24	3.20	$P = 0.002$

Data presented as mean ± SD.
S1, distance between the tangents of the lateral lumbar isthmus margins, vertical to the lamina terminalis; S2, distance between the tangents of the medial pedicle margins, vertical to the lamina terminalis; D, calculated value using the formula D = (S1 − S2)/2.
NS, no statistically significant between-group differences ($P > 0.05$; Independent samples t-test).

Table 5. Estimated versus real angle and distance measurements conducted by 40 experienced orthopaedic surgeons.

Parameter	Real value	Estimated value	Deviation	F	Statistical significance
Angle 1, °	5.00 ± 0.00	11.22 ± 5.35	124.40%	101.074	$P < 0.001$
Angle 2, °	10.00 ± 0.00	21.58 ± 7.85	115.80%	128.346	$P < 0.001$
Angle 3, °	20.00 ± 0.00	35.26 ± 8.97	76.30%	121.126	$P < 0.001$
Distance 1, mm	2.00 ± 0.00	2.20 ± 0.72	10.00%	93.391	NS
Distance 2, mm	4.00 ± 0.00	4.56 ± 1.24	14.00%	82.056	$P = 0.003$
Distance 3, mm	6.00 ± 0.00	7.14 ± 2.11	19.00%	130.534	$P < 0.001$

Data presented as mean ± SD.
NS, no statistically significant between-group differences ($P > 0.05$; Paired sample t-test).

distance between the tangent of the median pedicle wall and tangent of the isthmus lateral wall, significantly increased the accuracy of free hand screw insertion, shown by X-ray analysis following screw insertion.

Adequate application of anatomic landmarks is the key for safe and effective screw placement.[10–13] The present study did not use the diameter or radius of the pedicle to help with screw placement, because the centre of the pedicle cannot be seen by the naked eye and has to be defined by intraoperative X-rays. In the present study, the lateral edge of the isthmus and its tangent

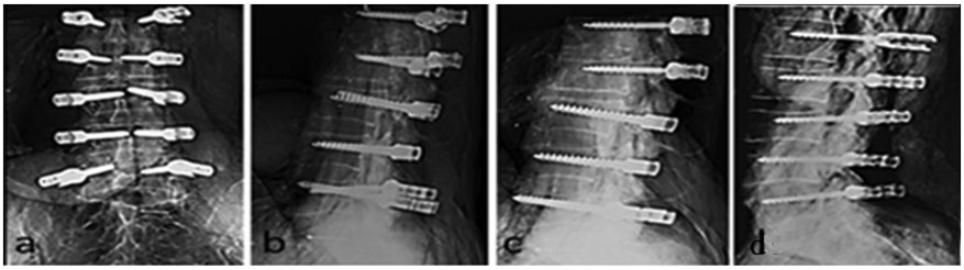

Figure 7. Representative X-ray images of a spinal specimen showing pedicle placement: (A and B) coronal and sagittal planes, respectively – in the coronal plane, the left side pedicles were placed before residents were informed about the 'D' value and pedicles on the right side were placed using the 'D' value-based technique; (C) sagittal plane showing pedicle placement before use of the 'D' value; and (D) sagittal plane showing pedicle placement using 'D' value-based technique.

Table 6. Accuracy of pedicle screw placement by six inexperienced orthopaedic surgeons on one cadaveric lumbar specimen each.

Group	Screw placement score[a]			Proportion of satisfactory screw placements
	I	II	III	
Without D value	12	10	8	12/30 (40)
With D value	26	4	0	26/30 (86.7)
Statistical significance	$P < 0.01$			$P < 0.01$

Data presented as *n* or *n* (%) incidence.

[a](I) All of the pedicle screw is in the pedicle; (II) < 50% of the pedicle screw has broken through the pedicle wall; (III) >50% of the pedicle screw has broken through the pedicle wall.

Statistically significant between-group differences regarding screw placement accuracy ($P < 0.01$, χ^2-test).

can be observed easily and directly without intraoperative x-rays, even when using the Wiltse approach.[14] Using the 'D' value proposed in the current research, the medial pedicle wall can be determined and protected during screw insertion, keeping the tip of the pedicle screw within the inner wall of the lumbar pedicle and steering clear of the nerve root.

In the current study, the 'D' values were found to increase gradually from L1 to L5. On X-ray films, 'D' values were found to be: L1, 2.1 ± 0.13 mm; L2, 2.3 ± 0.13 mm; L3, 3.6 ± 0.33 mm; L4, 4.4 ± 0.36 mm; and L5, 5.7 ± 0.36 mm. The 'D' values on cadaver specimens were found to be: L1, 1.92 ± 0.12 mm; L2, 2.06 ± 0.09 mm; L3, 3.36 ± 0.24mm; L4, 4.38 ± 0.15mm; and L5, 5.54 ± 0.24 mm. According to the results of the current study, the safe D value appears to be 2.5 to 6 mm, and 'D' values may be easily memorized as 2 mm L2, 3 mm at L3, 4 mm at L4, and 6 mm at L5. The value was found to be bigger in male versus female patients in the present study, thus, the 'D' value should not exceed 5.5 mm in female patients and 6 mm in male patients, in order to avoid breaching the inner wall of the lumbar pedicle.

Results of the current study indicate that S1, S2, and 'D' values are different between the different lumbar segments and different

sexes. Isthmus parameters obtained from X-ray films were found to be significantly higher than those from cadaveric specimens at all lumbar segments, except for L4. This may have been because most cadaveric specimens are dry and may have shrunk during the preservation process. The difference was less than 1 mm, however, and measurements from X-rays are more likely to be similar to patients in the clinical setting.

The 40 attending orthopaedic surgeons in the Department of Spinal Surgery, First Affiliated Hospital of Xinjiang Medical University participated in the present study and were found to have a mean estimation bias of 105.5% concerning the angle over screw fixation, but a substantially smaller estimation bias of 14.33% concerning distance. In addition, there was no significant difference between estimated and real 2 mm distance, with 2 mm estimates being correct for most surgeons. Thus, the present authors concluded that the distance between anatomic references can be used to aid in controlling the abduction angel during screw placement, and minimize the error introduced by subjective estimation of screw angel. It is apparent from the present study that surgeons tend to make minor mistakes in identifying small distances, but make significant errors with angles, and the present authors believe that pedicle screw insertion angle at different lumbar vertebra may be decided more accurately by relying on the 'D' value rather than rigidly estimating the degree of angle.

In terms of the relationship between 'D' value and pedicle screw placement, the present authors have found that controlling the track of the pedicle screw requires the application of certain anatomic parameters at the beginning, during and at the end of the screw placement process, to keep the screw on its intended course (Figure 8).

To meet the requirement of precise-anatomy target-oriented screw placement, the pedicle screw can be inserted using the 'D' value using a stepwise procedure, as described in the current methods. The current results showed that application of the 'D' value during pedicle screw insertion may significantly lower the risk of breaching the medial pedicle wall, and did not require any intraoperative fluoroscopic radiation, reducing potential exposure to strong radiation. The 'D' value is a stable and important anatomical characteristic of the lumbar spine that is not influenced by the patient's position and vertebrae rotation during surgery.

The present results may be limited by a number of factors. First, this was a single centre study and 'D' values were measured using a relatively small sample from a Chinese Han population. Thus, care should be taken when considering this value in terms of the wider population. Secondly, the method for assessing pedicle screw placement involved surgical residents first placing screws on the left side of the spine, without 'D' value knowledge, then placing screws on the right side using the 'D' value. No control was provided for left versus right side placement (such as selecting a proportion of surgeons to place the first screws on the right side, and second screws of the left), and any potential learning effect was not taken into account, which may affect the degree of improvement observed in the present results. In the present authors opinion, however, it is unlikely that placing five pedicle screws could have significantly improved the technique of the inexperienced orthopaedic residents included in the present study. Further studies involving a larger sample of lumbar X-rays, and larger surgeon sample from multiple centres, are required to validate the present results.

In conclusion, distance from the lateral isthmus tangent to the medial pedicle tangent, the 'D' value, gradually increases from 2 mm at L1 to 6 mm at L5 and can be easily and directly observed with the naked eyes

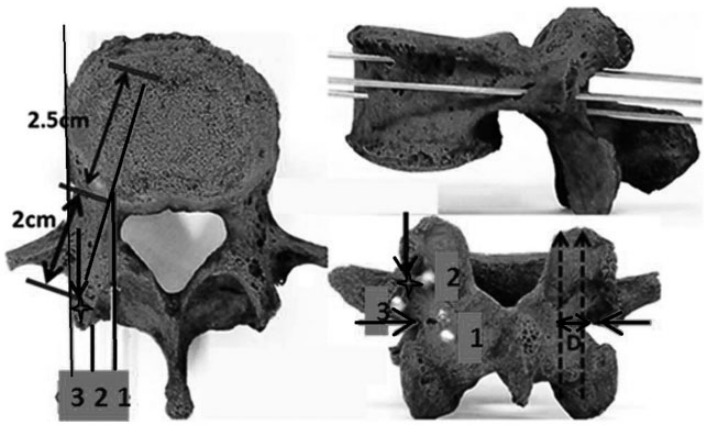

Figure 8. Representative images of Kirschner wire insertion points into lumbar vertebra: Left hand image showing Kirschner wire (1) with projected direction along the medial pedicle wall, and the 'D' value is the distance between the projected direction of wire (1) and tangent of the isthmus (horizontal double arrow on bottom right image marked with 'D'); Kirschner wire (2) is at the vertical midline of distance D, and has the same latitude as the pedicle screw insertion point; Kirschner wire (3) is inserted in the caudal end of the accessory process (vertical single solid arrow) and the screw is inserted at the intersection of the accessory process and border of isthmus (downward vertical arrow on left and bottom right image). It can be seen on the left-hand image that the insertion point should be moved laterally from Kirschner wire (2) in the transverse view. In order to avoid the screw breaching the pedicle inner wall, the movement of the tip of the screw should not exceed the 'D' value (should not cross the straight vertical line) until it is inserted to approximately 2 cm and arrives at the vertebral body; The top right image shows the positional relationship between the three Kirschner wires from the lateral side, and relative pedicle height; The bottom right image shows the positional relationship between the pedicle screw insertion point (vertical downward solid arrow and asterisk) and the three Kirschner wires, particularly Kirschner wire (2). Applying the 'D' value would help the operator imagine the pedicle median wall without using fluoroscopy (vertical broken arrows).

during surgery, without the need for fluoroscopy and associated radiation. The medial pedicle wall can be determined and protected during screw insertion using the 'D' value and the lateral isthmus tangent. Differences in 'D' value between the sexes were found to be less than 1 mm. As surgeons were found to make more precise estimates of distance than angle, applying the 'D' value during pedicle screw insertion may increase the accuracy of pedicle screw placement, and reduce the requirement for fluoroscopy and associated intraoperative radiation to patients and surgeons.

Declaration of conflicting interests

The authors declare that there is no conflict of interest.

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