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Original Article

Spiral CT measurement for atlantoaxial pedicle screw trajectory and its clinical application

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Abstract: Objective: This study aimed to focus on the atlantoaxial pedicle screw placement and evaluate the effects of anatomical data and degree of surgical exposure of the atlantoaxial pedicle screw trajectory determined using spiral CT on the reference sites for pedicle screw insertion and various parameters in clinical application. Method: The data of CT scan of cervical spine from individuals treated in our hospital were selected. Various anatomical parameters of the atlantoaxial pedicle screw trajectory were measured through multiplanar reconstruction (MPR) technology. Anatomical data and degree of surgical exposure of the atlantoaxial pedicle screw trajectory were obtained through spiral CT. Vernier calipers with least count of 0.01 mm was selected and the least count of the protractor was 0.2°. Prism 8.0 was adopted for graphical data analysis. The anatomical data of atlas of the local population were established. The measurement technique for pedicle screw trajectory and the method for pedicle screw insertion were mastered. Results: The results indicated that the intraoperative blood loss was between 30-280 ml with no case of excessive blood loss. Follow-up studies 10-18 months after the operations indicated stability of upper cervical spine without adverse conditions. The width of the pedicle screw was 13-24 mm, and the maximal inclination angle of the horizontal for the insertion was 17-21°. Conclusion: The atlantoaxial pedicle screw placement was an effective surgical treatment for stabilizing the upper cervical spine. The measurement data of the atlantoaxial pedicle screw path was obtained through spiral CT and the surgical placement of pedicle screw was guided through individual data. Postoperative CT scan was adopted to evaluate the accuracy of pedicle screw placement, record the occurrence of secondary injuries, improve the stability of clinical applications, and reduce the risks for patients.

Keywords: Atlantoaxial spine, pedicle screw, spiral CT, measurement of screw trajectory

Introduction

The studies of atlantoaxial pedicle ranged from anatomy to clinical applications. Multiple studies suggested unique anatomical morphology of atlas, and the atlantoaxial pedicle screw placement is an effective method for the treatment of traumatic spondylolisthesis and spinal disease. Atlantoaxial stabilization via pedicle screw fixation was an effective surgical treatment that decreased time for postoperative recovery and reduced treatment risk along with the application and generalization of the method [1]. The vertebral artery at the region of atlantoaxial pedicle runs through the transverse foramen of the atlas to the periphery of the atlantoaxial joint, and the artery near the region of spinal cord is more susceptible to injury that could lead to permanent damage to the patients' health. The atlantoaxial pedicle screw was inserted and fixed on both sides via the groove for vertebral artery on the posterior arch of atlas. The spiral CT measurement technique for atlantoaxial pedicle screw trajectory matured overtime.

The atlantoaxial pedicle is a special structure in the human body with the spinal cord in the canal at this region more susceptible to injury that could potentially lead to suppressed cardiovascular activity and even respiratory failure which could lead to death. The operations that take place on important tissues, the vertebral artery and internal carotid artery in the upper cervical spine, were more difficult. The operation requires special repair technique that involves the fixation technique of the atlantoaxial pedicle screws which could improve the stability of axial movement in cervical spinal joints. Comprehensive physical examination was performed on patients before the operation and the injured area was examined using CT scan. Posterior pedicle screw fixation was performed. The angle and procedure for insertion were determined based on each patient's condition. The condition for each individual was evaluated to avoid accidents [2-5]. In this study, the patients treated in our hospital and their postoperative conditions were recorded.

Axial pedicle screw placement is the main method for treating traumatic spondylolisthesis and other spinal diseases, whereas atlantoaxial pedicle screw fixation is the new effective technique for the treatment of traumatic instability of the upper cervical spine currently. With the generalized use of this method, the atlantoaxial pedicle screw fixation is shown to have unparalleled advantages compared to other fixation techniques and minimize the intraoperative pain and recovery time for patients [6, 7]. The minimal distance between the parallel atlantoaxial pedicle screws was the pedicle width which was set to be ranged from A1-A4. The minimal distance between the periphery of the atlas and axis and the inner margin of the transverse foramen was defined as the pedicle width for screw fixation. The intersection of the perpendicular bisector and the posterior arch of the atlas determined the lateral region for the pedicle screw insertion site. The screw was 5 mm.

Material and methods

Clinical information

The data of CT scan of cervical spine from 30 cases of healthy individuals were obtained from the imaging center database in our hospital. Various anatomical parameters of the atlantoaxial pedicle screw trajectory were measured through multiplanar reconstruction (MPR) technology. The anatomical data of atlas for the local population were established. The measurement technique for pedicle screw trajectory and the method for pedicle screw insertion were mastered. Among the selected individuals, 17 cases were male, 13 cases were female, and the age was between 23-58 years old with an average age of 45.9 years. The left and right atlantoaxial pedicle screw insertion was performed and the anatomical data and degree of surgical exposure of the atlantoaxial pedicle screw trajectory were obtained through spiral CT. Vernier calipers with least count of 0.01 mm was selected and the least count of the protractor was 0.2°. GraphPad Prism 8.0 software was adopted to plot graphs. This study has been approved by the Ethics Committee of Jieyang People's Hospital. All study participants provided written informed consent before participating in the study.

Inclusion criteria. 1) The mode of the dissecting equipment was set to be individualized and quantitative to provide accurate parameters for pedicle. 2) Variation or special cases in the morphology of pedicle as well as abnormality of vertebral artery were determined. 3) Preoperative design to select screws based on radiological parameters. 4) Reduction in intraoperative blood loss and operative time. 5) Decrease in times of repeated drilling for pedicle screw placement to reduce the risk of penetrating the pedicle wall. 6) Reduction in the time for fluoroscopy using C-arm X ray during the operation, thereby decreasing secondary injuries caused by radiation.

Operative methods

For the 30 cases of individuals selected, various anatomical parameters of the atlantoaxial pedicle screw trajectory were obtained through multiplanar reconstruction (MPR) technology. The anatomical data of atlas in the local population were established, which laid the foundation for arrangement of future surgeries. The recording of individual data for pedicle screw trajectory and the measurement of parameters of pedicle screw placement were necessary during the atlantoaxial pedicle screw placement. The postoperative CT scan data were used to assess the accuracy of the screw insertion, and cases of discomfort or severe injury 12-18 months after the operation were monitored [8-11]. All patients were examined with spiral CT scan before the operation. Multiple slices were used in the CT scan with a section thickness of 1.0 mm. The images were sent to the workstation for measurement. Multiplanar reformation method was used to assess various parameters of the atlantoaxial pedicle screw trajectory. The distance between the insertion point and the most lateral border, the distance between the insertion point and superior articular process, angle of inclination, and sagittal angle were determined based on the measurement data and the diameter and length of the pedicle screw were determined. The preoperative plan was carried out. The ped-

Table 1. Statistics of atlantoaxial pedicle screw placement measured via MPR technique ($P \geq 0.05$)

Unit and range	Left side	central side	right side
Pedicle width (mm)	10.11 ± 2.34 (11)	9.11 ± 1.41 (6)	8.91 ± 1.23 (13)
maximal inclination angle of the horizontal for the insertion (°)	15.76 ± 1.44 (8)	18.88 ± 2.11 (9)	18.65 ± 1.22 (13)
The pedicle screw length at maximal inclination angle (mm)	22.23 ± 3.23 (3)	24.56 ± 1.34 (10)	25.67 ± 2.22 (17)
The length of trabeculae lateral to the insertion site (mm)	26.34 ± 2.41 (5)	23.49 ± 1.34 (7)	24.76 ± 2.24 (18)
The insertion angle at the transverse section (°)	-9.41 ± 7.3 (12)	-9.23 ± 7.3 (9)	-9.01 ± 6.75 (9)
Minimal length of screw insertion (mm)	26.71 ± 2.33 (11)	27.83 ± 3.24 (8)	28.09 ± 2.04 (11)

As shown in **Table 1**, the pedicle width for left side insertion was within 13 mm and the maximal inclination of the horizontal was no more than 17°. The minimal length for screw insertion was within 26-28 mm. The pedicle width for central side insertion was within 11 mm and the maximal inclination of the horizontal was no more than 21°. The minimal length for screw insertion was within 30-32 mm. The pedicle width for right side insertion was within 10 mm and the maximal inclination of the horizontal was no more than 20°. The minimal length for screw insertion was within 30-31 mm. The data model of parameters for atlantoaxial pedicle screw placement was shown in **Figures 1** and **2**.

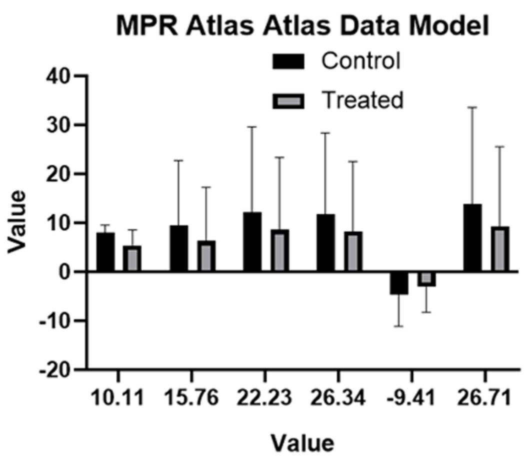

Figure 1. The data model of parameters for atlantoaxial pedicle screw placement measured via MPR. The operative time for all 30 cases was maintained between 100-130 min and the intraoperative blood loss was 30-150 ml. There was no incident of perioperative blood transfusion due to excessive blood loss and the no incident of patients with infected wounds or other complications.

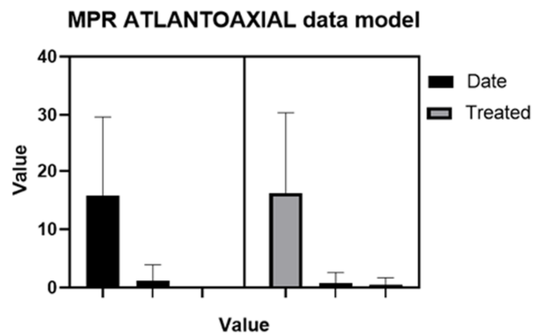

Figure 2. The data model of parameters for atlantoaxial pedicle screw placement measured via MPR. The basic data for atlantoaxial pedicle screws were balanced. The insertion sites and the angles of insertion were consistent. There was difference in maximal insertion lengths of the horizontal but not significant. The screw inserted was stable and effective.

icle screw insertion and fusion surgery were performed based on the preoperative plan [12-18]. The time for each screw placement, intraoperative blood loss, and success rate of the first insertion were recorded. All patients were examined with non-contrast CT scanning at the level of the pedicle to assess the accuracy of pedicle screw insertion.

Results

Overall outcomes

A total of 30 patients received the atlantoaxial pedicle screw placement surgery and the parameters were measured using MPR technique. The intraoperative blood loss was between 30-280 ml with no case of excessive blood loss. Follow-up studies 10-18 months after the operations indicated stability of upper cervical spine without adverse conditions. The measurement data for atlantoaxial pedicle screw insertions were shown in **Table 1**.

As shown in **Table 1**, the pedicle width for left side insertion was within 13 mm and the maximal inclination of the horizontal was no more than 17°. The minimal length for screw insertion was within 26-28 mm. The pedicle width for central side insertion was within 11 mm and the maximal inclination of the horizontal was no more than 21°. The minimal length for screw insertion was within 30-32 mm. The pedicle width for right side insertion was within 10 mm and the maximal inclination of the horizontal was no more than 20°. The minimal length for screw insertion was within 30-31 mm. The data model of parameters for atlantoaxial pedicle screw placement was shown in **Figures 1** and **2**.

Table 2. Summary of spatial distribution for screw insertion sites

The regions of the insertion sites			
A1 (8)	A2 (6)	A3 (7)	A4 (9)
Medial transverse section of the atlas	Outer margin of groove for vertebral artery	Pedicle	Pedicle
Length of L1	Length of L2	Length of L3	Length of L4
Atlas 26 mm	Atlas 50 mm	Axis 24 mm	Axis 24 mm

As indicated by **Table 2**, parameters of atlas: transverse section of the central part of the atlas: the length between posterior tubercle and site of insertion (L1) was 2.61 cm of the atlas, which was approximately 2.40-3.60 cm; the length between outer margin of groove for vertebral artery and the insertion site (L2) was 0.50 cm of the atlas, which was approximately 0.20-0.70 cm; pedicle width (L3) was 0.87 cm of the atlas which was approximately 0.50-0.90 cm; the length of pedicle screw insertion (L4) was 0.58 cm of the pedicle, which was approximately 0.35-0.80 cm; the angle of inclination (α angle) was 15.3° which was approximately 12.0-28°; the angle between the pedicle arch of atlas and lateral mass of the axis (β angle) was 117.1° and this angle minus 90° is the actual angle which was approximately 15.0-30°. See **Figures 3-6**.

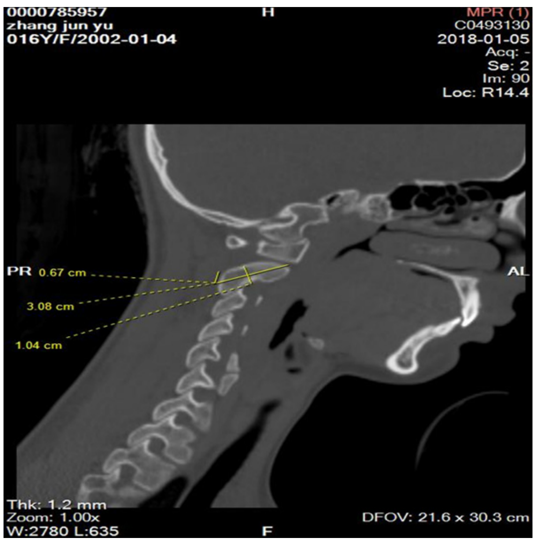

Figure 3. Image of pedicle screw insertion at the medial transverse section of the axis. The medial transverse section of the axis: the length of pedicle (L1) was 1.04 cm of the axis, which was about 0.50-1.20 cm.

Blood loss

As shown in **Figure 1**, the operative time for all 30 cases was maintained between 100-130 min and the intraoperative blood loss was 30-150 ml. There was no incident of perioperative blood transfusion due to excessive blood loss and the no incident of patients with infected wounds or other complications.

As shown in **Figure 2**, the basic data for atlantoaxial pedicle screws were balanced. The insertion sites and the angles of insertion were consistent. There was difference in maximal insertion lengths at the horizontal but not significant. The screw inserted was stable and effective [18].

Sites of insertion

The sites of insertion were shown in **Table 2**.

As indicated by the detailed parameters setting of the insertion sites in **Table 2**, parameters of atlas: transverse section of the central part of the atlas: the length between posterior tubercle and site of insertion (L1) was 2.61 cm of the atlas, which was approximately 2.40-3.60 cm; the length between outer margin of groove for vertebral artery and the insertion site (L2) was 0.50 cm of the atlas, which was approximately 0.20-0.70 cm; pedicle width (L3) was 0.87 cm of the atlas which was approximately 0.50-0.90 cm; the length of pedicle screw insertion (L4) was 0.58 cm of the pedicle [19], which was approximately 0.35-0.80 cm; the angle of inclination (α angle) was 15.3° which was approximately 12.0-28°; the angle between the pedicle arch of atlas and lateral mass of the axis (β angle) was 117.1° and this angle minus 90° is the actual angle which was approximately 15.0-30°. See **Figures 3-6**.

Discussion

The atlas is the topmost vertebra with specialized structure that contained anterior and posterior arch and two lateral masses and transverse processes of the atlas which formed a ring-shaped vertebra. The whole structure is without vertebral body or spinous process but with one large lateral mass on either side. The upper border of the anterior arch is the anterior tubercle, and the posterior of which formed joint with the odontoid process of the atlas. The superior and inferior sides of each lateral mass carried articular facets with occipital bone and axis respectively.

Figure 4. Image of the screw insertion site at the upper border of the lateral mass. The length between the upper border of the lateral mass and the screw insertion site (L2) was 0.67 cm of the axis, which was approximately 0.30-0.80 cm.

The central region of the posterior arch is the posterior tubercle and the groove for vertebral artery is superior to both sides of the arch. The transverse foramen is located in the transverse process at the lateral side. The vertebral artery ascends through the transverse foramen of the axis to the periphery of the atlantoaxial joint, and then ascends upwards through the transverse foramen of the atlas. It then turns backwards and medially towards the lateral mass in an acute angle to transmit through the groove for vertebral artery, which is superior to the posterior arch, to ascend medially. It then passes through the atlanto-occipital membrane to enter the spinal canal. The structure is complicated, and the operation is difficult. The spiral CT measurement for atlantoaxial pedicle screw trajectory is a technique for clinical application.

The data for CT scan of cervical spine from 30 cases of healthy individuals were obtained from the imaging center database in our hospital. Various anatomical parameters of the atlantoaxial pedicle screw trajectory were measured through multiplanar reconstruction (MPR) technology. The anatomical data of atlas for the local population were established. The measurement technique for pedicle screw trajectory and the method for pedicle screw insertion were mastered. The measurement data of the atlantoaxial pedicle screw trajectory were obtained through spiral CT and the surgical placement of pedicle screw was guided through individual data. Postoperative CT scan was adopted to evaluate the accuracy of pedicle screw placement and record the occurrence of secondary injuries.

Atlantoaxial fusion was performed through atlantoaxial stabilization with posterior screw and rod fixation combined with autogenous iliac bone graft for spinal fusion. The recovery time was short with no incident of excessive intraoperative blood loss or complications [20-22].

The maximal inclination of the horizontal for the insertion, appropriate range for the length of atlantoaxial pedicle screw insertion, and sites of insertion were monitored and controlled and the following problems were solved: 1) Accurate anatomical data were obtained through the spiral CT measurement of atlantoaxial pedicle screw trajectory, and the MPR technique was adopted to optimize the axial plane for screw trajectory selection in axial plane and improve reference sites and various parameters for insertion; 2) Detailed postoperative recovery plan for posterior pedicle screw fixation and detailed operative technique were optimized. Injuries of important surrounding tissues were avoided based on personal parameters measured via CT scan; 3) The most optimal technique for physical fixation that was reliable and convenient was proposed based on the individual characteristics of bone and reposition from 30 cases of pedicle screw placement [23-27].

Conclusion

Based on past clinical results, atlantoaxial pedicle screw fixation was shown to have strong clamping force, high stability, significant effectiveness, short operative time, less intraoperative blood loss, convenience for operation, and better protection for the atlas and axis. This treatment method could be widely applied for the treatment of atlantoaxial disease that included bone fractures, odontoid fractures that could not be treated by anterior odontoid screw fixation, ruptured transverse atlantal ligament, atlantoaxial dislocation, dysplasia of odontoid process or os odontoideum, rheuma-

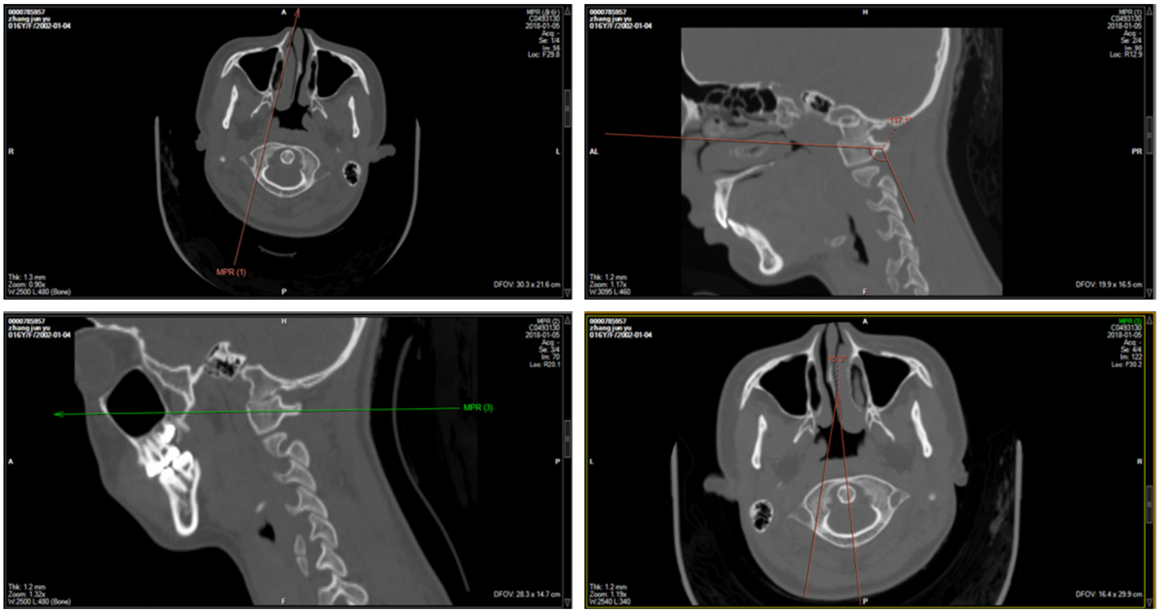

Figure 5. Image of pedicle screw insertion. Pedicle width (L3) was 0.92 cm of the axis, which was approximately 0.30-0.95 cm.

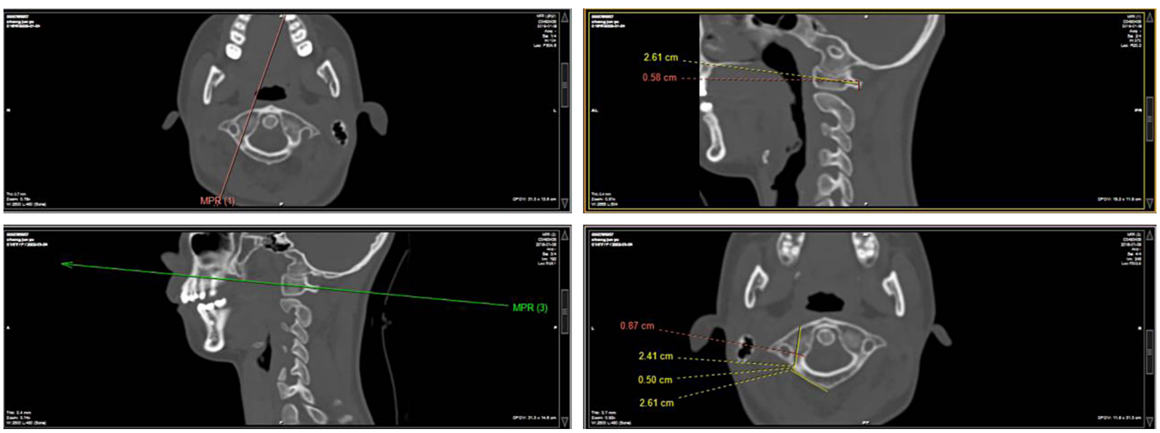

Figure 6. The screw insertion site at the outer margin of the lateral mass. The length between the outer margin of the lateral mass and the screw insertion site (L4) was 0.89 cm of the axis, which was approximately 0.35-0.90 cm; the inclination angle of the pedicle (γ angle) was approximately 14.0-30°; the head-tilting angle (θ) of pedicle was 121.7°. This angle minus 90° was the actual angle which was approximately 20.0-40°.

toid arthritis, tumors in the atlantoaxial region, *etc*.

The conventional treatment method lacked the scientific evaluation at posterior-anterior and lateral views compared to atlantoaxial pedicle screw placement. Over-extension as well as altered flexion and extension positions during the CT scan could lead to relatively high incidence of postoperative syndromes and complications, whereas the atlantoaxial pedicle screw placement could lead to high stability and safety in the surgeries. The atlantoaxial pedicle screw placement was an effective surgical treatment for stabilizing the upper cervical spine. The measurement data of the atlantoaxial pedicle screw path was obtained through spiral CT and the surgical placement of pedicle screw was guided through individual data. Postoperative CT scan was adopted to evaluate the accuracy of pedicle screw placement, record the occurrence of secondary injuries, improve the stability of clinical applications, and reduce the risks for patients [28]. The atlantoaxial abnormalities were observed using CT scan combined with 3-D reconstruction. MRI technique detected no abnormality in the regions for atlantoaxial pedicle screw insertion and related parameters. The bone thickness was less than 4 mm after recovery with no significant abnormality.

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Disclosure of conflict of interest

None.

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