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Original Article

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Comparison of Transoral Anterior Jefferson-Fracture Reduction Plate and Posterior Screw-Rod Fixation in C1-Ring Osteosynthesis for Unstable Atlas Fractures

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Objective: To compare the clinical outcomes of transoral anterior Jefferson-fracture reduction plate (JeRP) and posterior screw rod (PSR) surgery for unstable atlas fractures via C1-ring osteosynthesis.

Methods: From June 2009 to June 2022, 49 consecutive patients with unstable atlas fractures were treated by transoral anterior JeRP fixation (JeRP group) or PSR fixation (PSR group) and followed up at General Hospital of Southern Theatre Command of PLA; 30 males and 19 females were included. The visual analogue scale (VAS) score, Neck Disability Index (NDI), distance to anterior arch fracture (DAAF), distance to posterior arch fracture (DPAF), lateral mass displacement (LMD), Redlund-Johnell value, postoperative complications, and fracture healing rate were retrospectively collected and statistically analyzed.

Results: Compared with that in the PSR group, the bleeding volume in the JeRP group was lower, and the length of hospital stay was longer. The VAS scores and NDIs of both groups were significantly improved after surgery. The postoperative DAAF and DPAF were significantly smaller after surgery in both groups. Compared with the significantly shorter DPAF in the PSR group, the JeRP group had a smaller DAAF, shorter LMDs and larger Redlund-Johnell value postoperatively and at the final follow-up. The fracture healing rate at 3 months after surgery was significantly greater in the JeRP group ($p < 0.05$).

Conclusion: Both C1-ring osteosynthesis procedures for treating unstable atlas fractures yield satisfactory clinical outcomes. Transoral anterior JeRP fixation is more effective than PSR fixation for holistic fracture reduction and short-term fracture healing, but the hospital stay is longer.

Keywords: Atlas fracture, Unstable fractures, Transoral anterior approach, Posterior approach, C1-ring osteosynthesis

INTRODUCTION

Atlas fractures account for approximately 2%–13% of cervical fractures and approximately 1%–2% of total spinal fractures.[1] Currently, conservative treatment is favored for stable atlas fractures.[2,3] However, how to handle unstable atlas fractures, which include all fractures except anterior arch single fractures without transverse ligament rupture or posterior arch fractures, is debatable.[4] Conventional atlantoaxial or upper cervical fusion can result in loss of cervical motor function and lower quality of life,[5] while nonsurgical treatment methods are associated with a high nonunion rate of atlas fracture.[6] In 2004, Ruf et al.[7]

first proposed C1-ring osteosynthesis via a transoral approach to treating unstable Jefferson fractures. Subsequently, C1-ring osteosynthesis has gradually become one of the ideal procedures for treating unstable atlas fractures because it can instantly reduce and fix fractures while preserving the motor function of the upper cervical spine.[5,8-10]

Currently, C1-ring osteosynthesis is most commonly performed via transoral anterior plate fixation[9,11] and posterior screw-rod fixation.[12,13] Previous studies have aimed to investigate the effectiveness of each C1-ring osteosynthesis procedure. However, to the best of our knowledge, no comparative studies of these 2 procedures have been reported. In this study, we retrospectively analyzed the clinical data of 49 patients with unstable atlas fractures treated with C1-ring osteosynthesis via the use of the transoral anterior Jefferson-fracture reduction plate (JeRP)[14,15] or the conventional posterior screw rod (PSR). We compared the clinical efficacy of these 2 procedures, which is important for the selection of clinical procedures.

MATERIALS AND METHODS

1. Patient Selection

From June 2009 to June 2022, a total of 49 consecutive patients who met the inclusion and exclusion criteria and were treated by C1-ring osteosynthesis at General Hospital of Southern Theatre Command of PLA were recruited and followed up (Table 1). The detailed screening criteria were (1) diagnosis of traumatic atlas fracture by clinical and imaging examination, (2) Landells type II or III fracture, (3) Dickman type I or II injury, (4) no previous cervical disease or cervical trauma or operation, and (5) signed informed consent forms. The exclusion criteria were (1) other cervical vertebral fractures or mixed fractures, (2) chronic or nonunion atlas fractures, (3) neurological dysfunction of spinal cord injury, (4) inability to tolerate surgery, and (5) incomplete follow-up data.

The indications for anterior JeRP surgery were (1) diagnosis of unstable atlas fracture, (2) obvious symptoms that cannot be treated conservatively, (3) no contraindications to anterior surgery, such as oral inflammation or previous history of oral surgery affecting the anterior approach, and (4) after the preoperative conversation, patients independently selected the approach and signed the informed consent form. Indications for the PSR surgery included (1) diagnosis of unstable atlas fracture, (2) obvious symptoms that cannot be treated conservatively, (3) no contraindications to posterior surgery such as infection or inflammation of the posterior cervical tissue space, (4) unsuitable for anterior surgery such as patients with oral infections, oral deformities, low immunity, small intraoral volume, high atlantoaxial position, long fracture line extending lateral mass, or when the posterior pharyngeal wall tissue is too thin to cover the plate, etc., and (5) after the preoperative conversation, patients independently selected the approach and signed the informed consent form. All surgeries were performed by one skilled senior spine surgeon and his team.

Table 1. Comparison of 2 groups of baseline information

Variable	JeRP group (n = 31)	PSR group (n = 18)	p-value
Age (yr)	43.9 ± 14.0	42.4 ± 12.4	0.722
Sex			0.812
Male	19 (61.3)	11 (61.1)	
Female	12 (38.7)	7 (38.9)	
BMI (kg/m^2)	21.5 ± 1.9	21.2 ± 1.6	0.577
Symptoms			
Occipital neck pain	31 (100)	18 (100)	> 0.999
AIS grade	2.1 ± 0.3	2.3 ± 0.5	0.091
Comorbidities			
Osteoporosis	5 (16.1)	3 (16.7)	0.961
Diabetes	6 (19.4)	3 (16.7)	0.815
Cardiovascular disease	9 (29.0)	5 (27.7)	0.925
Combined other trauma	7 (22.5)	3 (16.7)	0.726
Injury time (day)	4.9 ± 3.3	4.7 ± 3.5	0.882
Type of injury			
Falling	10 (32.3)	7 (38.9)	0.638
MVA	15 (48.4)	9 (50.0)	0.913
Crushing	6 (19.3)	2 (11.1)	0.693

Values are presented as mean ± standard error or number (%).
JeRP, Jefferson-fracture reduction plate; PSR, posterior screw-rod; BMI, body mass index; AIS, American Spinal Injury Association Impairment Scale; MVA, motor vehicle accident.

Thirty-one patients were treated with transoral anterior JeRP fixation (JeRP group), including 19 males and 12 females, with a mean age of 43.9 ± 14.0 years. The mean follow-up time was 20.1 ± 10.6 months (range, 12–51 months); the other 18 patients were treated with PSR fixation (PSR group), which included 11 males and 7 females, with a mean age of 42.4 ± 12.4 years. The mean follow-up time was 19.4 ± 8.0 months (range, 12–36 months). All patients had a history of trauma, with a mean injury time of 4.9 ± 3.3 days in the JeRP group and 4.7 ± 3.5 days in the PSR group. The types of trauma included falling, motor vehicle accidents and crashing. All patients had symptoms of neck and occipital pain but no neurological symptoms. The

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American Spinal Injury Association Impairment Scale grade was used to assess the severity of cervical spine injury. Common preoperative comorbidities in patients included osteoporosis, diabetes, cardiovascular disease, and combined other trauma. All patients had anterior and posterior atlas arch fractures as shown by cervical spine x-ray, computed tomography, and magnetic resonance imaging examinations without significant spinal cord compression (Table 1). This study was approved by the Ethical Review Committee of General Hospital of Southern Theatre Command of PLA (2023011).

2. Surgical Procedure

1) Transoral anterior JeRP fixation[14,15]

Preoperative preparation: All patients were instructed to gargle 3 to 6 times daily with 0.02% chlorhexidine acetate before surgery. A professional dental cleaning procedure was also performed. A nasogastric feeding tube was placed 1 hour before surgery, and prophylactic broad-spectrum antibiotics were applied conventionally 30 minutes before surgery.

Surgical procedures: While under general anesthesia with nasotracheal intubation, the patient was placed in the supine position, and the neck was situated slightly hyperextended with skull traction. After routine oral cleaning and disinfection, the oral cavity was opened by a Codman retractor. A longitudinal incision of 3–4 cm was then made in the median posterior pharyngeal wall to incise the mucosa and split the longitudinal muscles. After the subperiosteal layer of the muscle and the prevertebral fascia were separated to reveal the anterior C1 arch and the lateral mass, the fracture was exposed. An appropriately sized plate was selected and placed transversely in front of the atlas. The wider side of the JeRP was placed on the lateral mass near the fracture line and fixed by 2 screws. Then, one temporary reduction screw was inserted through the slide hole of the plate onto the anterior arch of the other fracture side. After the compressing reduction forceps was installed, one arm hooked the reduction hole of the JeRP, and the other arm clasped the reduction screw and then closed the handle of the forceps to achieve fracture end closure. After the fracture was satisfactorily reduced under direct vision, the remaining anterior arch screws and lateral mass screws on the other side were fixed. Following the placement of the plate and screws, which was verified by C-arm fluoroscopy, the incision was closed in the muscular and mucosal layers (Fig. 1).

Postoperative management: After surgery, the tracheal airway cannula was removed after 24–48 hours, and the nasal feeding tube was left for 1 week. The 0.02% chlorhexidine acetate solution was used for mouth rinsing 3–6 times a day, and intravenous antibiotics were applied for 3 days. Cervical x-ray and CT scans were obtained 7 days postoperatively, and a cervical brace was fixed and protected for 3 months, with regular follow-up (Fig. 2).

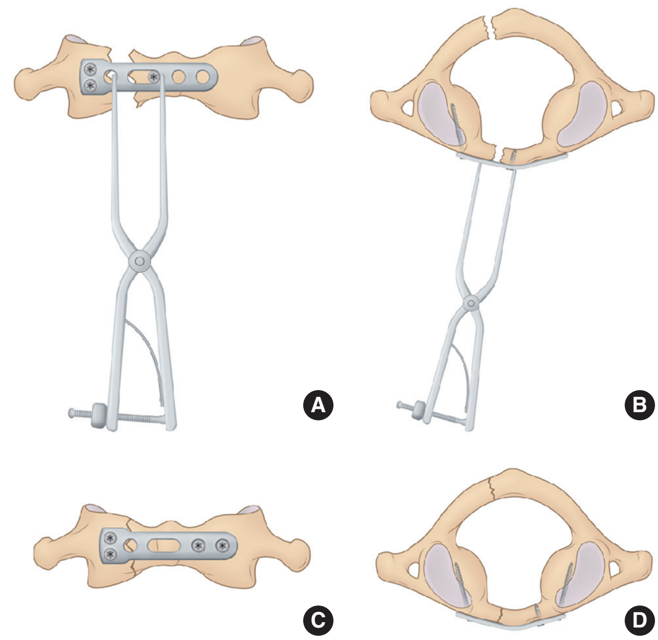

Fig. 1. Schematic of the Jefferson-fracture reduction plate (JeRP) procedure. (A, B) Coronal and axial pictures present the reducing process: after the compressing reduction forceps was installed, one arm hooked the reduction hole of the JeRP and the other arm clasped the reduction screw and then closed the handle of the forceps to achieve fracture end closure. (C, D) Coronal and axial pictures present the fixation: after the fracture was satisfactorily reduced, the remaining anterior arch screws and lateral mass screws on the other side were fixed.

2) PSR fixation

Preoperative preparation: Intravenous antibiotics were applied 30 min before surgery.

Surgical procedures: Under general anesthesia with nasotracheal intubation, the patient was placed in the prone position with the head mildly flexed forward, and skull traction was maintained. A median posterior incision from the occipital ridge to the C2 spinous process, approximately 6 cm in length, was made after routine disinfection. The lower occiput, C1 posterior arch, and bilateral C1–2 lateral mass joints were exposed via subperiosteal dissection. A C1 pedicle screw or a lateral mass screw was inserted, with priority of the C1 pedicle screw. A suitable length of connecting rod was selected and placed horizontally into both screw slots. Then, nuts were put into

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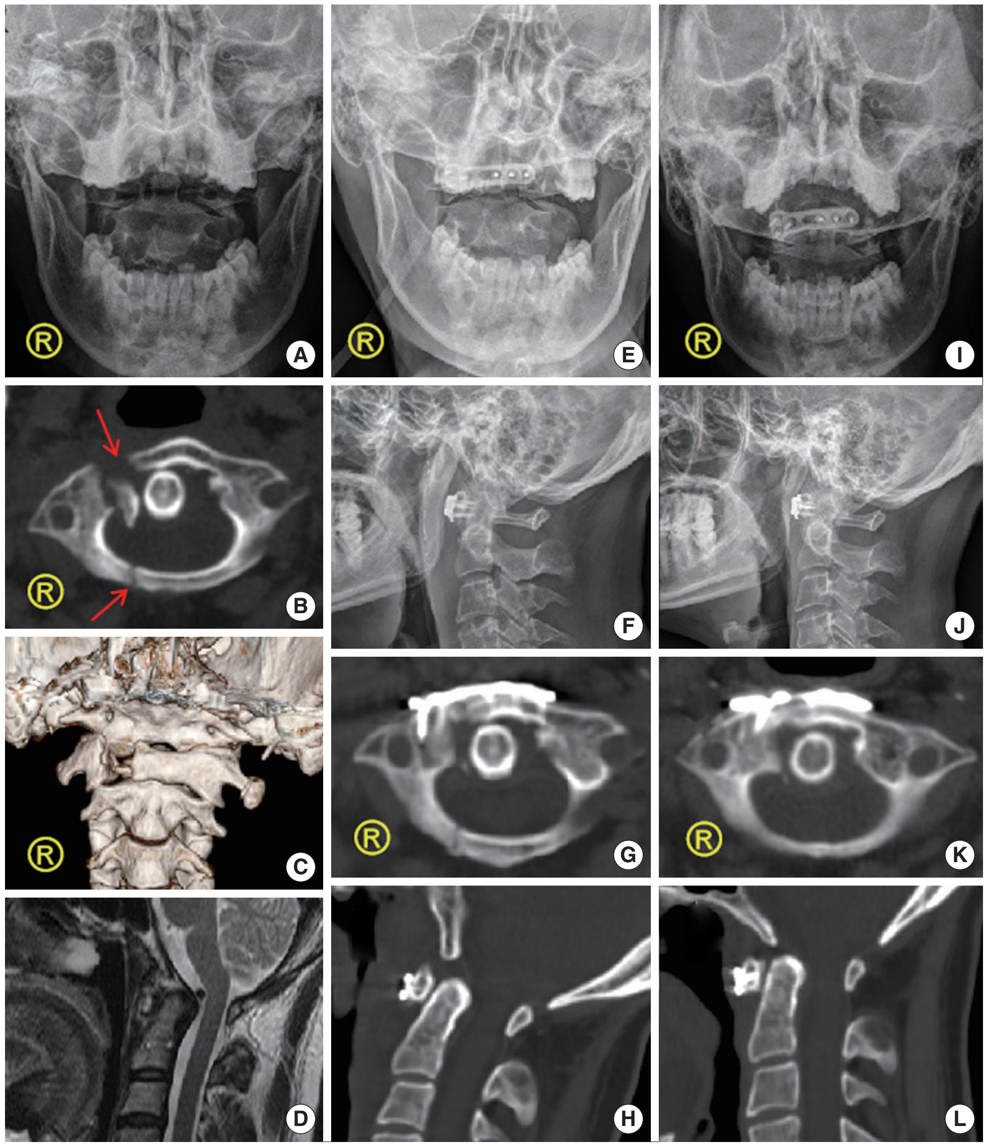

Fig. 2. A 50-year-old female with combined fractures of the anterior and posterior atlantoaxial arches was treated by transoral anterior C1-ring osteosynthesis using the Jefferson-fracture reduction plate (JeRP). (A) Preoperative open-mouth x-ray imaging showed displacement of the lateral masses. (B, C) The axial images of computed tomography (CT) scan and 3-dimensional reconstruction revealed fractures of the anterior and posterior arches with displacement of the lateral mass. (D) Preoperative magnetic resonance imaging showed no spinal cord compression. Red arrows showed the fracture breaks. (E, F) Postoperative open-mouth and lateral x-ray imaging identified the well C1–2 alignment. (G, H) Postoperative CT images revealed reduction of the fracture and adequate placement of the JeRP. (I, J) Open-mouth and lateral x-ray images at 6 months after surgery showed no loosening of the plate or screws. (K, L) CT images at 6 months after surgery revealed solid bone fusion.

both sides, and only one side was tightened. The fracture was repositioned by lateral compression with a pair of reduction forceps, after which the nut was locked on the other side. After the placement of the plate and screws was verified to be satisfactory by C-arm fluoroscopy, the incision was closed (Fig. 3).

Postoperative management: The drainage tube was removed when the postoperative drainage volume was less than 50 mL/24 hr. The sutures were removed 12–14 days after surgery. Cervical spine x-ray and CT examination were performed 1 week after surgery. The cervical brace was fixed and protected for 3 months, and regular follow-up was performed (Fig. 4).

3. Observed Indexes

The surgical time, bleeding volume, hospital stay and postop-

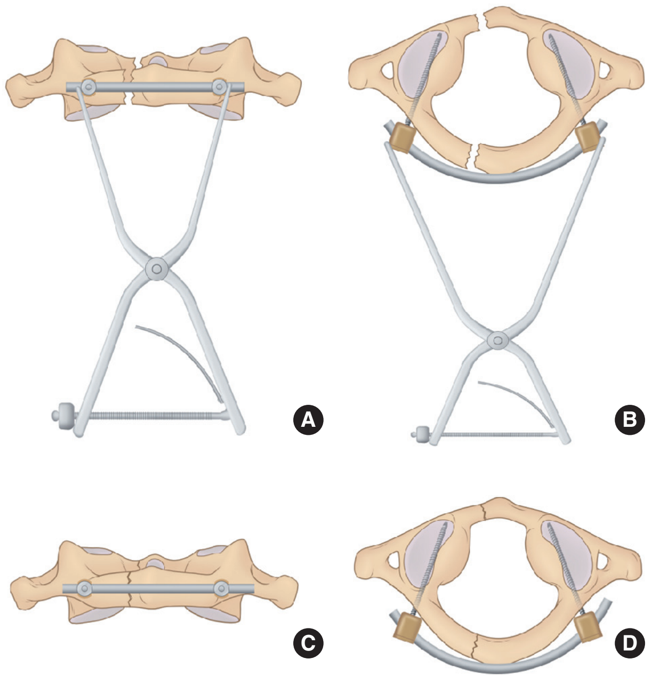

Fig. 3. Schematic of the posterior screw rod procedure. (A, B) Coronal and axial pictures present the reducing process: after C1 pedicle screws were inserted, a suitable length of connecting rod was selected and placed horizontally into both screw slots. Then, nuts were put into both sides, and only one side was tightened. The fracture was repositioned by lateral compression with a pair of reduction forceps. (C, D) Coronal and axial pictures present the fixation: after the fracture was satisfactorily reduced, locked the nut on the other side.

erative complications were recorded. The visual analogue scale (VAS) was used to assess the degree of occipital neck pain; the Neck Disability Index (NDI) was used to evaluate the cervical spine function. The distance of anterior arch fracture (DAAF), distance of posterior arch fracture (DPAF), lateral mass displacement (LMD), and the Redlund-Johnell value[16] (the vertical distance from the midpoint of the inferior border of the C2 vertebra to the McGregor line [the line between the posterior border of the hard palate and the posterior inferior border of the greater occipital foramen]) were measured before and after surgery to assess reduction (Fig. 5). All imaging indicators were measured and evaluated by 2 independent observers who were not involved with the study. Postoperative cervical spine x-ray and CT were reviewed to evaluate the internal fixation and fracture healing. We generally recommend our patients have follow-up imaging at 3, 6, and 12 months after surgery, and then every 12 months or at times of discomfort. All cases were followed up with imaging for at least 1 year.

4. Statistical Analysis

Statistical analysis was performed using IBM SPSS Statistics ver. 21.0 (IBM Co., Armonk, NY, USA). The measurement data were expressed as mean ± standard deviation. The pre- and post-surgery comparisons between the 2 groups were performed using the paired t-test, and the independent sample t-test was used for intergroup comparisons. the enumeration data were expressed as number (%), and the χ^2 test was used for intergroup comparisons. The level of significance was set at $p<0.05$. Intraobserver and interobserver reliability was assessed by kappa (κ) statistic and intraclass correlation coefficient (ICC).

RESULTS

1. Patient Characteristics

All 49 patients completed the surgery successfully. The mean surgical times were 104.5 ± 14.7 minutes (JeRP group) and 110.6 ± 18.5 minutes (PSR group), with no significant difference between the 2 groups (p = 0.214). The mean blood loss in the JeRP group was lower (69.4 ± 20.2 mL vs. 103.3 ± 25.4 mL, p < 0.001). The mean length of stay in the PSR group was 8.1 ± 1.6 days, which was significantly shorter than the 11.6 ± 1.6 days in the JeRP group (p < 0.001).

2. Clinical Symptom Parameters

There was no significant difference in the preoperative VAS scores (5.5 ± 1.1 vs. 5.3 ± 1.0, p = 0.569) or NDI (58.1% ± 4.1% vs. 57.6% ± 4.2%, p = 0.640) between the 2 groups. The postoperative (JeRP: 5.5 ± 1.1 vs. 0.8 ± 0.8, p < 0.001; PSR: 5.3 ± 1.0 vs. 1.1 ± 0.8, p < 0.001) and final follow-up (JeRP: 5.5 ± 1.1 vs. 0.4 ± 0.5, p < 0.001; PSR: 5.3 ± 1.0 vs. 0.3 ± 0.5, p < 0.001) VAS scores of both groups were significantly greater than the preoperative scores, with no difference between groups (0.8 ± 0.8 vs. 1.1 ± 0.8, p = 0.312; 0.4 ± 0.5 vs. 0.3 ± 0.5, p = 0.714). The NDI was significantly lower in both groups after surgery (JeRP: 58.1% ± 4.1% vs. 26.8% ± 4.0 %, p < 0.001; PSR: 57.6% ± 4.2% vs. 26.3% ± 4.4%, p < 0.001) and at final follow-up (JeRP: 58.1% ± 4.1% vs. 1.7% ± 2.4%, p < 0.001; PSR: 57.6% ± 4.2% vs. 2.2% ± 2.4%, p < 0.001), with no differences between the groups (26.8% ± 4.0% vs. 26.3% ± 4.4%, p = 0.721; 1.7% ± 2.4% vs. 2.2% ± 2.4%, p = 0.501).

3. Radiographical Parameters

There were no differences in preoperative parameters, such as DAAF, DPAF, LMD, or the Redlund-Johnell value, between the 2 groups. Postoperative DAAF and DPAF were significantly smaller in the PSR group (7.1 ± 2.0 mm vs. 4.6 ± 4.9 mm, p = 0.006;

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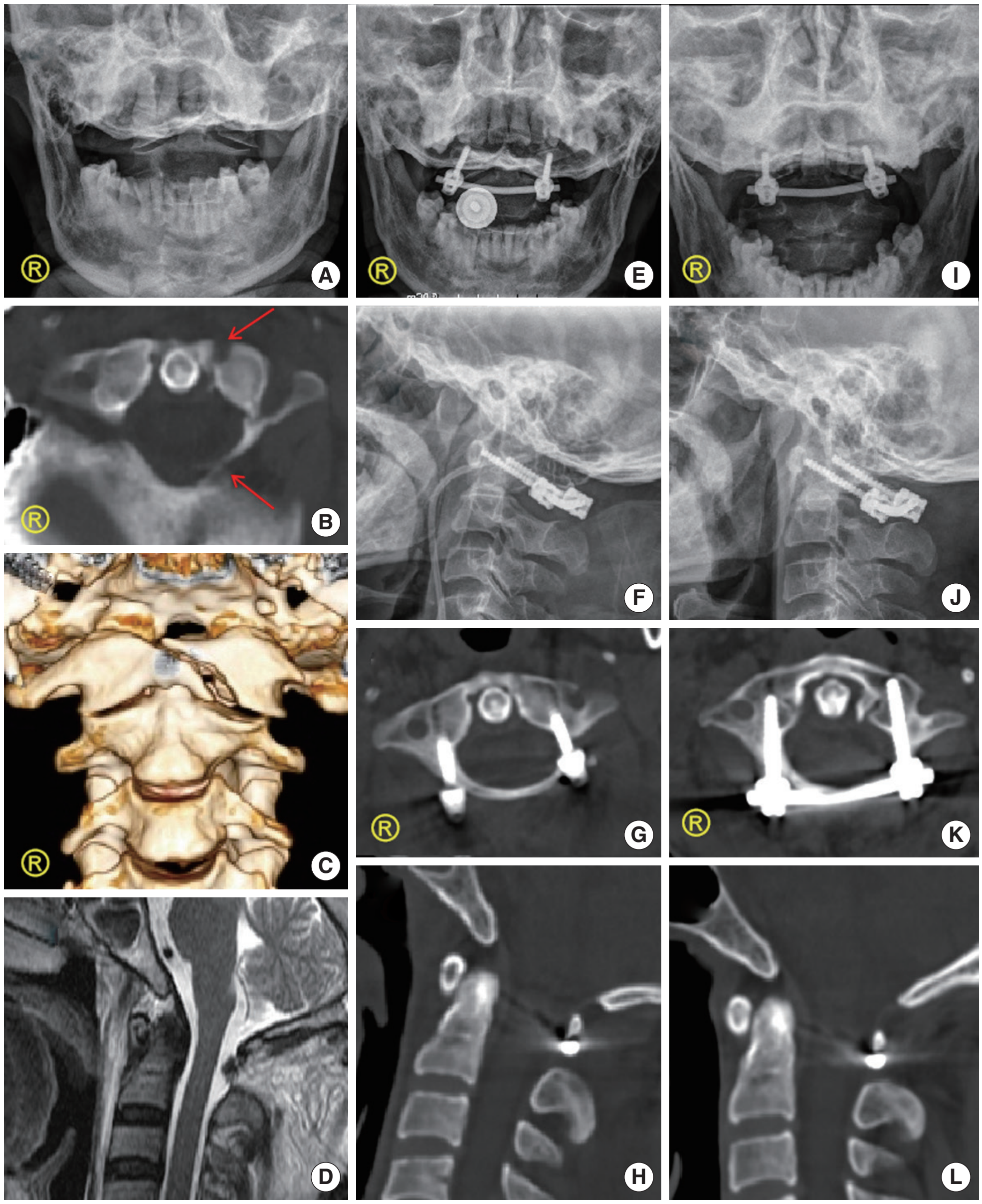

Fig. 4. A 61-year-old male with combined fractures of the anterior and posterior atlantoaxial arches was treated by posterior C1-ring osteosynthesis using the posterior screw rod. (A) Preoperative open-mouth x-ray imaging showed displacement of the lateral masses. (B, C) The axial images of computed tomography (CT) scan and 3-dimensional reconstruction revealed fractures of the anterior and posterior arches of the atlas with displacement of the lateral mass. (D) Preoperative magnetic resonance imaging showed no spinal cord compression. Red arrows showed the fracture breaks. (E, F) Postoperative open-mouth and lateral x-ray imaging showed good C1–2 alignment with adequate placement of PSR. (G, H) Postoperative CT image after surgery revealed reduction of fracture. (I, J) Open-mouth and lateral x-ray images at 9 months after surgery showed no loosening of the rob and screws. (K, L) CT images at 9 months after surgery revealed solid bone fusion.

2.9 ± 1.9 mm vs. 1.1 ± 1.4 mm, $p < 0.001$). In the JeRP group, the postoperative DAAF was also significantly smaller (7.2 ± 3.1 mm vs. 1.5 ± 1.6 mm, $p < 0.001$), whereas there was no significant difference in the DPAF reduction (2.2 ± 1.4 mm vs. 2.0 ± 1.4 mm, $p = 0.408$). However, the postoperative DAAF in the JeRP group was much smaller than that in the PSR group (1.5 ± 1.6 mm vs. 4.6 ± 4.9 mm, $p = 0.002$), while the postoperative DPAF in the JeRP group was greater than that in the PSR group (2.0 ± 1.4 mm vs. 1.1 ± 1.4 mm, $p = 0.028$). The LMDs of the JeRP group were 5.6 ± 2.6 mm, 0.9 ± 1.4 mm, and 0.5 ± 1.1 mm before surgery,

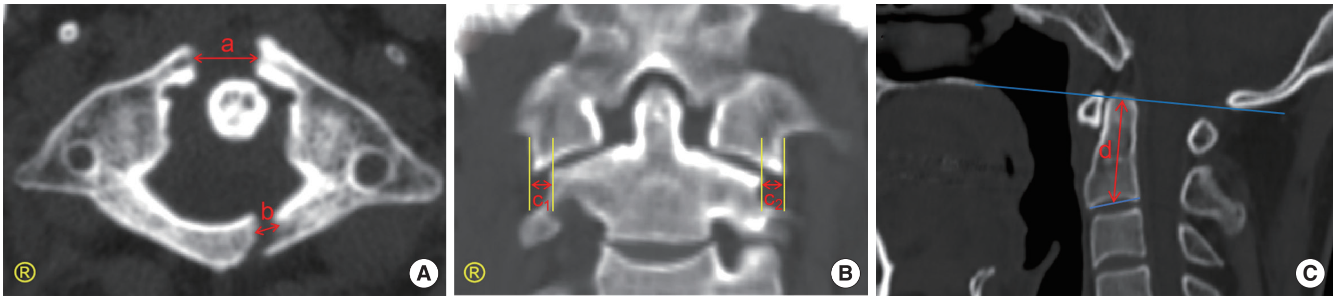

Fig. 5. Schematic diagram of measurement indicators in computed tomography (CT) scan. (A) Axial CT image shows the distance of anterior arch fracture equals "a"; the distance of posterior arch fracture equals "b". (B) Coronal CT image shows the lateral mass displacement equals "c1+c2". (C) Sagittal CT image shows the Redlund-Johnell value equals "d".

after surgery, and at the last follow-up, respectively; and those of the PSR group were 5.5 ± 3.3 mm, 2.2 ± 2.8 mm, and 1.9 ± 3.0 mm, respectively. The LMDs in both groups was significantly smaller after surgery (JeRP: $p < 0.001$; PSR: $p < 0.001$), and the postoperative and final follow-up LMDs in the JeRP group were significantly smaller than those in the PSR group (0.9 ± 1.4 mm vs. 2.2 ± 2.8 mm, $p = 0.042$; 0.5 ± 1.1 mm vs. 1.9 ± 3.0 mm, $p = 0.025$). The Redlund-Johnell values in the JeRP group were 37.9 ± 4.9 mm, 40.9 ± 4.3 mm, and 40.7 ± 4.2 mm before surgery, after surgery, and at the last follow-up, respectively; and these values equal 37.3 ± 2.7 mm, 38.5 ± 2.1 mm, and 38.6 ± 2.1 mm, respectively, in the PSR group. After surgery (JeRP: 37.9 ± 4.9 mm vs. 40.9 ± 4.3 mm, $p < 0.001$; PSR: 37.3 ± 2.7 mm vs. 38.5 ± 2.1 mm, $p < 0.001$) and at the last follow-up (JeRP: 37.9 ± 4.9 mm vs. 40.7 ± 4.2 mm, $p < 0.001$; PSR: 37.3 ± 2.7 mm vs. 38.6 ± 2.1 mm, $p = 0.002$), the Redlund-Johnell value significantly improved in both groups, and the Redlund-Johnell value was greater in the JeRP group than in the PSR group (40.9 ± 4.3 mm vs. 38.5 ± 2.1 mm, $p = 0.014$; 40.7 ± 4.2 mm vs. 38.6 ± 2.1 mm, $p = 0.029$). Both observers' intraobserver and interobserver reliability showed well in all radiographic parameters measured, including preoperative DAAF (ICC, 0.91; ICC, 0.86), postoperative DAAF (ICC, 0.89; ICC, 0.83), preoperative DPAF (ICC, 0.90; ICC, 0.84), postoperative DPAF (ICC, 0.91; ICC, 0.81), preoperative LMDs (ICC, 0.84; ICC, 0.80), postoperative LMDs (ICC, 0.85; ICC, 0.80), last followed-up LMDs (ICC, 0.88; ICC, 0.81), preoperative R-J value (ICC, 0.90; ICC, 0.81), postoperative R-J value (ICC, 0.91; ICC, 0.83), and last followed-up R-J value (ICC, 0.87; ICC, 0.84).

4. Complications and Healing

There was no difference in the incidence of complications after surgery between the 2 groups (atlantoaxial instability: $p = 0.9$; implants loosing: $p = 0.526$; screw misplacement: $p = 0.13$). Bone fusion was confirmed by continuous bone bridge formation without a visible fracture line at the fracture site on x-ray or thin-layer CT (0.9 mm) images.[17,18] Fracture healing was independently diagnosed by 2 orthopedic surgeons based on imaging. The fracture healing rates at 3, 6, and 12 months after surgery were 61.3%, 83.9%, and 90.3%, respectively, in the JeRP group. Similarly, the rates were 22.2%, 66.7%, and 83.3% in the PSR group, respectively. The fracture healing rate at 3 months after surgery was greater in the JeRP group (61.3% vs. 22.2%, $p = 0.008$), but no differences were found between the 2 groups at 6 and 12 months after surgery (83.9% vs. 66.7%, $p = 0.286$; 90.3% vs. 83.3%, $p = 0.656$). Two patients in the JeRP group and one patient in the PSR group exhibited atlantoaxial instability after surgery, which were revised by posterior atlantoaxial fixation and fusion; 2 patients with osteoporosis in the JeRP group developed implant loosening and were revised by posterior atlantoaxial fixation fusion after the anterior implants were removed; 2 cases of screw misplacement occurred in the PSR group after surgery and was revised by adjusting the screw position (Table 2). Well intraobserver and interobserver agreements were found for bone fusion rate at 3-month ($\kappa = 0.86$; $\kappa = 0.79$), 6-month ($\kappa = 0.84$; $\kappa = 0.81$) and 12-month ($\kappa = 0.82$; $\kappa = 0.78$) follow-up.

DISCUSSION

In this study, we compared imaging and clinical indices between 2 types of C1-ring osteosynthesis. We found that there was no difference in surgical time between the 2 groups. The PSR group had more intraoperative blood loss but a shorter length of stay. The posterior pharyngeal wall is adjacent to the prevertebral fascia without much neuromuscular tissue. Compared with the posterior approach, the anterior approach does not require more dissection of paravertebral tissue for expo-

Table 2. Comparisons of clinical data before and after surgery between the 2 groups

Variable	JeRP group (n = 31)	PSR group (n = 18)	p-value
Surgical time (min)	104.5 ± 14.7	110.6 ± 18.5	0.214
Bleeding (mL)	69.4 ± 20.2	103.3 ± 25.4	< 0.001*
Length of stay (day)	11.6 ± 1.6	8.1 ± 1.6	< 0.001*
Follow-up (mo)	20.1 ± 10.6	19.4 ± 8.0	0.813
DAAF (mm)			
Before operation	7.2 ± 3.1	7.1 ± 2.0	0.865
At discharge	1.5 ± 1.6	4.6 ± 4.9	0.002*
DPAF (mm)			
Before operation	2.2 ± 1.4	2.9 ± 1.9	0.370
At discharge	2.0 ± 1.4	1.1 ± 1.4	0.028*
LMD (mm)			
Before operation	5.6 ± 2.6	5.5 ± 3.3	0.900
At discharge	0.9 ± 1.4	2.2 ± 2.8	0.042*
Final follow-up	0.5 ± 1.1	1.9 ± 3.0	0.025*
R-J value (mm)			
Before operation	37.9 ± 4.9	37.3 ± 2.7	0.638
At discharge	40.9 ± 4.3	38.5 ± 2.1	0.014*
Final follow-up	40.7 ± 4.2	38.6 ± 2.1	0.029
VAS score			
Before operation	5.5 ± 1.1	5.3 ± 1.0	0.569
At discharge	0.8 ± 0.8	1.1 ± 0.8	0.312
Final follow-up	0.4 ± 0.5	0.3 ± 0.5	0.714
NDI (%)			
Before operation	58.1 ± 4.1	57.6 ± 4.2	0.640
At discharge	26.8 ± 4.0	26.3 ± 4.4	0.721
Final follow-up	1.7 ± 2.4	2.2 ± 2.4	0.501
Complications			
Atlantoaxial instability	2 (6.5)	1 (5.6)	0.900
Implants loosing	2 (6.5)	0 (0)	0.526
Screw misplacement	0 (0)	2 (11.1)	0.130
Fracture healing			
3-Month follow-up	19 (61.3)	4 (22.2)	0.008*
6-Month follow-up	26 (83.9)	12 (66.7)	0.286
12-Month follow-up	28 (90.3)	15 (83.3)	0.656

Values are presented as mean ± standard error or number (%).
JeRP, Jefferson-fracture reduction plate; PSR, posterior screw-rod; DAAF, distance of anterior arch fracture; DPAF, distance of posterior arch fracture; LMD, lateral mass displacement; R-J value, Redlund-Johnell value; VAS, visual analogue scale; NDI, Neck Disability Index.
*$p < 0.05$, statistically significant differences.

sure. However, the anterior approach is linked to a greater risk of infection because of the complex intraoral bacterial environment. To prevent infection, patients in the JeRP group had greater difficulty in perioperative care. In addition, patients' tracheal tubes cannot be removed immediately after JeRP, and transoral feeding should also be avoided with careful incision management. These factors lead to a longer hospital stay. The PSR group showed better improvement in postoperative DPAF than the JeRP group did, while the JeRP group showed better improvements in postoperative DAAF, LMDs, and the Redlund-Johnell value. Obviously, since the compression forces of the 2 procedures act directly on the anterior and posterior atlantoaxial arches, respectively, this could explain the greater postoperative improvement of the DAAF in the JeRP group and the greater postoperative improvement of the DPAF in the PSR group. The anterior arch participates in the construction of the atlantooccipital joint, atlantodental joint, and atlantoaxial lateral mass joint. In addition, anterior arch fractures are more likely to result in the displacement of bone fragments or atlantoaxial dislocation.[3,19] Thus, for unstable atlantoaxial fractures, especially when combined with posterior arch fractures, the reduction of anterior arch fractures is more important for stabilizing the upper cervical spine.[1,9] We suggest that the main reason is that the transoral anterior approach is the most direct way to reduce fractures in the anterior arch. This approach can restore the separated lateral mass with a smaller torque, which results in significant relief of lateral mass separation and upward displacement of the dentate process due to fracture of the anterior arch. And therefore, improve the reduction and recovery of LMDs and the Redlund-Johnell value. Although PSR fixation can directly reduce posterior arch fractures via compression at the end of bilateral screws, it can also cause the front of the lateral mass to swing laterally, leading to deviation of the reduction force transmission, insufficient anterior arch fracture reduction and even lateral mass dislocation. Especially when the anterior arch fracture distance is significantly greater than that of the posterior arch, posterior compression is stretched to the limit to close the anterior arch fracture completely. These imaging findings revealed that transoral anterior JeRP fixation provides better integral reduction than PSR fixation does. Additionally, which could explain why the short-term (3-month follow-up) postoperative fracture healing rate was greater in the JeRP group. This suggests that our patients who underwent JeRP could start functional exercises earlier than those who underwent posterior surgery, which is important for preventing postoperative complications such as scarring. Although both groups showed significant postoperative improvements in VAS scores and NDI, there was no statistically significant difference between the 2 groups. The effects of the 2 procedures on improving clinical symptoms were similar.

There was no difference in the overall complication rate between the 2 groups. Two of the 5 patients with osteoporosis in the JeRP group experienced internal fixation loosening at the long-term follow-up. The diagnostic criterion for osteoporosis was a DXA test with the T value less than -2.5. The anterior lateral mass screw fixation was performed in transoral anterior JeRP fixation, whose fixation strength is weaker than that of posterior pedicle screw fixation, especially in osteoporosis patients. Three cases of postoperative atlantoaxial instability were observed in both groups. This finding is similar to that of Tu et al.,[14] which suggests that C1-ring osteosynthesis may not be infallible. Because injuries of the transverse ligament itself are difficult to heal over time. At the same time, patients may also have injuries of muscles and other ligaments while the bone-muscle-ligament complex plays a crucial role in joint stabilization. Therefore, we suggest that preoperative 3-dimensional CT reconstruction of the ligaments around the atlantoaxial joint should be performed to more definitively judge ligament injuries, including the transverse ligament and others. It is also recommended that dynamic cervical x-rays be taken to judge the potential risk of atlantoaxial instability at postoperative follow-up. No postoperative complications such as dysphagia, hoarseness, and any disturbance in drinking and eating occurred in the JeRP group. We consider possible reasons including the small size of the steel plates used in JeRP and less postoperative stimulation of the esophagus and trachea. Besides, the indications for JeRP do not involve lateral mass fractures, with small surgical exposure and low risk of peripheral nerve injury. All surgeries were performed by an experienced senior surgeon, and surgical proficiency is also an important factor in minimizing complications such as peripheral nerve injuries.

In 1919, Jefferson[20] first proposed one classification method for atlas fractures based on the mechanism of injury and anatomical site. In 1988, Landells and Van Peteghem[21] categorized atlas fractures into 3 types: anterior or posterior arch fractures, anterior-posterior arch fractures, and lateral mass fractures. Subsequently, in 1991, Levine and Edwards[22] also divided atlas fractures into 3 types, namely, posterior arch fractures, lateral mass fractures, and both anterior and posterior arch fractures. Both Landells and Levine-Edwards classifications take fracture morphology into consideration and are widely used.

According to the guidelines of the American Congress of Neurological Surgeons (CNS), the integrity of the transverse ligament is the main basis for assessing the stability of atlas fractures, which means that atlas fractures with the intact transverse ligament are considered stable fractures; otherwise, fractures with the ruptured transverse ligament are considered unstable.[23] This method is now widely accepted. Then Dickman et al.[24] also described atlantoaxial transverse ligament injuries, where type I refers to rupture in the middle of the transverse ligament and type II refers to avulsion fracture of the transverse ligament at the attachment point of the lateral mass. However, through retrospective analysis of a large number of cases, Lee and Woodring[4] concluded that only anterior arch single fractures without combined transverse ligament rupture or simple posterior arch fractures should be considered stable fractures, while all other types of fractures are unstable fractures. The reason is that when multiple fractures of the anterior arch exist, even if the transverse ligament is intact, the anterior arch is too weak to restrain the odontoid from moving forward, thus leading to posterior dislocation. Additionally, when the anterior and posterior arches are both fractured, although the intact transverse ligament may prevent the separation of the lateral mass, there is a possibility of rotational displacement of the fractured mass using the attachment point of the transverse ligament as the fulcrum. Radcliff et al.[25] pointed out that the traditional Spence Rule which states that a displacement of the C1 lateral masses by > 6.9–8.1 mm suggests the loss of transverse ligament integrity, can be inaccurate. Based on the above, we believe that the method of assessing whether a C1 fracture is stable based on the integrity of the transverse ligament may not be accurate. We are inclined to Lee et al., that is, all fractures except for anterior arch single fracture without transverse ligament rupture and posterior arch fracture are unstable fractures, which is one of the exclusion criteria of this study.

Usually, separation and displacement of the atlas increase the space of the spinal canal, and patients with neurological dysfunction are rare. Therefore, reduction and stabilization are the most important aspect in the treatment of unstable atlas fractures. Nonoperative treatment is still recommended for patients with stable atlas fractures in the first stage. However, this therapy may not be appropriate for unstable fractures. One multicenter study indicated that surgical treatment was associated with a higher fusion rate, shorter fracture healing time, more favorable clinical outcomes, and better fracture reduction for unstable atlas fractures.[6]

For surgical methods, atlantoaxial fusion has been used mostly in the past and has been tested in a timely manner to

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obtain satisfactory results.[26] However, this surgery sacrifices a significant portion of the motor function of the upper cervical spine, especially axial rotational motion, thus reduces the life quality of patients after surgery. In 2004, Ruf et al.[7] first treated 6 Jefferson-fracture patients with transverse ligament rupture via transoral anterior screw-rod fixation as C1-ring osteosynthesis. With no postoperative atlantoaxial instability, all patients achieved good outcomes with preserved cervical motion. Subsequently, reports of C1-ring osteosynthesis for unstable atlas fractures, a physiological surgical fixation, have increased. However, whether transverse ligament rupture leads to late atlantoaxial instability has become a point of controversy for this surgery. Li et al.[8] proposed the "buoy phenomenon," suggesting that C1-ring osteosynthesis can restore the height of the occipital-atlantoaxial complex, which tightens the loose longitudinal ligaments to maintain the stability of the atlantoaxial joints. Kollerd et al.[27] and Li-Jun et al.[28] also reported in their biomechanical studies that C1-ring osteosynthesis can restore the stability of the atlantoaxial joints when combined with atlas fracture and transverse ligament rupture. A study showed that posterior C1-ring osteosynthesis is superior to atlantoaxial fusion in terms of preserving the physiological function of the cervical spine and long-term relief of neck pain.[5]

Now, the mainstream approaches for C1-ring osteosynthesis include the posterior and transoral anterior approaches. Posterior C1-ring osteosynthesis is typically represented by horizontal screw-rod fixation.[8,12] Ruf et al.[7] used a transoral anterior screw rod system to fix the atlas with satisfactory results, but this method did not fit the anatomical features of the anterior atlas structures. Transoral anterior C1-ring osteosynthesis is now most often performed with plate fixation.[1,7,9] The JeRP fixation system based on the anatomical parameters of the anterior atlantoaxial spine was designed by General Hospital of Southern Theatre Command of PLA for transoral anterior C1-ring osteosynthesis and has showed satisfactory results in clinical application.[14,15] It is important to mention that for the JeRP technique, when exposing C1, especially the lateral side of the lateral mass, some important anatomical structures around C1, such as the internal carotid artery (IC) and hypoglossal nerve and so on should receive more attentions. In cases of poor preoperative conditions, such as elderly patients with atherosclerosis of IC or in cases where the fracture extends far enough to make exposure difficult, intraoperative maneuvers should be performed with greater caution.

Our study presents some limitations. First, as our study was retrospective in nature, selection bias was inevitable in the case and procedure selection process. Particularly, for different procedures we did not use more sophisticated algorithms to screen for, and these make our results potentially biased and need to be confirmed by more prospective studies in the future. In addition, the sample size in this study was small, and a larger number of patients is needed to validate the differences between the 2 techniques. Finally, the follow-up period was short, and additional attention should be given to distant complications in the future.

CONCLUSION

Both anterior transoral JeRP and PSR fixation in C1-ring osteosynthesis for unstable atlas fractures have satisfactory clinical efficacy. Transoral anterior JeRP fixation provides better comprehensive fracture reduction and facilitates short-term fracture healing but has a longer hospital stay and a greater risk of potential infection. For patients with combined osteoporosis, internal fixation is more prone to loosening. PSR fixation has a low risk of internal fixation loosening but poorly reduces anterior arch fractures. Thus, increased fracture healing time is needed. Each type of surgery has advantages, and surgeons should design a reasonable surgical program based on the patient's individual situation and the surgical techniques they have mastered.

NOTES

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