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Cadaveric study of anatomical measurement of isthmus parameters of lumbar spine to guide cortical bone screw placement

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SUMMARY

OBJECTIVE: To reduce surgical exposure and improve accuracy, this study evaluated the anatomical distance parameter D (including D1, D2, and D3) of the lumbar isthmus for cortical bone screw insertion.

METHODS: A total of 25 structurally complete lumbar dry specimens were used for lumbar anatomy measurements. The six cadaver specimens were divided into upper and lower parts on the plane of the T11–T12 vertebrae, and we use the lower parts. Therefore, six lumbar wet specimens and another four complete lumbar dry specimens were selected. The lumbar isthmus tangent point was considered a coordinate origin, and the insertion point was determined through translating the distance of D1 value to the midline of the vertebral body horizontally and then vertically moved toward inferior board of the transverse process with the distance of D3 value.

RESULTS: In four dry and six wet intact lumbar specimens, cortical bone screws were placed according to the average value of the isthmus parameter D. A total of 100 trajectories were verified in specimens by X-ray and computed topography scan to evaluate the safety, accuracy, and feasibility of the surgical use of isthmus parameter D. Using this parameter, the rates of excellent screw placement were 95% (38/40) in four dry specimens and 88.7% (53/60) in six wet specimens.

CONCLUSION: The isthmus parameter D is easier to use by the operator, which can improve surgical accuracy and reduce operation time.

LEVEL OF EVIDENCE: Level IV, prospective study.

KEYWORDS: Lumbar. Anatomy. Cortical bone trajectory (CBT).

INTRODUCTION

The concept of cortical bone trajectory (CBT), proposed in 2009[1], is a new screw placement method that changes how the pedicle long axis is used as a trajectory for traditional pedicle screws. CBT makes trajectories display partial deviation on the head in the sagittal plane and for the outward angle on the cross section, ensuring that the screw is fitted with the cortical bone of the lateral edge of the pedicle and the upper end plate of the lumbar vertebra[2,3]. Compared with traditional pedicle screw technology, CBT has become an ideal internal fixation method for patients with osteoporosis and revision surgery[4,5].

Previous studies considered the ideal screw insertion point for lumbar cortical screws to be coronal at the intersection of the vertical midline of the articular process with the 1 mm horizontal line below the transverse process of the same side[1,6-8]. However, the reference for this method was based on mild degenerative lumbar facet joints and could not be localized for cases with serious facet joint hyperplasia.

In the present study, the isthmus parameter D was employed to determine CBT screw placement. Specimen measurement and screw insertion of anatomical samples were performed to investigate the accuracy and clinical safety of the use of isthmus parameter D as the new cortical bone screw insertion reference point.

METHODS

Object selection

A total of 25 structurally complete lumbar dry specimens were used for lumbar anatomy measurements. Another four complete lumbar dry specimens and six lumbar wet specimens were selected for screw insertion and CBT evaluation. This study was

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also approved by the Ethics Committee of the First Clinical Medical Institute of Xinjiang Medical University (approval no.: 20141218-01).

Anatomical specimen measurement

Based on our previous studies of traditional pedicle screw placement[9] and lumbar isthmus parameter measurement[10], the isthmus parameter D1 could not be directly measured on anatomical specimen, but could be derived from S1 and S2. Because it is not easy to put the arm of vernier caliper into the spinal canal of the anatomical specimen when measuring the distance S2 between the inner wall of the pedicle, the fine Kirschner measure method was adopted to accurately measure the distance S2 in the present study[9]. To better confirm the measurement base point, we selected the distance between the inner wall of the pedicle and the vertebral body junction (point) on both sides. After removing the specimen, we used a vernier caliper to measure the distance between the two fine Kirschner pins to get the distance S2. The straight distance between the tangent point of the lateral edge of the isthmus and the tangential line of the pedicle inner wall (parameter D1) was obtained from the formula: D1=(S1–S2)/2.

The lumbar vertebrae were fixed on a foam plastic board with Kirschner wire and adjusted until the vertebral body was completely perpendicular to the board surface. D2 was measured as the vertical distance between the line connecting the vertexes of the isthmus and the lower edge of the transverse process. We separately measured the left and right D2 values and recorded the average as the final D2 value (Figure 1). If the lower edge of the transverse process was not a straight line, we applied the short distance between the end of the accessory process crest and the base of the transverse process, as the baseline of D2 measurement, and marked it on the specimen.

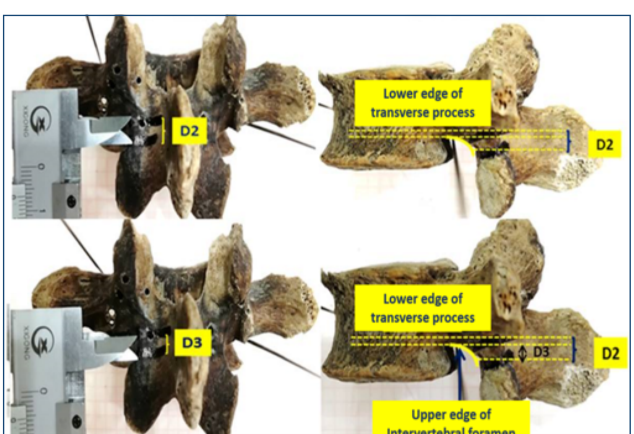

Figure 1. Diagram of the measurement of isthmus parameters D2 and D3.

Anatomical specimen lumbar isthmus parameter D3 obtained by the calculation "D2–1 mm" was the vertical distance from the line connecting the tangent points to 1 mm below the lower edge of the transverse process (Figure 1).

Screw insertion point selection

Without changing the horizontal axis, the vertical axis of the insertion point of the cortical bone screw was moved from the conventional mid-perpendicular line of the articular process to the tangent line of the median wall of the pedicle[8,10]. The lumbar isthmus tangent point was taken as a benchmark and then the D3 value was longitudinally shifted toward the cephalic side to obtain the vertical axis of the cortical screw insertion point. The horizontal axis of the screw insertion point was confirmed by referring to the D1 value of the lateral edge of the isthmus. The point where the vertical and horizontal axes intersected at the inside edge of the isthmus was regarded as the cortical screw insertion point. To enhance the holding power between the proximal cortex and the cortical bone of the lamina and pedicle, we used modified CBT screws that are different from traditional pedicle screws[1].

Anatomical specimen screw insertion

The screw insertion points on the 4 complete lumbar dry specimens and 6 wet specimens were based on the average values of isthmus parameters D1, D2, and D3 measured on 25 dry samples. All 100 trajectories were evaluated through visual observation, probe penetration, X-ray, and CT scans. The evaluation criterion was scored as described previously[11].

Statistical analysis

All analyses were performed using SPSS version 18.0 software (SPSS Inc., Chicago, IL, USA), and the results are presented as mean±standard deviation (SD). Variance analysis was used for comparisons between internal subgroups.

RESULTS

Anatomical specimen isthmus parameters

D1 gradually increased from the upper to lower lumbar spine (Table 1). The safety range of D1 should be limited between 2.5 and 5.5 mm. The D1 values of male patients were larger than those of female patients. Notably, D1 in the L5 segment should never exceed 6 mm to prevent the screw from entering the spinal canal during the insertion process.

The results of anatomical specimen distance D2 are presented in Table 1. The isthmus parameter D3 was defined as

D2–1 mm, indicating that D3 had a pattern similar to D2 (Table 1). D3 was based on the tangency point of the side edge curve of the isthmus. Compared with the traditional reference of the transverse process, the left and right sides of the isthmus were more symmetrical, suggesting that using D3 as a reference could improve screw insertion accuracy.

X-ray and CT examination results

The excellent rates of imaging evaluation results were 88.7% (53/60) and 95% (38/40). According to the previously published criterion[11], in wet lumbar specimens, four trajectories were evaluated as Grade II and three trajectories were considered as Grade III. For four dry specimens, two trajectories were evaluated as Grade II. These values demonstrated that the cortical screw insertion method based on isthmus parameter D was safe, accurate, and feasible.

DISCUSSION

Cortical bone does not undergo significant deformation and degeneration with age, so even osteoporotic cortical bone is relatively intact, although cancellous bone undergoes significant degeneration and has seriously reduced intensity[12]. Zdeblick et al. pointed out that the torque at screw insertion into the bone is the best indicator for predicting the failure of the bone and screw interface; that is, the bone strength determines whether the screw is loose[13].

From an anatomical perspective, to increase the holding force, the cortical bone screw insertion point should be as close as possible to the inner wall of the pedicle. To avoid damaging nerve structures within the spinal canal[14], the insertion point of the screw head should be proposed to the tangential site of the medial wall of the pedicle at the lateral edge of the isthmus. Using the modified CBT technique, the thicker periphery of the cortical bone screw at the insertion point (especially the lateral edge of the cortex) increases screw strength and avoids spondylolysis due to screw displacement. In addition, moving the cortical bone screw insertion point to the median side of the lumbar spine can also reduce the impact of the screw tail on the facet joint by increasing the distance between them; this reduces further degeneration of the facet joint.

Measuring isthmus parameters is helpful to estimate D values (including D1, D2, and D3) during surgery. A previous study proposed using X-ray to confirm the position of the highest intervertebral foramen point to further determine the optimal insertion point[16]. The tail of the lumbar accessory process crest was nearly consistent with the level of the lower edge of the transverse process. The distance between the accessory process near the base of the lumbar transverse process can be a good reference if it is difficult to identify the lower edge of the transverse process. This method reduces exposure of the transverse process and paraspinal muscles, minimizes soft-tissue injury and bleeding, and shortens operating time.

Notably, the most important factor affecting insertion torque was the length of the cortical screw in the lamina, not the length in the vertebral body or the total length of the screw[15]. Further measurements showed that the thickness of

Table 1. Distances D1, D2, and D3 measured by Vernier calipers on human lumbar spine specimens.

Lumbar segments	D1 (χ±s mm)	D2 (χ±s mm)		D3 (χ±s mm)	
L1	1.92±0.12	Left side	4.83±0.87	Left side	3.83±0.87
		Right side	4.84±0.85	Right side	3.84±0.85
		Average value	4.84±0.86	Average value	3.84±0.86
L2	2.06±0.09	Left side	5.98±0.77	Left side	4.98±0.77
		Right side	5.97±0.78	Right side	4.97±0.78
		Average value	5.98±0.77	Average value	4.98±0.77
L3	3.36±0.24	Left side	5.26±0.84	Left side	4.26±0.84
		Right side	5.25±0.84	Right side	4.25±0.84
		Average value	5.26±0.84	Average value	4.26±0.84
L4	4.38±0.15	Left side	3.75±0.41	Left side	2.75±0.41
		Right side	3.77±0.41	Right side	2.77±0.41
		Average value	3.76±0.40	Average value	2.76±0.40
L5	5.54±0.24	Left side	2.22±0.37	Left side	1.22±0.37
		Right side	2.19±0.36	Right side	1.19±0.36
		Average value	2.20±0.37	Average value	1.20±0.37

the isthmus or lamina at the cortical screw insertion point gradually increased. The L1 isthmus was 7 mm, and the value increased from L2, up to 10.5 mm at L5. According to the geometric angle, when the thickness of each segment of the lumbar spine was fixed, the effective length of the screw in the lamina could only be increased by enhancing the abduction angle of the cortical bone screw. CBT technique could increase the length of the cortical bone thread by at least 5 mm, or at least two full turns, which improves screw stability in the lumbar spine.

These values are similar to the excellent rates reported for traditional cortical bone screw technology in the literature[17,18]. These results demonstrated that the cortical bone screw placement method based on isthmus parameter D was safe, accurate, and practical. During CBT screw insertion, exposing the lateral edge of the isthmus is sufficient for screw placement without additional exposure of the transverse process. Screw insertion at the intersection of the two isthmus parameters (D1 and D3) will make surgery safer, less invasive, and easier. It will reduce intraoperative bleeding, fluoroscopy location time. We recommended that the screw placement angle for improved CBT technology should be larger than the recommended abduction angle of 10° for traditional CBT screw placement. The L1 and L2 angles in the upper lumbar spine should be controlled at approximately 10°, the angle of L3 should be 10°–15°, and those of L4 and L5 should be 15°–20°.

Furthermore, our modified cortical screw placement method did not change the horizontal axis of the cortical screw placement coordinate system; rather, it shifted the placement point further toward the midline, increasing the thickness of the peripheral cortical bone of the screw to increase the initial stability of the screw placement and the holding power (Figure 2). The tail of the screw is not near the intervertebral space level or corresponding articular joints, so it does not affect interbody cage placement in clinical practice. In special cases that require a very large cage, the screw is placed in the previously prepared screw path after cage placement. However, because the screw insertion point of this modified CBT technology is closer to the spinal process and laminar decompression area, there are certain limitations of application for patients requiring extensive lamina decompression. Thus, we recommend application of traditional pedicle screws in such severe clinical cases, and novel CBT was adopted for patients with mild or moderate lumbar spinal stenosis.

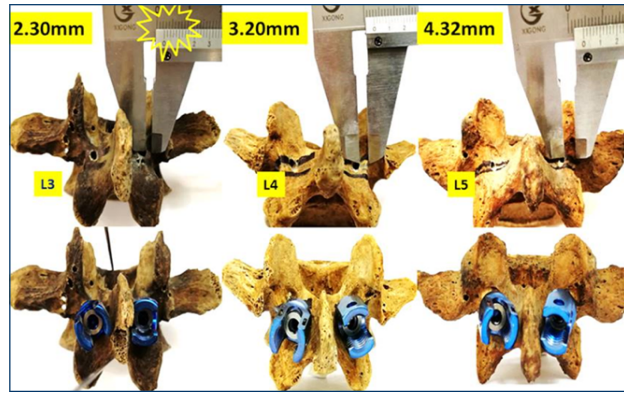

Figure 2. The insertion point of L3–L5 lumbar vertebrae using the modified cortical screw technique.

CONCLUSION

The isthmus parameter D is easier to use by the operator, which can improve surgical accuracy and reduce operation time.

AUTHORS' CONTRIBUTIONS

PR: Conceptualization, Methodology, Writing – original draft. **DA:** Software, Formal Analysis. **SW:** Visualization, Validation. **NA:** Resources, Investigation. **AK:** Data curation. **SW:** Conceptualization, Methodology, Supervision. All authors read and approved the final manuscript.

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