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Original Article

A novel entry point for pedicle screw placement in the thoracic spine

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Abstract

This study was aimed to introduce a novel entry point for pedicle screw fixation in the thoracic spine and compare it with the traditional entry point. A novel entry point was found with the aim of improving accuracy, safety and stability of pedicle screw technique based on anatomical structures of the spine. A total of 76 pieces of normal thoracic CT images at the transverse plane and the thoracic pedicle anatomy of 6 cadaveric specimens were recruited. Transverse pedicle angle (TPA), screw length, screw placement accuracy rate and axial pullout strength of the two different entry point groups were compared. There were significant differences in the TPA, screw length, and the screw placement accuracy rate between the two groups ($P < 0.05$). The maximum axial pullout strength of the novel entry point group was slightly larger than that of the traditional group. However, the difference was not significant ($P > 0.05$). The novel entry point significantly improved the accuracy, stability and safety of pedicle screw placement. With reference to the advantages above, the new entry point can be used for spinal internal fixations in the thoracic spine.

Keywords: entry point, screw placement, thoracic spine, biomechanical stability

Introduction

Pedicle screws are commonly used for rigid fixation in spine surgeries[1–3]. They provide robust and quick stability. Thoracic fractures represent 20% to 30% of vertebral fractures and this spinal segment has very little mobility. The deformities in the sagittal plane are often less dramatic when compared to the lumbar spine. However, neurological complications are more likely due to the presence of the spinal cord throughout the thoracic segment and small diameter of the spinal canal[4]. Several techniques have been developed to increase the accuracy of pedicle screw placement, including intraoperative CT, image-assisted navigation and intraoperative fluoroscopy in the thoracic spine[5–7]. Moreover, some techniques of freehand pedicle screw placement in the thoracic spine primarily are based on medial angulation and various entry points[8–11]. Although the accuracy of screw placement was increased slightly, these techniques increased radiation exposure and operative time to patients and surgeons[8–9]. Roy-Camille *et al.*[2] proposed a screw pedicle placement method that the screws were parallel to the vertebral endplate, and the entry point was located

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in the intersections of the thoracic transverse process midline and the facet joint midline.

Kim *et al.*[12] indicated the entry points of the thoracic pedicle screw placement in different levels: 1. Proximal thoracic (spine T1,T2): the intersections of the bisected transverse process and lamina at the lateral pars. 2. Mid-thoracic (spine T7-T9): the intersections of the proximal edge of the transverse process and lamina, just lateral to the mid-portion of the base of the superior articular process. 3. Lower thoracic (spine T11-T12): the intersections of the bisected transverse process and lamina at the lateral aspect of the pars.

In the present study, we described our experience with pedicle screw placement in the thoracic spine using a free hand technique by a novel entry point. In this technique, pedicle screws were placed *via* the approach between the multifidus and the longissimus, focusing on the entry point which was located on the intersection of the line of the lateral edge of the inferior articular process and the bisected transverse processes. The study was aimed to evaluate the accuracy, safety and biomechanical stability of this technique.

Materials and methods

Patients

Normal thoracic CT images at the transverse plane were obtained from the Imaging Department of the authors' affiliated hospital (76 patients, including 40 males and 36 females, median age: 46 years; range: 18-70 years) were recruited. The images of spine fractures, spondylolisthesis, tumor, and severe degeneration were excluded. This clinical study was approved by the Ethical Committee of the First Affiliated Hospital of Nanjing Medical University, and written informed consent was obtained from all patients.

Radiological measurements

The conventional entry point in this study was the point created by the intersection of the bisected transverse process and the midline of the superior facets. The novel entry point in this study was located on the intersection of the line of the lateral edge of the inferior articular process and the bisected transverse processes. The novel entry point (P) and the traditional entry point (P') are shown in ***Fig. 1***.

The distance was measured from the traditional entry point to the vertebral anterior edge (L). Then, we measured the angle relationship between the approach *via* this entry point and the sagittal plane. This angle was called transverse pedicle angle (TPA) (E).

The measurement method for the novel entry point was similar to the one mentioned above. We measured

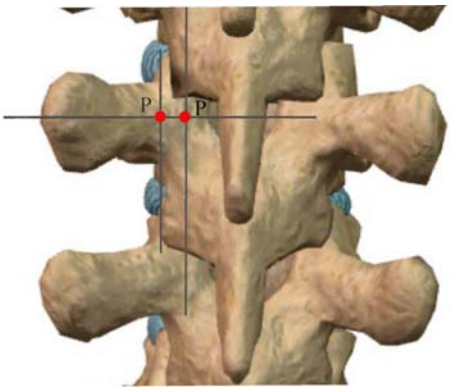

Fig. 1 **Two different entry points in the thoracic spine.** The novel entry point (P) is located on the junction point of the line of the lateral edge of the inferior articular process and the bisected transverse processes. The traditional entry point (P') in this study is the point created by the intersection of the bisected transverse process and the midline of the superior facets.

the distance from the novel entry point to the vertebral anterior edge (L'). Also, the angle relationship between the approach *via* the novel entry point and the sagittal plane was measured, and was called TPA (E'). The measurement method of TPA *via* the two different entry point is shown in ***Fig. 2***. The measurement method of the distance from the entry point to the vertebral anterior edge is shown in ***Fig. 3***.

Biomechanical analysis

The thoracic pedicle anatomy of 6 cadaveric specimens was studied at the authors' affiliated institution. Three males and 3 females were included. The age of the specimens ranged from 38 to 80 years with an average age of 52 years. None of the cadavers had a

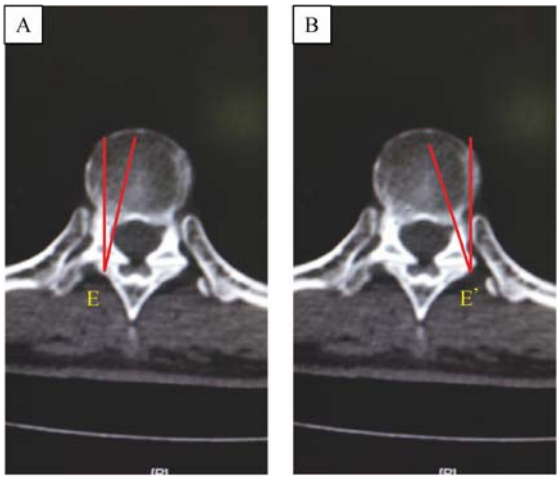

Fig. 2 **The transverse pedicle angle (TPA) *via* two different entry points.** A: the TPA *via* the traditional entry point for screw pedicle placement (E). B: the TPA *via* the novel entry point for screw pedicle placement (E').

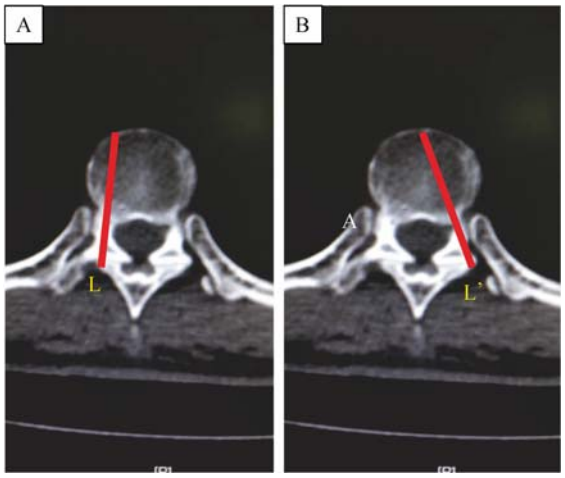

Fig. 3 **The measurement method of the distance from the entry point to the vertebral anterior edge.** A: The left line is the screw length through the traditional entry point (L). B: the right line is the screw length through the novel entry point (L').

history of spinal trauma, infection, neoplasm or developmental malformation. The study protocol was approved by the local institutional review board at the authors' affiliated institution and the study was carried out in accordance with the institutional and state guidelines regarding use of human cadavers. The spinal surgical instruments were provided by Shanghai Sanyou. The types of screw are shown as follows (diameter, length): (4.0 mm, 30 mm), (4.0 mm, 35 mm), (4.5 mm, 35 mm), (4.5 mm, 40 mm), (5.0 mm, 40 mm), and (5.0 mm, 45 mm).

Type BLR-1 biomechanical testing machine (maximum power 20kN, precision grade 0.5, date of 2005 ~ 02) was used in the study.

Group A used the traditional entry point on the left sides. Group B used the novel entry point on the right sides. The choice of the pedicle screws in each segment is shown in the ***Table 1***. All operations were completed by one surgeon, and after location, we observed the pedicle screws in three-dimensional C arm to compare the success rate between the two methods (***Fig. 4***). The definition of success: the screws were located in the pedicle cortex totally. The definition of failure: the screws punctured through the pedicle cortical bone. Subsequently, the specimens were fixed in a special mold, using the electronic universal testing machine BLR-1, with 5 mm/minute speed to test maximum axial pullout strength of the two methods (***Fig. 5***).

Table 1 **The choice of the pedicle screws in each segment**

Segment	Group A (diameter/length)	Group B (diameter/length)
T1-T3	4.0 mm/30 mm	4.0 mm/35 mm
T4-T8	4.5 mm/35 mm	4.5 mm/40 mm
T9-T11	5.0 mm/40 mm	5.0 mm/45 mm

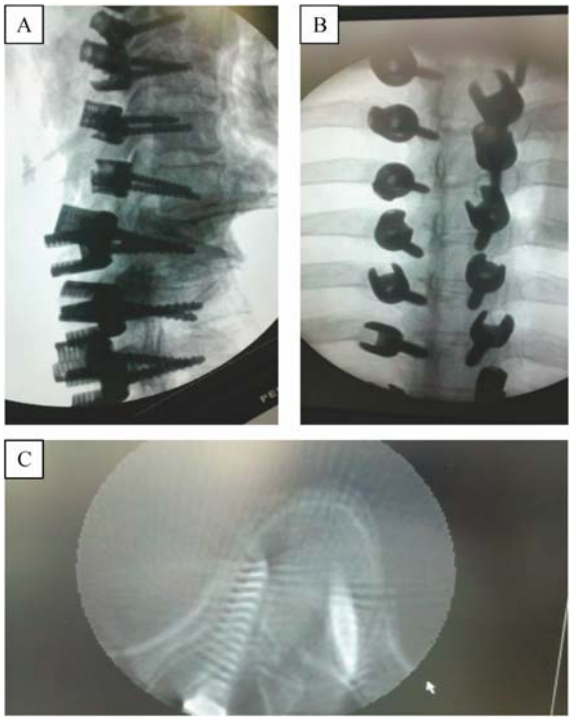

Fig. 4 **The pedicle screws in the three-dimensional C arm.** A: Lateral X-ray film after screw placement; B: frontal X-ray film after screw placement; C: transect X-ray film after screw placement.

Statistical analysis

SPSS 13.0. was employed to conduct statistical analysis. All continuous data were presented as mean±standard deviation (SD) and all categorical data as percentages or numbers. Statistical analyses for comparisons between groups were performed using the independent Students' *t*-test, the frequencies and the failure rates between two groups were compared using the chi-square test, and $P < 0.05$ was considered statistically significant.

Results

TPA

The widest TPA was (E = 24.56°±2.13°, E'= 30.98°±2.77°) at the T1 level in males and (E = 31.88°±1.49°; E'= 34.30°±1.38°) in females. The narrowest TPA was (E =–4.54°±1.35°; E'=–2.54°±1.85°) at the T11 level in males and (E =–2.54°±1.85°, E'=–0.07°±1.23°) in females (***Table 2***). Statistical analysis showed that the TPA gradually decreased from T1 to T11 and the TPA of the novel entry point was significantly greater than that of the traditional group ($P < 0.05$). Statistically significant difference in TPA was found between females and males at the level of T1, T4, T5 and T10 ($P < 0.05$).

Fig. 5 **The electronic universal testing machine BLR-1**

Screws lengths

The longest average screw length was [L =(33.73±4.55) mm, L'=(40.10±5.63) mm] at T11 level in males and [L =(28.77±1.51) mm, L'= (31.28±1.51) mm] at T11 level in females. The shortest average length [L =(24.56±2.13) mm, L'=(30.98±2.77) mm] in males and [L =(24.57±0.83) mm, L'= (26.60±1.22) mm] in females was at the segment of T1. There was a significant increase in screw length from the T1 to T11 thoracic vertebrae ($P<0.05$). The screw length of male vertebrae were significantly longer than that of female vertebrae in the majority thoracic levels ($P<0.05$) except the levels of T1 and T2. The results of the TPA and the screw length are shown in ***Table 2***.

Success rates

A total of 132 screws were implanted in 6 cadavers (66 from novel entry points and 66 from traditional entry points). The mean age, weight and height of the

Table 2 **Measurement of the transverse pedicle angle and the screw length for male and female**

Level	Gender	Transverse pedicle angle (^{0})		Screw length (mm)	
		E	E'	L	L'
T1	Male	30.10±4.66	33.72±4.68*	24.56±2.12	30.98±2.76**
	Female	31.88±1.49	34.30±1.38*	24.57±0.83	26.60±1.22*
T2	Male	21.52±4.65	25.63±4.96*	26.39±2.11	32.54±3.59*
	Female	23.45±1.71	26.15±2.25*	24.85±0.78	26.63±0.83*
T3	Male	14.28±2.31	18.20±3.09**	26.23±2.90	32.50±3.36**
	Female	16.25±1.78	19.14±2.18*	25.41±0.94	27.31±1.19*
T4	Male	9.79±2.07	12.67±2.22*	28.42±3.83	34.04±3.68*
	Female	12.53±1.48	15.45±1.52*	25.75±0.77	28.24±1.23*
T5	Male	7.44±1.53	10.10±2.01*	28.91±3.70	35.50±4.43**
	Female	9.39±1.05	12.69±0.85*	26.67±1.35	29.26±0.90*
T6	Male	5.22±1.40	7.30±1.95*	30.04±3.71	36.57±4.05*
	Female	6.66±1.66	10.02±1.53**	26.99±0.83	29.26±0.86*
T7	Male	3.14±1.77	5.81±2.13*	30.94±4.34	35.84±4.84*
	Female	3.98±2.01	7.48±1.51*	27.54±1.18	29.94±1.26*
T8	Male	1.83±1.60	3.76±1.73*	31.63±4.46	38.02±5.27*
	Female	2.32±1.87	4.86±2.41*	27.72±1.46	30.34±1.35*
T9	Male	-1.10±2.19	1.53±2.01*	32.51±4.70	39.68±4.86**
	Female	0.43±2.11	3.39±1.67*	28.01±1.49	30.60±1.62*
T10	Male	-3.06±2.12	-0.47±2.53**	33.15±4.32	39.38±4.54**
	Female	-1.74±0.83	1.33±1.31*	28.49±1.20	30.87±1.34*
T11	Male	-4.54±1.35	-2.54±1.85*	33.72±4.55	40.10±5.63**
	Female	-3.41±0.94	-0.07±1.23**	28.77±1.51	31.28±1.51*

*$P<0.05$; **$P<0.01$

cadavers in the two groups were similar. The failure rates of the two different techniques are shown in ***Table 3***. In detail, the failure rate was 12.1% in the novel entry point group, and 15.1% in the traditional entry point group. The results revealed no significant differences between the two groups. The pedicle screw failure rate was the highest in T4 and T5 for both techniques (33.3% in the novel entry point group, and 41.6% in the traditional entry point group).

Axial pullout strengths

From T1 to T11 levels, excluding failure screws, there were no significant differences in axial pullout strength between the novel entry point group and the conventional entry point ($P>0.05$). In the novel entry point group, T11 had the largest average maximum axial pullout strength (604.71±223.06), and T1 had the smallest average maximum axial pullout strength (323.53±208.78). In the traditional entry point group, the largest average maximum axial pullout strength was in the level of T11 (539.22±184.15), and the smallest average maximum axial pullout strength was in the level of T2 (219.18±89.32). The average maximum axial pullout strength of the two groups is shown in ***Table 4***.

Discussion

Transpedicular screw fixation is becoming more common in spine surgery[13–15]. However, this procedure is technically challenging and brings along complications, particularly in the thoracic spine. It is proved that minimally invasive surgical techniques bring many benefits to patients. However, diminished visualization of anatomy may increase intraoperative complications for surgeons and patients[16–17]. Accordingly, it is imperative to evaluate varying surgical methods and navigation aids so as to optimize clinical outcomes. Image navigation systems have been considered to improve the accuracy of transpedicular screw placement. Substantial research suggests that intraoperative CT navigation improves the accuracy of pedicle screw placement[18–21]. However, this surgical method will cause substantial radiation exposure to surgeons and patients. The ideal pedicle screw placement technology has the characteristics of constant needle entry points, less radiation exposure, little trauma, and high accuracy rates[22]. Based on the previous studies, we improved a minimally invasive thoracic pedicle screw technique, with minimally invasive incision, exposing the inferior articular process and transverse process. We chose the outer edge of the extension line of the inferior articular process and the middle line of the transverse process as the entry points. After screw placement, the position was confirmed by X-ray examination, and radiation exposure was significantly reduced.

The TPA with this novel entry point of thoracic screw placement is an important factor for the accuracy of screw placement. Cinotti *et al.*[23] pointed out that different thoracic pedicle TPAs in different segments were an important factor in the failure of the screw placement. According to our studies, the widest average angle was 33.72±4.68 degrees (T1 level) in males and 34.30±1.38 degrees (T1 level) in females. The narrowest average angle was 2.54±1.85 degrees (T11 level) in males and 0.07±1.23 degrees (T11 level) in female. TPA decreased from T1 to T11 levels. TPA had no significantly differences between males and females with the exception of the average TPA on T4 level which was significantly wider in females than in males. The finding is similar to previous studies that the narrowest angle was always found at T11 level. Compared with the traditional entry points, the novel

Table 3 **The number of failed pedicle screws of the two methods**

Levels	The pedicle screws failure of the novel entry point	The pedicle screws failure of the traditional entry point
T1	0	1
T2	1	1
T3	0	0
T4	2	2
T5	2	3
T6	1	1
T7	1	1
T8	0	1
T9	0	0
T10	0	0
T11	0	0

Table 4 **The axial pullout strength of the two kinds of screw pedicle placement**

	The novel entry point group (N)	The traditional entry point group (N)	*P*
T1	323.53±208.78	302.09±202.62	0.87
T2	371.87±195.86	219.18±89.32	0.11
T3	388.23±242.83	281.34±77.07	0.38
T4	478.42±201.95	391.40±180.65	0.47
T5	347.35±137.78	315.30±64.52	0.62
T6	464.12±254.35	503.96±208.08	0.77
T7	448.45±263.56	528.81±271.07	0.61
T8	523.67±343.00	533.28±293.51	0.96
T9	587.65±299.67	488.82±221.61	0.53
T10	552.82±89.16	519.67±263.93	0.65
T11	604.71±223.06	539.22±184.15	0.59

entry point had the characteristics of more partial entry points, larger TPA, and a lower probability for the screw to penetrate through the vertebral body. Thus, this new entry point for pedicle screw placement was better in safety and stability.

According to a previous study[24], the length of pedicle screw had a significant influence on the biomechanical stability. Weinstein *et al.*[25] found that the fixation strength increased by 15%-20% when the screws were in the vertebral cancellous bone, increased by another 16% while the screws were in the cortical bone, and increased by another 20%-25% when the screws penetrated through the cortical bone. Failure in axial pullout was tested using the electronic universal testing machine BLR-1. Longer screws showed higher pullout strength than all the other screws. Mckinley's study[26] confirmed that the 35 mm long screw bears the bending moment increased by 16% when compared to the 40 mm screw in the vertebral body. Barber *et al.*[27] showed that paired pedicle screws at 30 degrees of convergence offered more resistance to axial pullout (28.6% on average) and sustained higher loads at the clinical threshold of loosening (101% on average) than paired pedicle screws placed in parallel. Therefore, longer screw length and larger TPA make the stability of pedicle screw fixation better. Our study suggested that the screws of the new entry point group are longer than those of the traditional group. Therefore, compared with the greater screw length and the larger TPA, the novel entry point for pedicle screw placement has better stability than the traditional group.

Almost all published studies showed that the breach rate of the thoracic level is the highest in the spinal segments[28]. In our study, we developed a new entry point with the aim of improving the accuracy and safety of pedicle screw technique. The results demonstrated that pedicle screws can be accurately and safely inserted with the new entry point. According to the statistical data, we can conclude that this new entry point significantly improved the accuracy rate of pedicle screw placement compared to the traditional entry point. The failure rate of screw placement was relatively higher at the level of T4- T5 in both groups. The reason was that the level of T4-T5 showed smaller diameters, the relatively thinner pedicles and lower angles of convergence than other pedicles[29], it is difficult to make correct placement of pedicle screws. Therefore, it is not recommended to refer to this new entry point at the T4-T5 level. To ensure the safety and the accuracy of pedicle screw placement, radiographic data should be studied carefully before the operations to evaluate the anatomic relationship of pedicle diameter, pedicle length, and the TPA.

In conclusion, our study confirmed that this new entry point can significantly improve the accuracy rate and make the screws more stable in the process of pedicle screw placement. Moreover, this new entry point can avoid extensive exposure of the paraspinal muscles, ligaments and the facet joint, without affecting the stability of the spine. Therefore, the novel entry point of pedicle screw placement is safter, simpler, more accurate, and more stable than the traditional entry point in the thoracic spine.

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