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Comparing Accuracy of Cervical Pedicle Screw Placement between a Guidance System and Manual Manipulation: A Cadaver Study

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Background: The aim of this study was to compare the accuracy of cervical pedicle screw placement between a three-dimensional guidance system and manual manipulation.

Material/Methods: Eighteen adult cadavers were randomized into group A (n=9) and group B (n=9). Ninety pedicle screws were placed into the C3-C7 under the guidance of a three-dimensional locator in group A, and 90 screws were inserted by manual manipulation in group B. The cervical spines were scanned using computed tomography (CT). Parallel and angular offsets of the screws were compared between the two placement methods.

Results: In group A, 90% of the screws were within the pedicles and 10% breached the pedicle cortex. In group B, 55.6% were within the pedicle and 44.4% breached the pedicle cortex. Locator guidance showed significantly lower parallel and angular offsets in axial CT images ($P<0.01$), and significantly lower angular offset in sagittal CT images ($P<0.01$) than manual manipulation.

Conclusions: Locator guidance is superior to manual manipulation in accuracy of cervical screw placement. Locator guidance might provide better safety than manual manipulation in placing cervical screws.

MeSH Keywords: **Cervical Atlas • Dimensional Measurement Accuracy • Manipulation, Spinal • Phospholipid Transfer Proteins**

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Background

Since Abumi et al. [1] first reported cervical pedicle screw fixation and its application in over 300 cases [2], this technique has received increasing attention. Compared to lateral mass screw fixation and anterior cervical fixation, cervical pedicle screw fixation has higher pullout force resistance [3–5]. Cervical pedicle screw fixation can achieve three-column stability and rigid fixation, and is especially suitable for patients with cervical spine instability caused by osteoporosis, cervical spine injuries, bone degeneration, and tumors [6–8]. However, cervical pedicle screw placement involves higher risks than pedicle screw placement in the thoracolumbar spine, and demands much more surgical skill [9]. The cervical pedicles are small and have very thin lateral walls, with great variations in their directions. Thus, cervical pedicle screw insertion has a certain risk of perforation, which may cause complications such as nerve root compression, vertebral artery injury, and even spinal cord injury [10–15].

A cervical pedicle screw can be inserted using one of the three methods: manual insertion [16], computer-assisted image-guiding insertion [17], and placement with cervical pedicle three-dimensional locator guidance [18]. Manual placement varies greatly in accuracy depending on the specific insertion method and surgeon's experience [16,19], and therefore has variable safety. Computer-assisted insertion has good accuracy, stability, and safety [17,20,21], and one of its advantages is percutaneous placement of screws [22]. Conflicting results have been obtained on whether computer-assisted placement can lower the incidence of pedicle perforation [11,12,17,23–28]. Computer-assisted navigation also failed to show any clinical benefits [22,29]. The high cost further restricted the application of computer-assisted navigation.

Cervical pedicle locator guidance is cost-effective and can work with all imaging systems. This study aimed to compare the accuracy of screw placement between the three-dimensional locator guidance and manual manipulation.

Material and Methods

Cadavers

Eighteen formalin-embalmed adult cadavers were randomly divided into group A (n=9) and group B (n=9). The cadavers were provided by the Nanjing Medical University. The Ethics Committee of our hospital approved this study. The C3–C7 vertebrae were scanned using computed tomography (CT) (a 256-slice Brilliance iCT scanner, Philips Medical Systems, Nederland) in the axial and sagittal planes. The slice thickness was 1 mm. The CT images were measured for the reference of screw insertion. Cadavers were put in the prone position. A posterior median incision was carried out in the neck. Paravertebral muscles were dissected to expose the bilateral masses and inferior borders of the articular process.

Screw placement

In group A, the screw was placed using locator guidance. Data from the CT image of the C3–C7 vertebrae were input into the locator to regulate the processus articularis feet, lateral mass feet, columella, angular arm, and gunsight. The fixing knobs were screwed. The hooklets attached to the processus articularis feet were inserted into the joint space and pulled tight to maintain the processus, with articularis feet tightly touching the inferior borders of inferior articular process. A hole was made using a tailor-made long drill and a screw of 2-mm diameter was inserted [18].

In group B, the screw was inserted using manual manipulation. The entering point of the screw was determined using the Abumi technique and a caliper [1]. The abduct angle of the pedicle was measured using an angle measuring instrument. In the sagittal plane, the offset angle was estimated caudally or cranially. The posterior cortex of the lateral mass was not ground. The pedicle bone marrow was not detected using a probe. The entering point and trajectory of the screw were determined. A hole was made using a 2-mm-diameter drill. A screw of 2-mm diameter was inserted. C-arm X-ray guidance was not used during the procedure.

Offset evaluation

After insertion of screws in the two groups, each cadaver underwent sagittal and axial CT scans. The parallel offset and angular offset were measured between the screw and the pedicle axis in CT images with a caliper and an angle-measuring instrument. The offsets were graded according to the following criteria:

I: Parallel offset ≤1 mm [18] and angulate offset ≤5°.
II: Parallel offset >1 mm [18].
III: Angulate offset >5° [18].
Excellent: The screw is completely within the pedicle. Parallel offset ≤1 mm and angulate offset ≤5°.
Fair: The screw is completely within the pedicle. Parallel offset >1 mm, or angulate offset >5°, or both.
Poor: The screw penetrates the pedicle cortex.

Statistical analysis

Continuous data are presented as mean ± standard deviation. Categorical data are presented as frequencies and percentages. Comparisons were made using Student's *t*-test or chi-square test. All statistical analyses were performed using SPSS 17.0 software (SPSS, Chicago, IL, USA). $P<0.05$ was considered statistically significant.

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Table 1. Nails insertion results of locator guidance.

	C3 (%)	C4 (%)	C5 (%)	C6 (%)	C7 (%)	Total (%)
Within pedicle	16 (88.9)	16 (88.9)	16 (88.9)	15 (83.3)	18 (100)	81 (90)
Outside pedicle	2 (11.1)	2 (11.1)	2 (11.1)	3 (16.7)	0 (0.0)	9 (10)
NRI	0 (0.0)	0 (0.0)	1 (5.6)	1 (5.6)	0 (0.0)	2 (2.2)
VAI	0 (0.0)	0 (0.0)	1 (5.6)	0 (0.0)	0 (0.0)	1 (1.1)
SCI	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)

NRI – nerve root injury; VAI – vertebral artery injury; SCI – spinal cord injury.

Table 2. The number of offset error nails of locator guidance in its cross-sectional CT Image.

	C3 (%)	C4 (%)	C5 (%)	C6 (%)	C7 (%)	Total (%)
I	11 (61.1)	14 (77.8)	15 (83.3)	10 (55.6)	13 (72.2)	63 (70.0)
II	6 (33.3)	2 (11.1)	3 (16.7)	6 (33.3	2 (11.1)	19 (21.1)
V	1 (5.6)	2 (11.1)	0 (0.0)	2 (11.1)	3 (16.7)	8 (8.9)

I – vertical offset distance of the nail axis ≤1 mm and simultaneity an angular offset ≤5° from the pedicle axis.

Results

Accuracy of locator guidance

A total 90 screws were inserted in the C3–C7 vertebrae in group A. Among them, 81 screws (90%) were entirely within the pedicle and 9 screws (10%) breached the pedicle cortex. Two screws injured the nerve root and one screw injured the vertebral artery (Table 1).

In the axial CT image, 63 screws (70%) had a parallel offset ≤1 mm and an angular offset ≤5° from the pedicle axis, 19 screws (21.1%) had a parallel offset >1 mm, and 8 screws (8.9%) had an angular offset >5° (Table 2). Parallel offsets in the axial and sagittal CT image were 0.56±0.70 mm and 1.04±0.99 mm, respectively; angular offsets in the axial and sagittal CT image were 1.69±2.41°C and 6.54±7.08°C, respectively (Figures 1, 2).

Accuracy of manual manipulation

A total 90 screws were inserted in the C3–C7 vertebrae in group B. Among them, 50 screws (55.6%) were entirely within the pedicle and 40 screws (44.4%) breached the pedicle cortex breach. Nineteen screws injured the nerve root and four screws injured the vertebral artery (Table 3).

In the axial CT image, 25 screws (27.8%) had a parallel offset ≤1 mm and an angular offset ≤5° from the pedicle axis, 38 screws (42.2%) had a parallel offset >1 mm, and 54 screws (60%) had an angular offset >5° (Table 4). Parallel offsets in the axial and sagittal CT images were 1.19±1.02 mm and 1.35±0.99 mm, respectively; angular offsets in the axial and sagittal CT images were 11.27±9.34°C and 9.84±8.22°C, respectively (Figures 1, 2).

Comparative analysis of groups A and B

The parallel offset in the axial CT images was significantly lower in group A than group B (*P*<0.01). The parallel offset in the sagittal CT images in group was significantly higher than the axial images (*P*<0.01) (Figure 1). However, there was no significant difference in the parallel offset between group A and group B in the sagittal CT image (*P*=0.05). The parallel offset of groups also did not differ significantly between the axial and sagittal CT images (*P*>0.05) (Figure 1).

The angular offset in the axial and sagittal CT images of group A was significantly higher than that of group B (*P*<0.01). The angular offset of group A differed significantly between the axial and sagittal CT images (*P*<0.01) (Figure 2). There was no significant difference in angular offset of group between the axial and sagittal CT images (*P*>0.05) (Figure 2).

Discussion

Our study showed that locator guidance has better accuracy than manual manipulation in cervical pedicle screw placement and lower risks of injuries of the pedicle, nerve root, and vertebral artery. Parallel offset of screws from the pedicle axis in axial CT images can help to evaluate the offset of insertion

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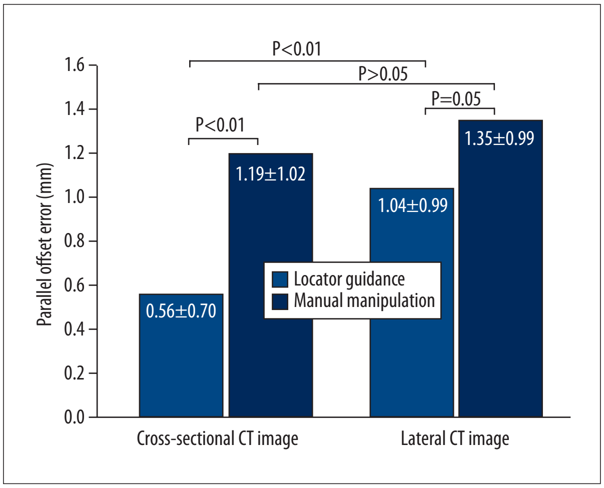

Figure 1. There were significant differences between group A and B in the axial CT images and between the axial and sagittal CT images of group A. There were no significant difference between group A and B in the axial CT images or between axial and sagittal CT images of group B.

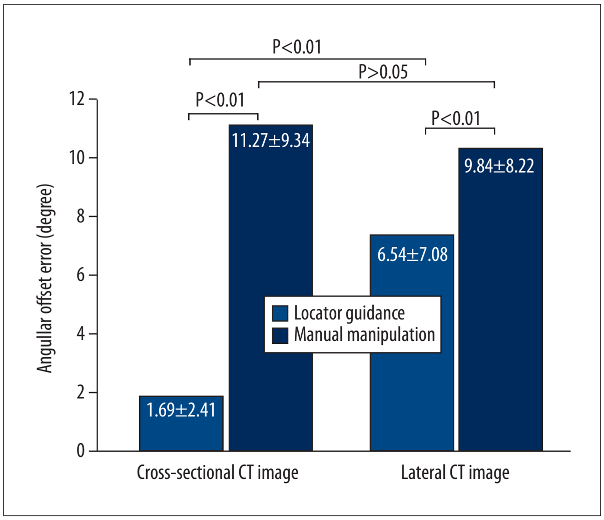

Figure 2. There were significant differences between group A and B in the axial and sagittal CT image and between axial and sagittal CT images of group A. There was no significant difference between axial and sagittal CT images of group B.

Table 3. Nails insertion results of manual manipulation.

	C3 (%)	C4 (%)	C5 (%)	C6 (%)	C7 (%)	Total (%)
Within pedicle	8 (44.4)	13 (72.2)	5 (27.8)	14 (77.8)	10 (55.6)	50 (55.6)
Outside pedicle	10 (55.6)	5 (27.8)	13 (72.2)	4 (22.2)	8 (44.4)	40 (44.4)
NRI	4 (22.2)	2 (11.1)	8 (44.4)	2 (11.1)	3 (16.7)	19 (21.1)
VAI	1 (5.56)	0 (0.0)	2 (11.1)	0 (0.0)	1 (5.56)	4 (4.4)
SCI	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)

NRI – nerve root injury; VAI – vertebral artery injury; SCI – spinal cord injury.

points. Angular offset of screws from the pedicle axis can help to evaluate the abduct angle offset of screw trajectory.

In our study, C-arm X-ray guidance was not used to assist screw placement; therefore, the accuracy of locator guidance and manual manipulation was compared in the same condition. According to the Abumi procedure [1], the insertion point was 5 mm medial to the lateral border of the lateral mass and slightly inferior to the inferior border of the articular process of the superior vertebra. However, due to the arched shape of the lateral border of the lateral mass, it was difficult to precisely determine the distance between the insertion point and the lateral border of the lateral mass, regardless of CT image, or during the operation, even when aided by a caliper. Therefore, the parallel offsets between axes were so large that 38 (42.2%) screws had a parallel offset >1 mm (Table 4II). In contrast, the three-dimensional locator determined the horizontal insertion point by locating the posterior tangent line of the lateral masses and the inferior point of the inferior articular process and measuring the posterior tangent line DD [18] of the lateral masses in CT image. This can decrease the number of screws with a parallel offset >1 mm to 19 (21.1%) screws (Table 2II).

The abduct angle in manual manipulation was determined by measuring the CT image (range from 25° to 45°) [1]. An angle-measuring instrument was used to accurately measure the abduct angle of the pedicle and to guide the screw insertion. However, 54 screws (60%) had an angular offset >5° (Table 4 V) because the surface of the lateral mass was uneven and the spinous process was not absolutely upright. The orientation of the locator depends on its parts (angular arm and gunsight) [18] and results from measurement of the CT image referring to the surface of the lateral masses rather than the spinous process. Therefore, only 8 (8.9%) screws had an angular offset >5° (Table 2V). In the axial CT images, both incidences of parallel offset (≤1 mm) and angulate offset (≤5°) were

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Table 4. The number of offset error nails of manual manipulation in its cross-sectional CT image.

	C3 (%)	C4 (%)	C5 (%)	C6 (%)	C7 (%)	Total (%)
I	4 (22.2)	5 (27.8)	8 (44.4)	3 (16.7)	5 (27.8)	25 (27.8)
II	7 (38.9)	5 (27.8)	8 (44.4)	8 (44.4)	10 (55.6)	38 (42.2)
V	12 (66.7)	12 (66.7)	10 (55.6)	11 (61.1)	9 (50.0)	54 (60.0)

I – vertical offset distance of the nail axis ≤1 mm and simultaneity an angular offset ≤5° from the pedicle axis; II – vertical offset distance of the nail axis >1mm from the pedicle axis; V – angle of the nail axis >5° with the pedicle axis.

Table 5. Hitting accuracy of pedicle of two insertion techniques.

	HAP (%)	ASR (%)	RSR (%)	UR (%)
Locator guidance	90	60.49	17.28	22.22
Manual manipulation	55.6	25	25	50

HAP – hitting accuracy of pedicle; ASR – absolute stability rate of the hitting accuracy of the pedicle; RSR – relative stability rate of the hitting accuracy of the pedicle; UR – unstability rate of the hitting accuracy of the pedicle.

less, and the screw axis was close to the pedicle axis. There was great contrast between locator guidance (63 screws, 70%) and manual manipulation (25 screws, 27.8%) (Tables 2, 4I). The difference in both parallel offset ($P<0.01$) and angular offset ($P<0.01$) was statistically significant between group A and group B in the axial CT image (Figures 1, 2). These results indicate that the locator can enhance the breadthwise accuracy of screw placement compared with manual manipulation.

Also, the parallel offset ($P<0.01$) and angular offset ($P<0.01$) of the locator were significantly different between the axial and sagittal CT images (Figures 1, 2). These results suggest that the breadthwise accuracy was higher than that of the lengthwise accuracy. There were no significant difference in the parallel offset ($P>0.05$) and angular offset ($P>0.05$) of the manual manipulation between the axial and sagittal CT images (Figures 1, 2). These results indicate that the probabilities of offset in all manners were approximately equal.

Breach of the pedicle cortex is currently the most common standard for evaluation in both cadaveric and clinical studies [10,25,27,30,31]. Our study, however, further graded the screw placement accuracy to excellent (grade I: ≤1 mm and ≤5°) and fair (grade II: >1 mm and >5°). The failure rate of screw insertion manipulated by Abumi himself was 6.7% [10]. During screw placement, Abumi ground the cortex at the point for insertion, explored the pedicle marrow cavity using a probe, and used X-ray guidance. The first two steps were indispensable for correcting the offset of insertion point and angle. The use of a probe further determined the insertion direction during exploration. Therefore, Abumi's procedure was based on experience rather than quantitative parameters, despite the reference of CT image. On the contrary, the locator guidance can be easily manipulated and is a precise method with minimal experience required. For locator guidance, the parameters for location can be selected by measuring the CT image. The two factors of point location and screw trajectory in Abumi's procedure were reduced to only one location on the posterior surface of the lateral masses for placing the locator [18].

Conclusions

For the placement of cervical pedicle screws, locator guidance has better accuracy than manual manipulation. We speculate that locator guidance might provide better safety than manual manipulation in placing cervical screws.

Disclosure of conflict of interest

None.

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