RESEARCH ARTICLE

Comparison of Perpendicular to the Coronal Plane *versus* Medial Inclination for C2 Pedicle Screw Insertion Assisted by 3D Printed Navigation Template

Chao Wu, MD[1,2], Jiayan Deng, MD[2], Qing Wang, MD[3], Danwei Shen, MD[2], Binwei Qin, BD[3], Tao Li, MD[1], Xiangyu Wang, MD[1], Baifang Zeng, BD[1,3]

[1]Department of Orthopedics, Zigong Fourth People's Hospital, Zigong, [2]Institute of Digital Medicine, Zigong Academy of Big Data for Medical Science and Artificial Intelligence, Zigong, 643000 and [3]Department of Orthopedics, Hospital of Southwest Medical University, Luzhou, China

Objective: C2 pedicle screw insertion is very important in posterior upper cervical surgery. The traditional screw placement technique requires us to consider both medial inclination and cephalad angle, it is difficult to operate intraoperatively. This paper is to explore a novel method of C2 pedicle screw placement compared with traditional C2 pedicle screw.

Methods: A total of 44 patients diagnosed with atlantoaxial fracture or instability from May 2018 to November 2020 were involved in this retrospective study, and they were divided into C2-PPS group (perpendicular to the coronal plane C2 screw, 24 patients) and C2-TPS group (traditional C2 pedicle screw, 20 patients). The diameter of the maximum tangential circle, distance between geometric center and median sagittal plane and screw length of PPS and TPS were measured based on the 3D model of C2, respectively. Then the 3D printed navigation templated were designed and manufactured by 3D printing to assisted the PPS and TPS placement, respectively. The surgical time and radiation exposure times during operation were recorded; the post-operative grading criteria, deviation of screw entry point and deviation of screw angle of two groups were evaluated, respectively.

Results: A total of 48 screws were inserted in the C2-PPS group, and 40 screws were inserted in the C2-TPS group. There were 46 screws with grade 0 (95.8%) in the PPS group and 31 screws with grade 0 (77.5%) in the TPS group, ($P = 0.03$). The radiation exposure times in the C2-PPS group and C2-TPS group were 4.7 ± 1.5 and 7.8 ± 3.8, respectively, ($P = 0.045$). The deviations of screw entry point in the C2-PPS group and C2-TPS group were 1.2 ± 0.8 mm and 3.2 ± 1.3 mm, respectively; the deviations of screw angle in the C2-PPS group and C2-TPS group were $2.1 \pm 1.6^\circ$ and $4.8 \pm 2.0^\circ$, respectively, ($P = 0.000$). The diameters of the maximum tangential circle in the C2-PPS group and C2-TPS group were 5.5 ± 1.0 mm and 5.3 ± 0.9 mm, respectively. The distances between the geometric center and median sagittal plane in the C2-PPS group and C2-TPS group were 15.4 ± 2.3 mm and 18.0 ± 3.3 mm, respectively; The screw lengths in the C2-PPS group and C2-TPS group were 25.9 ± 3.2 mm and 27.6 ± 3.7 mm, respectively, ($P = 0.000$).

Conclusion: Eighty percent of C2-PPS corridor can accommodate a 3.5 mm diameter screw, and with an average screw length of 26 mm. Navigation templates assisted the C2-PPS placement is less surgical time, less radiation exposure times, more safe and more accurate than C2-TPS.

Key words: Axis; Navigation templates; Pedicle screw

Address for correspondence: Chao Wu, Department of Orthopedics, Zigong Fourth People's Hospital, 19 Tanmu Lin street, Zigong, Sichuan 643000, China. Email: flightiness@163.com
Received 15 May 2022; accepted 8 September 2022

Introduction

As a posterior fixation procedure for the upper cervical spine, C2 screw placement is an important surgical technology.[1] There are many C2 internal fixation techniques, including C2 pedicle screws and C1–C2 transarticular screws, C2 pars screws, C2 laminar screws, and C2 parsicle screws.[2–7] Stable and effective screw fixation can significantly improve the stability of the upper cervical spine. The C1-C2 transarticular screws can damage the motion segments and pars screws must stop short of the vertebral foramen, limiting the typical length of these screws to only 14–18 mm, while laminar screws are not fixed by three columns and have poor mechanical properties. Transpedicular screws are favored by spinal surgeons.[8] However, the complex anatomical structure of this area poses a great challenge to the clinical experience and technology of the surgeon, resulting in high risk for this surgical method.[9,10] The C2 parsicle screw technique can improve the safety of screw placement, but it requires a larger medial inclination and a larger cephalad angle and is difficult to operate intraoperatively.[11] Computer navigation can significantly improve the accuracy of screw placement to 93.6%,[12] but the equipment is expensive and clinicians require much time and effort to learn the process. Drift may also occur during the operation, affecting the accuracy of nail placement. Studies have introduced 3D printing navigation template auxiliary screw placement. The core of this technology is to find the C2 anatomy pedicle corridor and use the navigation template to assist the screw placement, which can significantly improve the accuracy of screw placement to 95.31% and 98%.[13,14] However, a series of problems also appear during operation, such as navigation template shaking and soft tissue which affects placement of the navigation template, thus reducing the accuracy of crew placement.

A novel C2 screw fixation technique perpendicular to the coronal plane (C2-PPS) was developed, which reflects the nature of the screw incorporating aspects of transarticular screw fixation and pedicle screw fixation. There is no medial inclination similar to that of the transarticular screw, but the cephalad angle of the screw is smaller than that of the transarticular screw and the entry point is in a position inferior and medial to that of the traditional C2 pedicle screw (C2-TPS) entry point. This technique preserves the C1-2 motion segments, and the screw medial inclination is easy to

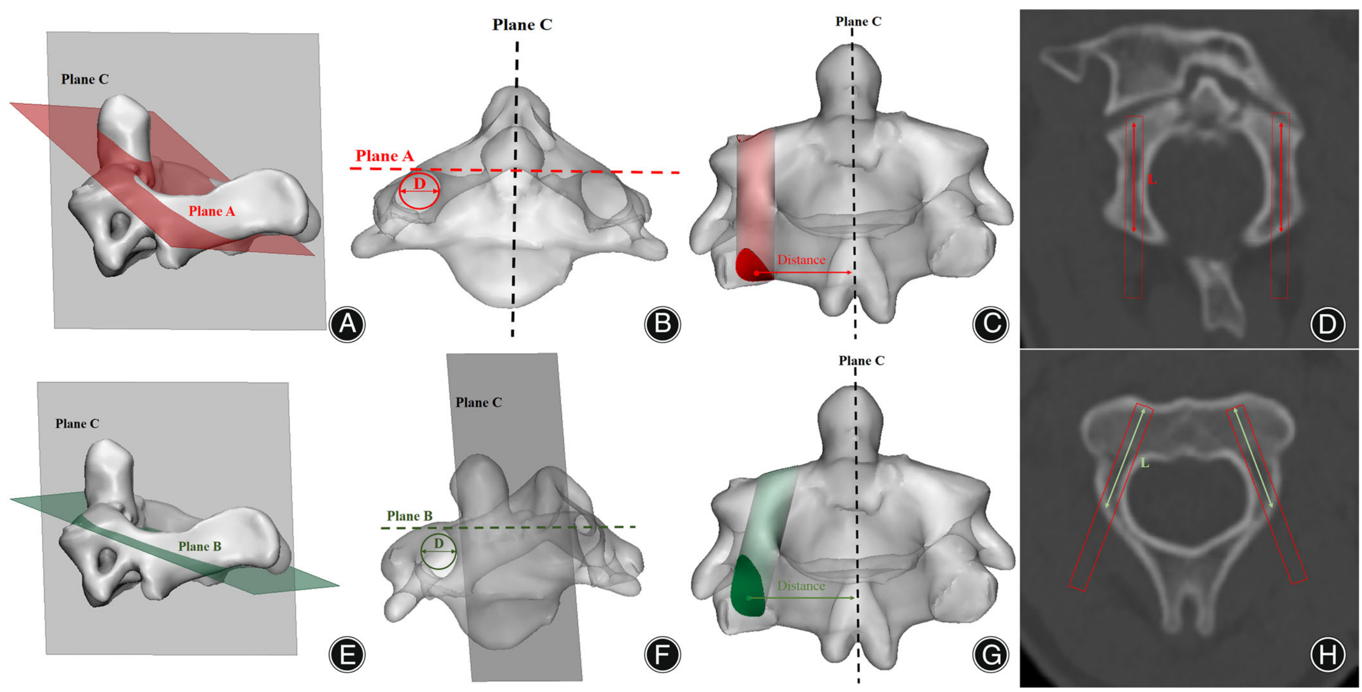

Fig. 1 Acquisition of the trajectory of C2-PPS and C2-TPS. (A) Plane A was defined as a plane parallel to the upper edge of the C2 pedicle; (B) Plane C was defined as the median sagittal plane based on the 3D model of C2, the red circle show the maximum tangent circle of C2-PPS and "D" represent the diameter of the circle; (C) The corridor of C2-PPS is shown by red columns, and the center of the red columns represent the screw entry point of C2-PPS, and the "distance" show the linear distance from entry point to the plane C; (D) "L" show the length of PPS based on the axial CT image of C2; (E) Plane B was formed by bilateral midpoint of superior and inferior articular processes, and root of dens C2; (F) Plane C was defined as the median sagittal plane based on the 3D model of C2. The green circle show the maximum tangent circle of C2-TPS and "D" represent the diameter of the circle; (G) The corridor of C2-TPS is shown by green columns, and the center of the green columns represent the screw entry point of TPS, and the "distance" show the linear distance from entry point to the plane C; (H) "L" show the length of TPS based on the axial CT image of C2

determine, since it is not affected by lateral soft tissue tension. It is relatively easy to operate and can ensure the length and purchase of the screw. In this study, the anatomical parameters of the C2-PPS and C2-TPS corridors were analyzed through 3D modeling, and the accuracy of pedicle screw placement assisted by a 3D-printed navigation template was improved by changing the medial inclination of the pedicle screw.

This study aimed to: (i) evaluate the feasibility of a novel C2 screw insertion technique perpendicular to the coronal plane; and (ii) assess the safety of PPS and TPS placement assisted by the 3D printing navigation template.

Materials and Methods

Acquisition of the Trajectory of C2-PPS and C2-TPS

This study was approved by Zigong No. 4 People's Hospital Review Board (IRB Number, 2016-003). The patient's CT data with the Dicom format (thickness was 0.625 mm) were imported into Mimics 22.0 (Materialise, Leuven, Belgium). The mask of C2 was separated based on the CT threshold of bone and included all cortical and cancellous bone. Then, the 3D model of C2 was built based on the C2 mask. A plane parallel to the upper edge of the C2 pedicle was defined as plane A. The median sagittal plane was defined as plane C (Fig. 1A). C2 was rotated until plane A and plane C from two vertical lines to obtain the C2-PPS corridor. The center of the tangent circle was defined as the entry point of the C2-PPS, and the diameter of the tangent circle (D) was measured (Fig. 1B). Plane B was defined according to the method reported by Ebraheim *et al.*[11] (Fig. 1E). C2 was rotated along plane B to obtain the C2-TPS corridor, the center of the tangent circle was defined as the entry point of the C2-TPS, and the diameter of the tangent circle (D) was measured (Fig. 1F). The linear distance (Distance) from the PPS entry point to plane C was measured (Fig. 1C); The linear distance from the TPS entry point to plane C was measured (Fig. 1G). The length of PPS (L) was measured on the axis of C2 (Fig. 1D); The length of TPS (L) was also measured on the axis of C2 (Fig. 1H).

Patient Demographics

A total of 44 patients were involved in this study from May 2018 to November 2020. Preoperative anterior and lateral radiographs and computed tomography angiography (CTA) were obtained for all patients. The inclusion criteria were as follows: (i) atlantoaxial fracture or instability was diagnosed after trauma; (ii) atlantoaxial posterior fixation was performed; (iii) all screws were implanted assisted by a 3D-printed navigation template; and (iv) aged 20 to 75 years, and followed for more than 1 year. The exclusion criteria were: (i) pathological fractures; (ii) severe systemic diseases; and (iii) severe osteoporosis.

The maximum tangent circle of the C2 pedicle screw was measured by the above method, and the maximum tangent circle in 44 patients (a total of 88 C2 pedicles) was greater than 4 mm. A total of 44 patients were enrolled (Table 1), and the patients were divided into two groups: 24 patients were treated with the perpendicular C2 pedicle screw technique (group-PPS), and 20 patients were treated with the traditional C2 pedicle screw technique (group-TPS).

Design of the Navigation Template

A virtual screw with a diameter of 3.5 mm was inserted along the C2-PPS in the PPS group. Then, the virtual screw and the 3D model of C2 were imported into 3-matic 13.0 (Materialise, Leuven, Belgium). The surface of the bone was extracted by diffusing around the screw entry point, including the root of the spinous process. The extracted surface was stretched 3 mm toward the spinous process to form the base of the navigation template. A hollow navigation tube 10 mm in length along the direction of the virtual screw was designed to guide the K-wire insertion. A handle in an upward direction was designed for the surgeon to fix the navigation template during the operation. The base, navigation tube and handle were unionized to format the navigation template (Fig. 2A,C). The design of the navigation template in the TPS group was similar, but the direction of the navigation tubes was different (Fig. 2B,D).

The navigation templates were exported in STL format and then imported into a 3D printer (3DS, project 3600; material, Photosensitive resin). Then, the 3D printed navigation templates were shaped for surgery.

Preoperative Preparation

The C2 model was printed in preparation, the navigation template was attached to the 3D model of the C2, and the K-

TABLE 1 Evaluation of surgical indications between two groups

Variables	C2-PPS group	C2-TPS group	Statistics	*P*
Number of patients	24	20		
Age (mean ± SD)	37.9 ± 9.5	38.2 ± 6.1	−0.029	0.978
Gender (N)				
Male	14	12	0.013	0.911
Female	10	8		
BMI (kg/cm^2)	22.9 ± 2.7	23.6 ± 3.2	−0.976	0.327
Trauma causes (N)				
Motor vehicle accident	12	10	0.041	0.98
High-energy fall	10	8		
Other injury	2	2		
Type of Axis instability				
Axis fracture	17	15	0.096	0.953
Other fracture	7	5		
Fracture and dislocation	13	11		

wires 2.0 mm in diameter were inserted into the 3D model of the C2 along the navigation tube of the navigation template. The position of the k-wires in the 3D model was observed, and the safety of screw placement was assessed.

Surgical Technique

Setup

Under general anesthesia, the patient was placed on the radiolucent operation table in the prone position and their head was fixed in a Mayfield head holder.

Exposure

Via a posterior median approach, surgical exposure was accomplished to the lateral border of the C1-C2 articulation (Fig. 3A). During the procedure, great care was taken to avoid disrupting the large epidural venous plexus along the C1-C2 joint. The template base was completely attached to the lamina and spinous processes of C2 (Fig. 3B).

Preparation of the Screw Path

The navigation template was securely placed intraoperatively by holding the handle, and two K-wires with a diameter of

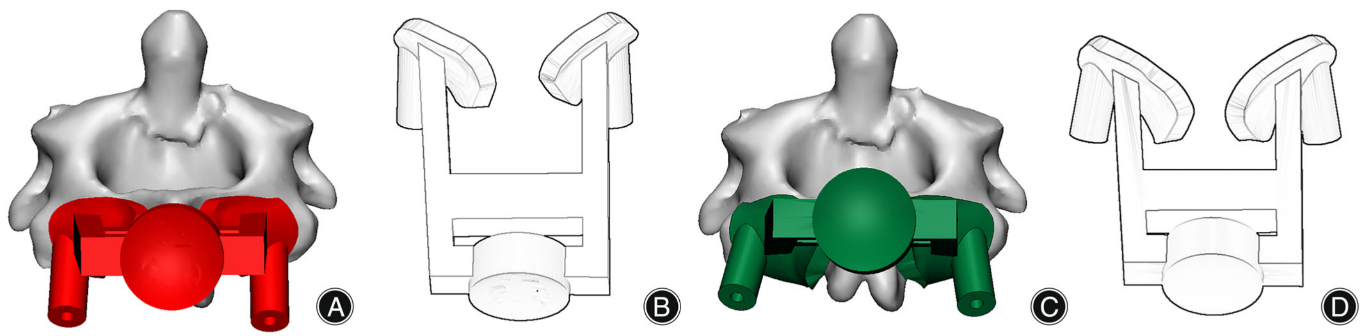

Fig. 2 Design of the navigation template. (A) The navigation template for PPS is closely attached to C2; (B) Sketch of the navigation template for C2-PPS; (C) The navigation template for TPS is closely attached to C2; (D) Sketch of the navigation template for TPS

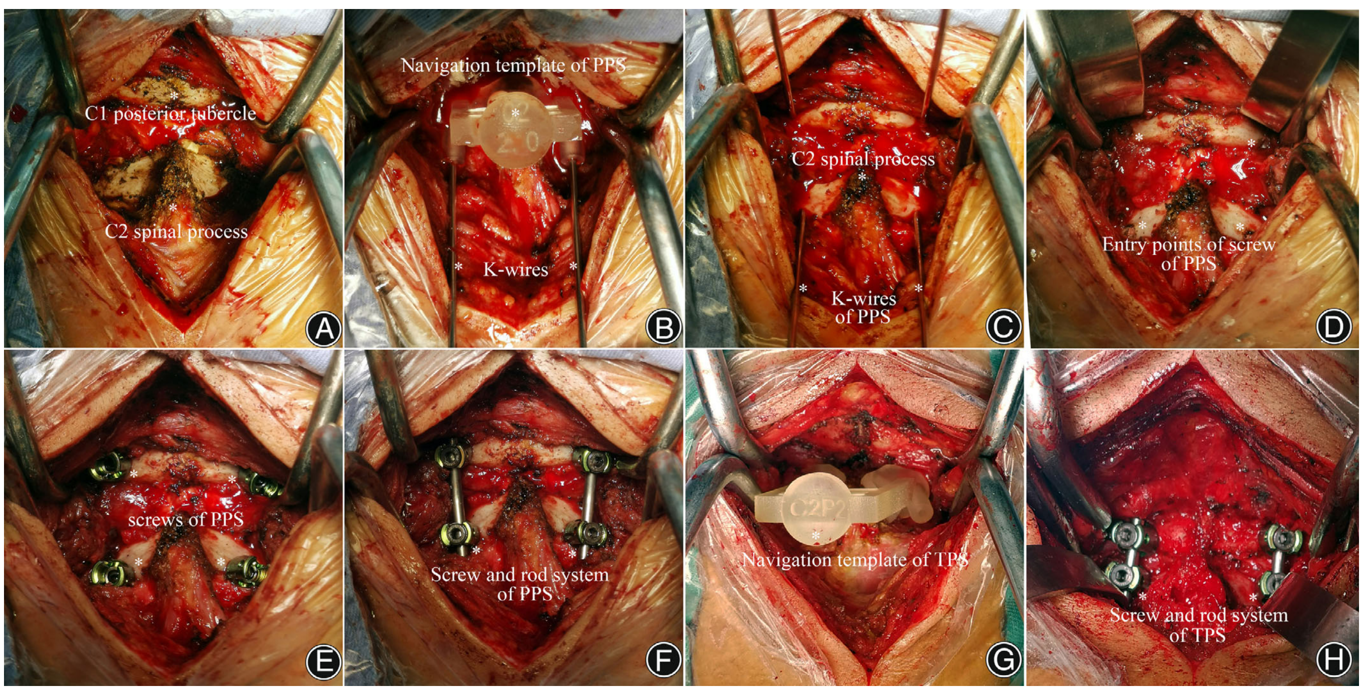

Fig. 3 The surgical procedure. (A) Lateral border of the C1-C2 articulation was exposure; (B) The navigation template for C2-PPS is closely attached to C2; (C) Two K-wires with diameter of 2.0 mm were inserted; (D) Remove K-wires and confirm the entry point pf C2-PPS; (E), Screw with diameter of 3.5 mm were placed along the trajectory of C2-PPS; (F), The screw and rod system is fixed of C2-TPS group; (G) The navigation template for C2-TPS is closely attached to C2; (H) The screw and rod system is fixed of C2-TPS group

2.0 mm were inserted into the pedicle through the navigation tube perpendicular to the coronal plane or without medial inclination (Fig. 3C,D). Posterior and lateral fluoroscopy of the cervical spine was performed to confirm the location of the screw path (Fig. 4A,B). In the C2-TPS group, the procedure was similar, but a navigation template with medial inclination was used to assist k-wire implantation (Fig. 3G).

Screw Placement and Fixation

The 3.5 mm diameter screws were implanted into the pedicle along the above trajectory (Fig. 3E). The C1-C2 screws were connected and fixed through two connecting rods (Fig. 3F, H), and the wounds were stratified and sutured.

Evaluation Criteria

Diameter of the maximum tangential circle: The diameter of the maximum tangential circle for the C2-PPS corridor or C2-TPS corridor reflects the screw capacity and feasibility of screw placement.

Distance between the geometric center and the median sagittal plane

The linear distance from the entry point to the sagittal plane, which helps clinicians to find the entry point quickly by using the sagittal plane as a reference during the operation.

Screw length

The screw length was defined as the distance of the C2-PPS corridor or C2-TPS corridor center in bone, and the

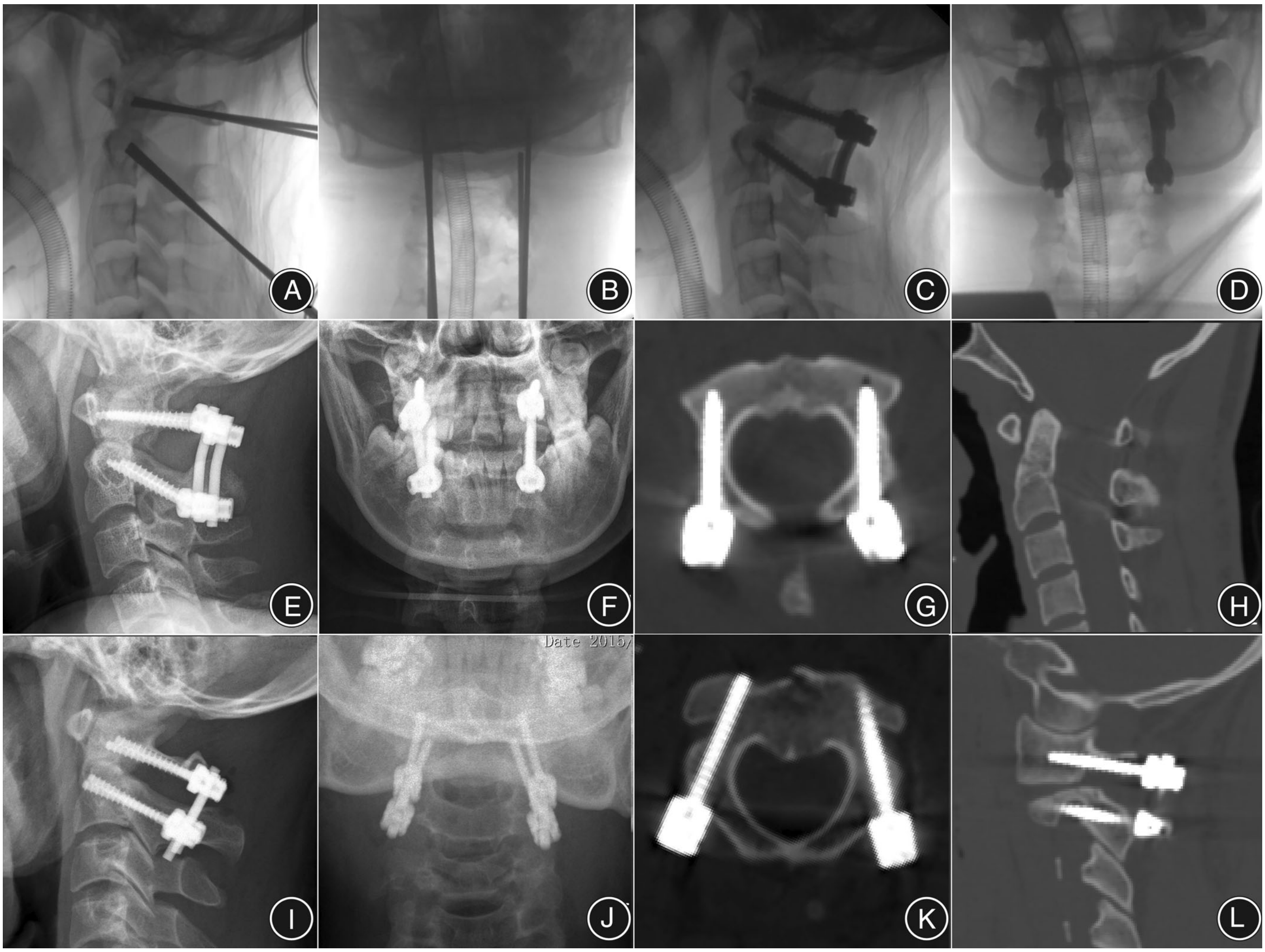

Fig. 4 (A–H) Intraoperative and postoperative images of a 45-year-old female patient with an axis fracture in C2-PPS group; (A, B), Intraoperative fluoroscopy of Kirschner wires were inserted; (C, D) Intraoperative fluoroscopy of screws were inserted; (E, F), Postoperative anteroposterior and lateral X-ray; (G), Axial view of postoperative CT (Grade 0); (H), Sagittal CT 3 months postoperatively. (I–L), Intraoperative and postoperative images of a 41-year-old male patient with an axis fracture in C2-TPS group; (I, J), Postoperative anteroposterior and lateral X-ray; (K, L) Axial view of postoperative CT show a screw penetrated bone cortex greater than 2 mm, without any symptoms (Grade 0)

screw length can reflect the stability and mechanical strength of the fixation.

Grading

Grade 0, safe placement, screws located in cancellous bone; Grade 1, cortical bone perforation less than 2 mm; Grade 2, cortical bone perforation greater than 2 mm. The grading score was used to evaluate the safety of the screws. Grades 0 and 1 placement were considered to be successful and safe, and grade 2 indicated the possibility of nerve damage.

Deviation of the screw entry point

The deviation between the actual screw entry point and the virtual screw entry point reflects the accuracy of screw placement.

Deviation of the screw angle

Deviation between the actual screw angle and the virtual screw angle, which reflects the accuracy of screw placement.

Statistical Analysis

All statistical analyses were performed with SPSS 19.0 (SPSS Inc., Chicago, IL, USA). Power analysis was performed, and the power was set at 0.8. Chi-square tests were performed for sex, trauma causes, type of atlantoaxial instability and grading criteria between the two groups. Mann–Whitney–Wilcoxon tests were performed for radiation exposure times between the two groups. For age, BMI, diameter of the maximum tangential circle, distance between the entry point and sagittal plane, screw length, surgical time, deviation of the screw entry point and deviation of the screw angle, T tests were performed between the two groups. The reliability analysis was performed between two orthopedic surgeons for the diameter of the maximum tangential circle, distance between the entry point and sagittal plane, screw length, deviation of the screw entry point and deviation of the screw angle. The confidence interval was set as 95%, and a P value less than 0.05 was considered to be statistically significant.

TABLE 2 Clinical and radiographic evaluation of postoperative screws insertion between template group and conventional group

Variable	C2-PPS group	C2-TPS group	Statistics	*P*
Surgical time (min)	93.7 ± 21.8	103.7 ± 37.9	−0.651	0.519
Radiation exposure times	4.7 ± 1.5	7.8 ± 3.8	−2.065	0.045
Grading criteria				
Grade 0	46	31	7.031	0.03
Grade 1	2	7		
Grade 2	0	2		
Deviation of screw entry point (mm)	1.2 ± 0.8	3.2 ± 1.3	−5.545	0.000
Deviation of screw angle (°)	2.1 ± 1.6	4.8 ± 2.0	−4.975	0.000

Results

Clinical Indications

The operation was successfully completed in all patients, without aggravation of nerve injury, and the follow-up was 12–20 months, with an average of 15.6 months. No screw loosening or fracture occurred in the two groups. A total of 48 screws were inserted in the C2-PPS group, and 40 screws were inserted in the C2-TPS group. The surgical times in the C2-PPS group and C2-TPS group were 93.7 ± 21.8 min and 103.7 ± 37.9 min, respectively. The radiation exposure times in the C2-PPS group and C2-TPS group were 4.7 ± 1.5 and 7.8 ± 3.8, respectively, and there were significant differences between the two groups (Table 2, 3).

Radiological Parameters

The diameters of the maximum tangential circle in the C2-PPS group and C2-TPS group were 5.5 ± 1.0 mm (ICC:0.78) and 5.3 ± 0.9 mm (ICC:0.80), respectively. The distances between the geometric center and median sagittal plane in the C2-PPS group and C2-TPS group were 15.4 ± 2.3 mm (ICC:0.81) and 18.0 ± 3.3 mm (ICC:0.79), respectively, and there was a significant difference between the two groups. The screw lengths in the C2-PPS group and C2-TPS group were 25.9 ± 3.2 mm (ICC:0.85) and 27.6 ± 3.7 mm (ICC:0.88), respectively, and there was a significant difference between the two groups (Table 3). The deviations of screw entry point in the C2-PPS group and C2-TPS group were 1.2 ± 0.8 mm (ICC:0.84) and 3.2 ± 1.3 mm (ICC:0.85), respectively. The deviations of screw angle in the C2-PPS group and C2-TPS group were 2.1 ± 1.6°(ICC:0.81) and 4.8 ± 2.0°(ICC:0.79), respectively, and there was a significant difference between the two groups. There were 46 screws with grade 0 (95.8%) in the PPS group and 31 screws with grade 0 (77.5%) in the TPS group, and there was a significant difference between the two

TABLE 3 Anatomic measurement of the pedicle corridor of axis between two groups

Anatomic measure	C2-PPS group (n = 48)	C2-TPS group (n = 40)	statistic	*P*
Diameter of the maximum tangential circle (mm)	5.52 ± 1.01	5.28 ± 0.94	0.725	0.47
Distance between geometric center and median sagittal plane (mm)	15.41 ± 2.34	18.04 ± 3.27	−4.243	0.000
Screw length (mm)	25.94 ± 3.22	27.55 ± 3.65	−4.295	0.000

groups ($P = 0.03$) (Table 2). In the C2-PPS group, the screw was grade 0 (Fig. 4A–H); in the C2-TPS group, one screw was grade 2 (Fig. 4I–L).

Discussion

In our study, the maximum diameter of the C2-PPS corridor with no significant difference from that of the C2-TPS (5.52 *vs* 5.28 ± 0.94, $P = 0.47$), and with an average screw length of 26 mm, which means majority patients could safely accommodate a 3.5 mm diameter C2-PPS screw. A total of 48 screws were inserted in the C2-PPS group, and 40 screws were inserted in the C2-TPS group. There were 46 screws with grade 0 (95.8%) in the PPS group and 31 screws with grade 0 (77.5%) in the TPS group, which indicate that the navigation templates assisted C2-PPS placement is more safe than C2-TPS. The screw entry point deviation and screw angle deviation of C2-PPS placement were significantly less than that of C2-TPS(1.2 ± 0.8 *vs* 3.2 ± 1.3, $P < 0.05$; 2.1 ± 1.6 *vs* 4.8 ± 2.0, $P < 0.05$), which indicate that the navigation templates assisted C2-PPS placement is more accurate than C2-TPS. The Radiation exposure times of C2-PPS is significantly less than that of C2-TPS (4.7 ± 1.5 *vs* 7.8 ± 3.8, $P = 0.045$).

Feasibility of C2-PPS

C2 pedicle screws have been widely used in the treatment of atlantoaxial instability due to their favorable mechanical properties. Therefore, many researchers have analyzed the anatomical and imaging morphologies of C2 pedicles.[11,15–17] However, there is no clear definition of the pedicle screw entry point location, and there is also no range of recommendations for the medial angle and cephalad angle; proposed that the screw entry point of the pedicle screw was located according to the upper margin of the lamina and the inner wall of the pedicle, but no medial inclination or cephalad angle was provided for reference.[18] Cortical breakthrough rates were as high as 33% in C2 pedicle screw placement by freehand technology,[19] and the success of pedicle screw placement largely depends on the clinical experience of the surgeon. In this research, a novel C2 pedicle corridor perpendicular to the coronal plane was developed, and we quickly obtained the C2-PPS or C2-TPS corridor through a digital 3D model of C2. A total of 44 patients were enrolled in this study for measurement of the maximum tangent circle diameter of the C2 pedicle corridor, and the maximum tangent circle diameter of the C2 pedicle corridor in 36 patients (36/44, 81.8%) was larger than 4 mm. The average maximum tangential circles in the C2-PPS and C2-TPS groups were approximately 5.5 mm and 5.3 mm, respectively. Similar to the research, the majority of patients can accommodate a screw with a diameter of 3.5 mm.[2,16,20] The distance between the geometric center and the median sagittal plane and the screw length were measured at the same time. The average distance between the entry point of the C2-PPS group and the medial sagittal plane was approximately 15 mm, and was approximately 18 mm in the C2-TPS group, indicating that the entry point of the PPS was more medial than that of the TPS. The average screw length of the PPS group was approximately 26 mm, which met the clinical mechanical requirements and fixed strength.[21,22]

Safety of PPS Placement Assisted by the Navigation Template

With the development of posterior internal fixation of the upper cervical spine, screw-rod structures have been widely used for C1-C2 joint stabilization. In cadaver studies, C2 pedicle screws have shown superior biomechanical stability compared to pars screws and translaminar screws and are therefore considered as the preferred candidate for C2 internal fixation.[23] Techniques for posterior C2 pedicle internal fixation include C2 pedicle screw fixation proposed by Borne *et al.* in 1984,[24] C1-C2 transarticular screws proposed by Magerl and Seemann in 1987,[25] and C2 parsicle screws proposed by Kepler *et al.* in 2020.[7] The entry point of the C2 parsicle screw was more lateral than the pedicle screws, closer to the transverse foramen and had a larger cephalad angle compared to the C1-C2 transarticular screw. Nevertheless, the entry point and cephalad of traditional C2 pedicle screws were between them, and it is difficult to achieve personalization of screw placement because of the anatomic variation and the resistance of muscle tissue.[26,27] In our study, we developed a novel C2 screw fixation technique perpendicular to the coronal plane (C2-PPS). The entry point of the PPS was more medial than that of the traditional pedicle screw, and the C2-PPS had a smaller cephalad angle than the C1-C2 transarticular screw and no medial inclination. To verify its effectiveness, we used 3D print technology to manufacture an individualized navigation template to assist implantation of C2-PPS or C2-TPS, and the results showed that grading criteria, screw entry point deviation and screw angle deviation were all better than those in the C2-TPS group (screw entry point deviation of 1.2 ± 0.8 mm in the PPS group *vs* screw entry point deviation of 3.2 ± 1.3 mm in the TPS group; screw angle point deviation of 2.1 ± 1.6° in the PPS group *vs* screw angle point deviation of 4.8 ± 2.0° in the TPS group). The results indicate that PPS placement has better accuracy with the assistance of a 3D-printed navigation template. The reasons are as follows: First, the internal inclination of C2-PPS is easy to control during operation. If the patient is placed in a standard position, the inclination angle can be determined by whether the screw is perpendicular to the operating table. Second, compared with the TPS, the PPS entry point is more medial, so there is less exposed soft tissue. The guide tube without a medial angle for the PPS is easier to place during the operation than that for the TPS. Finally, the navigation template for the TPS is more difficult to closely attach to C2 than that for the PPS.

Surgery Tips

First, patients with a pedicle corridor diameter greater than 4 mm are suitable for C2-PPS. Otherwise, lamina screws or pars screws are recommended. Second, the base thickness of the navigation template is recommended to be set at 3 mm, and the base of the navigation template can be bilaterally wrapped into the screw entry points to reduce the incision and stripping and medially wrapped around the spinous process root to increase the stability of attachment. The length of the navigation tube is recommended to be set at 10 mm, with an inner diameter of 2.1 mm that can accommodate K-wires with a diameter of 2 mm. Finally, outer soft tissue dissection should be based on the attachment surface of the navigation plate base, and K-wires can be used to deepen the drilling hole step by step. Details about specific operations can be found in Wu *et al.*[28] C2-PPS has a larger cephalad angle than C2-TPS and requires more caudal exposure intraoperatively.

Strengths and Limitations

Strengths

First, the parameters of PPS corridor were obtained in the 3D model, which provided data support for surgery; Second, the preoperative design was implemented and verified by 3D-printed navigation template assisted PPS and TPS screw placement, and the study results were more credible.

Limitation

First, this technology is not suitable for patients with pedicle diameters less than 4 mm. Second, patients with C2 deformities and vertebral artery malformation were not included in this study. Finally, the sample size might be insufficient, and we will enroll more patients to this research in the future.

Conclusion

C2 pedicle screw corridor perpendicular to the coronal plane could be quickly obtained by a perspective model with a three-dimensional structure. In our study, approximately 80% of the C2-PPS corridor had a maximum diameter larger than 4 mm, which could safely accommodate a 3.5 mm diameter screw, with an average screw length of 26 mm. Navigation templates assisted the screw placement perpendicular to the coronal plane is less surgical time, less radiation exposure times, more safe and more accurate than screw placement with medial inclination.

Ethics Approval

This study was approved by the ethics committee of Zigong Fourth People's Hospital (No. 02, 2013). All patients signed the informed consents to participate in the study.

Acknowledgments

Thanks to the Zigong fourth people's hospital for providing the experimental equipment and site. This study was funded by Zigong Key Science and Technology Program (2022YGY0104); Sichuan University-Zigong City Science and Technology Cooperation Project (2021CDZG-22); Sichuan Medical Association Research Project (S20010); Sichuan Key Science and Technology Program (2021YJ0049).

Author Contribution

Chao Wu was responsible for experiment design and paper review; Jiayan Deng for data analysis and paper writing; Danwei Shen, Binwei Qin for data preprocessing; Tao Li, Qing Wang and Xiangyu Wang for clinical trials.

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