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Original Article

A novel pedicle screw placement technique with reference to the percutaneous anatomic landmarks of the highest point of the spinous process

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Abstract: Pedicle screw placement is technically demanding and involves radiation exposure in thoracic and lumbar spine. A large number of rays have a serious impact on both patients and surgeon. The purpose of our study was to introduce a new free-hand pedicle screw placement which can reduce the exposure as compared with the traditional posterior open method. The sagittal screw angle between the vertebral upper end plate and percutaneous anatomic landmarks of the spinous process was measured from MR images before the operation. Total 126 cases of single-segment thoracolumbar fractures without neurologic injury underwent pedicle screw fixation via two different approaches (i.e., a new free-hand pedicle screw placement and the traditional posterior open method). In the new free-hand technique group, without exposure of the spinal process, the pedicle screw was inserted perpendicularly to the percutaneous anatomic landmarks of the highest point of spinous process according to the angle measured from the MRI before operation. In the conventional technique group, we perform a posterior midline incision at the target segment and striped the paraspinal muscle along the spinous process and the vertebral lamina, and then the intraoperative fluoroscopic guidance was used to determine sagittal screw angle and transverse screw angle. The angulation between the vertebral upper end plate and the percutaneous anatomic landmarks of the spinous process from MRI was close to 90°. Screw placement accuracy, operative time, blood loss, postoperative drainage, postoperative hospitalization time, and radiation exposure time of the two methods were compared. There was no statistical difference in the placement accuracy of the new free-hand technique and the conventional technique group (P=0.741). The operative time, blood loss, the postoperative hospitalization time, postoperative drainage and the frequency of intraoperation of the two methods were also compared, there were significant differences between the new free-hand group and the conventional group. This novel percutaneous pedicle screw placement technique referring to the anatomic landmarks of the spinous process is an accurate, reliable and safe technique for treating simple fracture in the thoracic or lumbar spine. In this novel screw placement procedure, there is less radiation exposure for surgeons and much lower fluoroscopy exposure for patients.

Keywords: Thoracolumbar fracture, radiation exposure, anatomic landmarks, spinous process

Introduction

Pedicle screw fixation has become one of the most widely employed fixation techniques in spinal surgery [1, 2]. In pedicle screw fixation, accurate insertion is essential to avoid neurological injury and weak stability. The pedicle screws should be placed at proper sagittal and transverse screw angle according to the corresponding entry point, so as to make the pedicle screws be located at the right place [3, 4]. Although a variety of different techniques are used for the placement of thoracic and lumbar vertebrae, there are two mainly techniques for pedicle screw placement: the computer-assisted navigation technique and the free-hand technique [5-8]. The computer-assisted navigation technique can provide lower potential for neurovascular injury and superior fixation, but it results in more radiation exposure, additional costs and more surgical steps [9]. For the current free-hand technique, there is no reference to determine the placement angle (the sagittal screw angle and transverse screw angle), but only the intraoperative fluoroscopic guidance and the surgeon's experience. Although the cur-

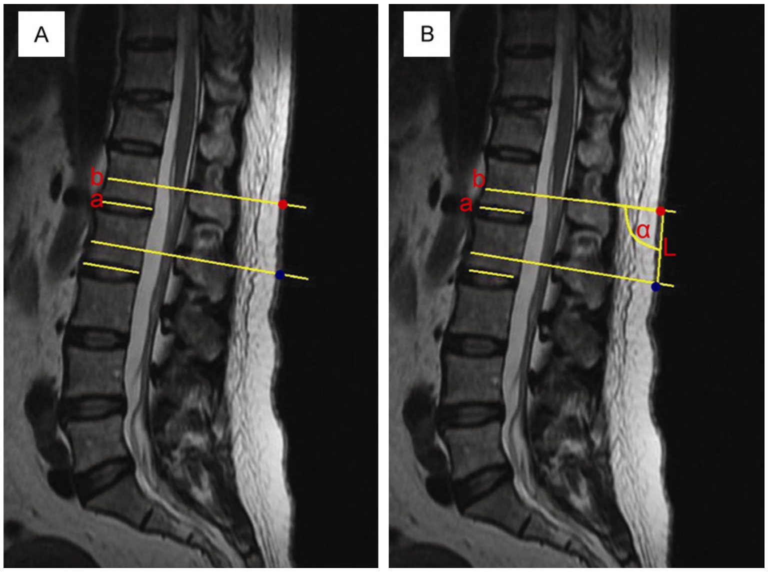

Figure 1. A: Line a, the line through the surface of the upper endplate; Line b, the line is parallel to line a, and cross the percutaneous anatomical landmarks at the blue point. Another line was painted in the adjacent segment and crossed the corresponding percutaneous anatomical landmarks of the pat the red point. B: We made a line (L) between the blue point and the red point, and measured the angle (α) between the line L and the line b. The angle is considered as the sagittal screw angle for the pedicle screws placement.

rent free-hand technique is simpler than the computer-assisted navigation technique, it requires more time and more radiation exposure. What's more, the traditional free-hand technique needs to sufficiently expose the back column of the spine and may cause much more blood loss and more recovery time for patients [10, 11]. The previous results showed [12] that the spinous process can be a reference to place the pedicle screws in the thoracolumbar segment. In order not to expose the spinous process and reduce the surgical trauma, we are trying to find the angle relationship between the vertebral upper end plate and percutaneous anatomic landmarks of the highest point of spinous process from MR images.

The purpose of our study was to introduce a new free-hand pedicle screw placement technique referring to the percutaneous anatomic landmarks, as compared with the traditional free-hand posterior open method.

Materials and methods

Anatomy relationship

100 pieces of normal thoracolumbar MR images at middle sagittal plane from the imaging department of authors' affiliated hospital (43 male and 57 female, BMI (body mass index) range from 17.52 to 24.31, median age 46 years old; range from 21 to 88 years old) were recruited. The images of spine fractures, spondylolisthesis, tumor, severe degeneration were excluded. The angle relationship between the upper vertebral endplate and percutaneous anatomic landmarks of the spinous process from MR images was measured by Picture archiving and communication system (PACS). The measurement method is shown in **Figure 1A**, **1B**. Firstly, we made a line parallel to the surface of the upper endplate (line b, which is parallel to line a), which crossed the percutaneous anatomical landmarks of the spinous process at the blue point. Then, another line was painted in the adjacent segment and crossed the corresponding percutaneous anatomical landmarks at the red point. Lastly, we made a line (L) from the blue point to the red point, and measured the angle (α) between the line L and the line b. The measurement method is shown in **Figure 1A**, **1B**. The angle is considered as the sagittal screw angle for the pedicle screws placement. The segment from T1 to L5 was measured with the same method in each MR image.

Surgical technique

Patients: Total 126 consecutive patients with types A, B1 and B2 (according to Gertzbein classification) thoracolumbar fractures who underwent a posterior spinal fixation surgery in the period from January 2014 to September 2016 were included. Among them, 59 individuals received treatment using the new free-hand technique, and the left 67 were treated in the conventional technique groups. Totally, 268 pedicle screws were implanted in the new free-hand group, 296 in the conventional group. The same surgeon operated in both groups. Thoracolumbar fractures, lumbar spondylolisthesis, spinal stenosis, etc. were carried out in the operations of internal fixation. Data of

Table 1. Data of patients and levels of inserted screws

	Age		Gender		BMI (Body Mass Index)		Number of screws in different vertebral level					
	Mean	Range	Male	Female	Mean	Range	T10	T11	T12	L1	L2	Total
Group 1 (n=59)	57.43	21-72	32	27	21.34	17.83-25.44	34	48	76	68	42	268
Group 2 (n=67)	55.35	26-74	36	31	20.93	17.52-24.96	36	42	88	94	36	296

Note: Group 1, the new free-hand technical group. Group 2, the conventional technical group.

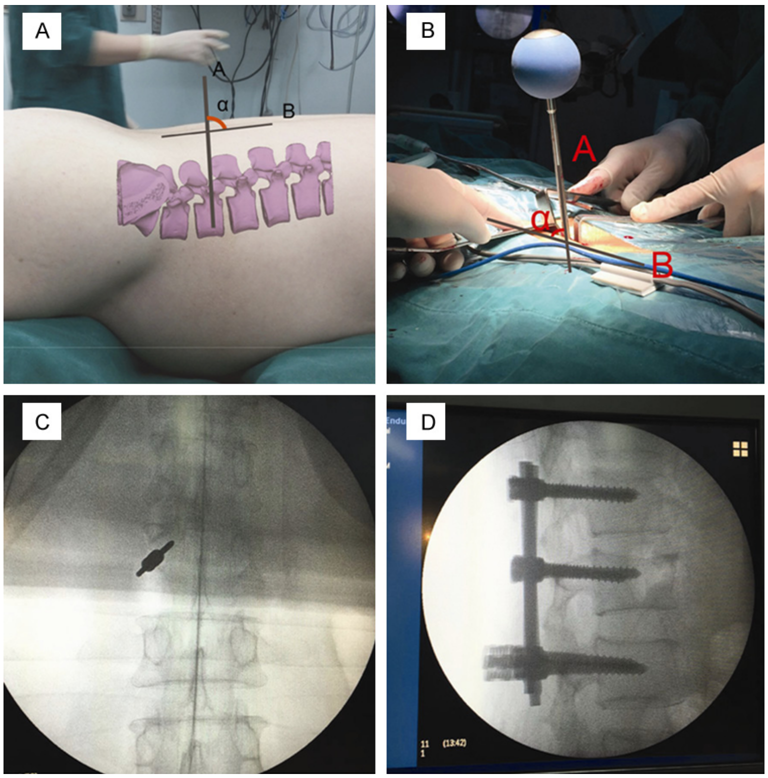

Figure 2. A, B: Line B, the line through the percutaneous anatomnical landmarks of the spinous process. Line A, the line of the orientation of the guide wires to implant the pedicle screw. The angle α is the angle between line A and line B, which considered as the sagittal screw angle for the pedicle screws placement. C: The X-ray was used one time in the operation to determine the location of the guide wires. D: After operation, the X-ray was used to determine the location of all the pedicle screws.

patients and segments of inserted screws were shown in the **Table 1** in detail. The single axial screws (Weigao company, Shandong, China) were used for our percutaneous pedicle screw internal fixation. The screw positions were evaluated by postoperative CT scan to check for malposition.

Surgical methods: For the conventional posterior open approach, we performed a posterior midline incision at the target segment and cut the paraspinal muscle along the spinous process and the vertebral lamina. Then, the facet joints and roots of the transverse process were exposed by a retractor. The entry point was determined based on anatomical landmarks according to the AO method.

For the novel free-hand technique group, firstly we measured the angle relationship between the vertebral upper end plate and percutaneous anatomic landmarks of the spinous process on MRI before operation. Then body positioning was performed in a manner that same as that in the conventional posterior open approach. The small incisions were located next to the posterior midline. Then, dissection was performed through the intermuscular plane between the multifidus and the longissimus muscles until the outer edge of the facet joints are reached. In this technique, the entry point is placed at the intersection of the line bisecting the base of the transversen process and the line touching the lateral border of the superior articular process. Without exposure of the spinal process, the pedicle screws were inserted to the percutaneous anatomic landmarks of the spinous process according to the angle measured from the MRI. C-arm was just intermittently used to check and adjust positions of the guide wires and screws. After all screws were inserted, the positions of screws were assessed by C-arm again. The surgical technique of the new free-hand pedicle screw placement was shown in **Figure 2**.

Measured parameters: The accuracy rate of the pedicle screw placement was measured by the grading system which described by Rao et

Table 2. The angle between the vertebral upper end plate and percutaneous anatomic landmarks of the spinous process from MR images in different vertebral level

	N	Minimum	Maximum	Mean	SD
T1	100	76.7	97.4	87.953	4.0416
T2	100	72.4	97.5	85.523	4.7958
T3	100	71.5	95.7	83.192	4.5362
T4	100	74	93.0	83.35	3.931
T5	100	76.2	94.2	84.085	3.6926
T6	100	73.6	97.9	86.439	3.6756
T7	100	78	95.0	87.80	3.475
T8	100	83.0	97.2	88.628	2.6827
T9	100	78.8	99.1	88.387	3.1440
T10	100	78.2	98.7	88.335	3.4947
T11	100	78.0	99.5	88.446	2.8591
T12	100	79.1	95.9	89.197	2.8345
L1	100	80.6	99.1	90.459	3.1339
L2	100	84.5	100.2	90.052	2.6929
L3	100	82.3	102.4	90.820	4.0267
L4	100	81.0	97.4	89.243	3.8120
L5	100	78.5	100.6	87.734	4.5364

Note: N indicates the number of the images of normal thoracolumbar.

al. In brief, Grade 0 was defined as no perforation; Grade 1 was defined as only thread of screw outside pedicle (<2 mm of perforation); Grade 2 was defined as core of screw outside pedicle (2 mm to 4 mm of perforation) and Grade 3 was defined as screw completely outside pedicle (>4 mm perforation). Grade 2 and 3 perforations was considered dangerous, because they can cause nerve root irritation and spinal cord injury conceivable. Therefore, they were classified as critical perforations. Only screws in Grade 0 were considered as accurate insertion. Also, the operative time, blood loss, postoperative drainage, postoperative hospital stays, and X-ray exposure time were considered as the study parameters. Blood loss was estimated by weighing the sponges and determining the blood volume in the suction bottle. The volume of postoperative drainage was measured by weighing wound dressings and estimated the blood volume in the drainage package in the two groups. Postoperative hospital stay was counted from the first day after the operation to the discharge day.

Statistical analysis

Mean values and Standard deviations for all variable parameters were calculated for two groups. χ^2 test was used to compare the accuracy rates of pedicle screws between the two groups, independent-sample t test was used to compare the functional outcome between the two groups. To test for the significance of the findings, statistical probability (*P* value) for comparison between the groups was calculated using SPSS 22.0. The significance level was set at *P* value less than 0.05.

Results

Measurement of the angulation relationship

In the measured results, the angle from T1 to L5 ranges from 83.192° to 90.820°. Among them, the average angle of T4 is the smallest (mean ± SD 83.35°±3.931°, range from 74° to 93°), the average angle of L3 is the largest (mean ± SD 90.82°±4.027°, range from 82.3° to 102.4°). In the **Table 2**, from T8 to L4, the angle we measured was close to 90°, so we can get the conclusion that from T8 to L4, the pedicle screw can be inserted with reference to the percutaneous anatomy landmarks of the spinous process. The pedicle screw can be implanted correctly and accurately from T8 to L4 when the screw was perpendicular to the percutaneous anatomy landmarks of the spinous process. However, for the other segments, we have to make the pedicle screw implantation according to the angle measured before operation. After measurements and analysis, theoretically, it is feasible that from T8 to L4, if pedicle screws were placed perpendicularly to the percutaneous anatomy landmarks of the spinous process, they would be parallel to the surface of the upper endplate.

Accuracy rate of pedicle screw placement

Among all the pedicle screws, both groups required no intraoperative adjustment. No complications such as spinal cord, nerve root or blood vessel injuries occurred. Total 126 patients received 564 pedicle screws placed in the thoracic or lumbar spine. In the new free-hand group, total 268 pedicle screws were inserted from T10 to L2, the number of grades 0 was 250, and the number of grade 1 to grade 3 was 18. The breach rate was 6.71%. In the traditional group, 296 screws were implanted from T10 to L2. The number of grade 0 was 274, the number of grade 1 to grade 3 was 22, and the breach rate was 7.43%. The number of screws inserted at each level was shown in the **Table 3**.

Table 3. Pedicle breaches per each level

Level	Total screws	NO. Breaches (%)	The new free-hand technical group				Total screws	NO. Breaches (%)	The conventional technical group			
			Grade 0	Grade 1	Grade 2	Grade 3			Grade 0	Grade 1	Grade 2	Grade 3
T10	34	2 (5.88)	32	1	1	0	36	3 (8.33)	33	2	1	0
T11	48	3 (6.25)	45	2	1	0	42	3 (7.14)	39	1	1	1
T12	76	6 (7.89)	70	3	2	1	88	8 (9.09)	80	4	2	2
L1	68	4 (5.88)	64	4	0	0	94	6 (6.38)	88	3	1	2
L2	42	3 (7.14)	39	2	1	0	36	2 (5.56)	34	2	0	0
Total	268	18 (6.71)#	250	12	5	1	296	22 (7.43)#	274	12	5	5

#Accuracy rates of the two groups were compared by χ^2 test. There was no significance difference of the accuracy rate between the two groups (p=0.741). Grade 0 was defined as no perforation; Grade 1 was defined as only thread of screw outside pedicle (<2 mm of perforation); Grade 2 was defined as core of screw outside pedicle (2 mm to 4 mm of perforation) and Grade 3 was defined as screw completely outside pedicle (>4 mm perforation).

Table 4. Functional outcome

	The new free-hand technique group N=59	The conventional technical group N=67	t value
Operative time (minutes)	90.23±16.75	102.89±18.97*	-4.011
Blood loss (mL)	80.61±34.25	106.68±34.64*	-4.239
Postoperative drainage (mL)	33.25±17.84	63.76±34.87*	-6.288
Postoperative hospitalization time (days)	6.83±1.89	9.49±1.93*	-7.818
The radiation exposure frequency (times)	3.03±0.81	5.96±1.22*	-15.975

Note: * vs the new freehand technique group, p<0.05.

Accuracy rates of the two groups were compared by χ^2 test. Analysis of data was conducted using SPSS 22.0. The results showed that there was no significant difference between the two groups in the accuracy rates (χ^2=0.109, p=0.741).

Functional outcome

Total 59 patients took operations in the new free-hand group, and 67 patients in the conventional technology group. In the measured surgical results, the operation time (minutes) was 90.23±16.75 in the new free-hand group, and 102.89±18.97 in the traditional group. The blood loss (mL) of the new free-hand group was 80.61±34.25, and 106.68±34.64 in the traditional group.

Postoperative drainage volumes (mL) of the two groups were separately 33.25±17.84 and 63.76±34.87. The postoperative hospital stay (days) of the two groups were 6.83±1.89 and 9.49±1.93. As for the frequency of intraoperative radiation exposure, the new free-hand group was 3.03±0.81, the conventional group was 5.96±1.22. For the surgical outcomes, there were significant differences in the operation time, the blood loss, the postoperative hospital stay, the postoperative drainage and intraoperative radiation exposure frequency between the two groups. The results were showed in **Table 4**.

Therefore, the new free-hand group has obvious advantages compared to the conventional technology group in the operation time, the blood loss, the postoperative hospital stay, postoperative drainage and the frequency of intraoperative radiation exposure.

Discussion

With the increased use of pedicle screw placement in the surgical treatment of spinal fracture, the intuitively beneficial goal is the improved accuracy and a lower radiation exposure [13]. Misplaced screws can lead to a lot of complications, such as injury to the spinal cord or nerve roots [14-16], dural tear [14, 15], neurologic deficit [15, 16], skeletal perforation and neurologic deficit [15, 16].

For many years, percutaneous pedicle screws placement have been used in minimally invasive spine surgery in order to improve the accuracy of pedicle screw implantation and to reduce exposure to radiation [17]. Percutaneous pedicle screws inserted have many advantages, such as protecting muscle from extensive damage, reducing postoperative pain, blood loss, hospital stay time, and less infection rate [18-20]. However, for both surgeons and patients, the fluoroscopy time is extensively long for many percutaneous pedicle screw technologies [21]. The radiation exposure of the percutaneous pedicle screws technology was much higher than the conventional open technology in many reports [22, 23]. Extensive radiation exposure may cause induce cancer, skin injury, and lead to hereditary effects [24]. Thus, it is an important goal to reduce the X-ray exposure for both surgeons and patients.

According to our study, the angle we measured between the vertebral upper end plate and the percutaneous anatomic landmarks of the spinous process from T8 to L4 was approximately 90°. Therefore, in order to design our new free-hand technique, we only need to insert the pedicle screw perpendicularly to the percutaneous anatomic landmarks of the spinous process, and the pedicle screw will be parallel to the surface of the upper end plate.

Comparing with the conventional group, the new free-hand technology had no significant difference in the operation time, the blood loss, and the hospitalization time, the radiation exposure and the postoperative drainage volume ($p<0.05$). Therefore, the great advantage of the new free-hand technique apparently is the reduction of the frequency of radiation exposure. It can not only reduce the danger of radiation exposure, but also make the operation much simpler. Furthermore, the surgeon can refer to the intraoperative anatomy to guide screw placement directly without exposing the spinous process. In this study, the accuracy rate was 93.29% in the new free-hand technique group, and 92.57% in the traditional group. Accuracy rates of the two groups were compared by χ^2 test. The results showed that there was no significant difference between the two groups in the accuracy rates ($\chi^2=0.109$, $p=0.741$).

However, our study was limited because it just focused on simple fractures in the thoracic or lumbar spine, and the small number of cases. Furthermore, the study may have been subjected to selection bias because of the exclusion of the patients associated with nerve or spinal cord injury, spinal serious transformation, spinal deformity or severe combined injury.

In a follow-up study, we will examine pedicle screw placement by this method in other diseases of the spine, including spinal deformities. What's more, to enhance the safety of pedicle screw fixation, the choice of the correct percutaneous anatomic landmark of the supraspinal ligament was sufficient. Therefore, pedicle screw placement with a new free-hand technique referring to the percutaneous anatomic landmarks of the spinous process is a method with less radiation exposure and the similar accuracy rate to treat the thoracolumbar spinal fracture as compared with the traditional posterior open method.

Conclusions

In conclusion, the method of this novel percutaneous pedicle screw placement is a safe, effective technique for the treatment of the spinal fracture. In this new pedicle screw placement procedure, there is less radiation exposure for surgeons and much lower fluoroscopy exposure for patients with the satisfactory accuracy rate of pedicle screw insertment.

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Disclosure of conflict of interest

None.

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