

“Direct vision” operation of posterior atlantoaxial transpedicular screw fixation for unstable atlantoaxial fractures

A retrospective study

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Abstract

Background: The posterior screw fixation in atlas via posterior arch and lateral mass, also called C1 “pedicle” screw, combined with C2 pedicle screw fixation has shown better biomechanical stability in unstable atlantoaxial fractures. However, its popularization has to fulfill the limitation imposed by anatomical characteristics. The aim of this study was to explore the manipulation, effect, and safety of the atlantoaxial transpedicular screw fixation under “direct vision” for the treatment of unstable atlantoaxial fracture.

Methods: All the patients diagnosed with unstable atlantoaxial fracture, who received surgery treatment of C1, C2 internal fixation from January 2012 to December 2014 were reviewed. Only these patients that were diagnosed with atlantoaxial instability secondary to trauma and were treated with atlantoaxial transpedicular screw fixation under “direct vision” and iliac autograft were included. The safety of transpedicular screw placement, postoperative outcome, atlantoaxial stability, autograft fusion, and complications was observed and analyzed retrospectively. The pain visual analog scale (VAS) and the Japanese Orthopedic Association (JOA) score were used as surgical curative effect evaluation standards.

Results: We reviewed a total of 92 patients diagnosed with unstable atlantoaxial fracture, who received surgery treatment of C1, C2 internal fixation from January 2012 to December 2014, and 87 patients were treated with atlantoaxial transpedicular screw fixation under “direct vision” and were included this analysis. A total of 306 transpedicular screws in atlas and axis were placed successfully. All cases were followed-up >12 months. The overall breach rate was 11.36%. None of the breaches resulted in new-onset neurological sequela. The neurological status in cases with bilateral upper extremities numbness and lower extremities weakness had improved after surgery. At the latest follow-up, the neck VAS and JOA scores were significantly improved ($P < .01$) than those preoperatively. No cases demonstrated implantation failure and bone graft absorption on the postoperative x-ray films and CT scans.

Conclusion: Atlantoaxial transpedicular screw fixation under “direct vision” and iliac autograft for the treatment of unstable atlantoaxial fracture has shown simple manipulation and efficient performance. Thus, the technique of C1–C2 fixation is feasible in treating unstable atlantoaxial fracture.

Abbreviations: AP = anterior-posterior, ASIA = American Spine Injury Association, JOA = Japanese Orthopedic Association, TL = transverse ligament, VAS = visual analog scale.

Keywords: atlantoaxial fixation, atlantoaxial fracture, direct vision, internal fixation, posterior, transpedicular screw

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LC and EY contributed equally to this study.

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1. Introduction

Atlantoaxial fracture is a common upper cervical trauma primarily caused by high falling accident or traffic accident. Isolated fractures of the atlas, including isolated anterior or posterior arch, lateral mass, and combined anterior/posterior arch fractures without transverse ligament (TL) rupture can typically be treated with cervical immobilization alone, such as skull traction or Halo-vest.^[1] However, early operative treatment is a reasonable option for such risk factors associated with a high degree of non-surgical failure including TL injuries with or without a C1 ring fracture,^[2] age >50 years, dens displacement >5 mm, type IIA odontoid fractures and old odontoid fractures, and inability to achieve or maintain acceptable fracture alignment with external immobilization.^[3–6] Compared to other techniques of C1–C2 fixation such as the C1–C2 lateral mass screw, C1–C2 transarticular screw technique as well as the posterior wiring techniques, the atlantoaxial transpedicular screw fixation is advantageous, especially in biomechanical

stability.^[7–10] Thus, C1–C2 transpedicular screw fixation has become a popular fixation technique among the posterior atlantoaxial fixation techniques.^[11,12] However, the complex anatomical structure of this region ascribes the implantation of pedicle screw as a technique with the high requirement and risk, necessitating an exact 3-dimensional understanding obligatory for a successful screw insertion. The ideal entry point should be at the center of C1 “pedicle”; however, the current free-hand techniques cannot assist the surgeon in an intuitive determination of its precise location.^[13–15] Although these pedicle screws can be placed with the help of intraoperative 3D navigation,^[16] the cost-ineffectiveness and inconvenience limit its application and several factors, such as respiration and registration, would designate it as “misleading.” Moreover, other techniques are in regular usage on cadaver study, and their clinical efficiency is unknown.^[17] The present study introduces a relatively safe and strongly operational method of atlantoaxial pedicle screw insertion.

2. Methods

Between December 2012 and January 2014, patients that were diagnosed with unstable atlantoaxial fracture and treated with atlantoaxial transpedicular screw fixation under “direct vision” were reviewed and included. The informed consents of all the objective were obtained and preserved in a single institution (Shanghai JiaoTong University Affiliated Sixth People’s Hospital, Shanghai, China). The patients treated with other methods of C1, C2 fixations, such as lateral mass fixation, transarticular screws fixation, and so on, and patients with C1 posterior arch at the VA groove measured <3.5 mm were excluded. All the x-rays comprise posteroanterior, lateral, and mouth-open views, CT plain scanning and 3-dimensional reconstruction, and MRI to confirm the fracture sites, fracture severity, damage status of the spinal cord, accuracy of screw placement, and postoperative bone fusion situation. CT scans were serially examined at immediate 3 and 6 months postoperatively to define bone fusion from the existence or absence of bridging bone and the presence of bony trabeculation across graft and lamina of C1 and C2. The judgment of bone fusion was evaluated at 6 months postoperatively regardless of overall follow-up period. The study was approved by the Ethics Committee of Shanghai Jiaotong University Affiliated Sixth People’s Hospital.

2.1. Follow-up evaluations

The visual analog score (VAS) and Japan Department of Orthopedics Association (JOA) score before and after operation during follow-up were used to evaluate the improvements in pain and limitation of motion of occipitocervical region, respectively. The American Spine Injury Association (ASIA) classification^[18] was used to evaluate the status of spinal cord function at the latest follow-up. The assessment of the status of bone fusion, which was defined as nonsymptomatic and the fragment stability on dynamic radiographs and fusion demonstrated on postoperative CT scans, could be used to evaluate the accuracy of screws with the help of modified classification of Gertzbein and Robbins^[16,19,20] (Fig. 1) after 1 year.

2.2. Statistical analysis

The data were analyzed using the Statistical Package for the Social Sciences (SPSS Inc, Chicago Version 18.0) for windows. Continuous variables are presented as the means \pm standard

deviation or medians and were compared using ANOVA and post hoc test. Statistical significance of measurements was determined at a 95% level of significance. A *P*-value of <.05 was considered significant and a *P*-value of <0.01 highly significant.

2.3. Surgical procedure

All patients in our cohort were operated in a supine position after anesthesia for the removal of a cortical iliac bone grafting, and then was preserved in Aseptic environment for the standby application. Then, the patients were placed in the prone position after iliac incision closure. The median incision was made with the protection of continuous skull traction. With cervical rear muscles subperiosteal dissected bilaterally, C1 posterior arch, spinous process, vertebral lamina, and lateral mass of C2 were unfolded. This process must be performed along the posterior arch and can avoid injury to the vertebral artery and epidural venous plexus. Then, the superior border of C1 posterior arch and bottom of the groove for vertebral artery, using the raspatory, were probed without deliberately dissecting the vertebral artery (see Fig. 1, Supplemental Content, which demonstrates the way to probe the superior border of C1 “pedicle.”, <http://links.lww.com/MD/B749>). The vertebral artery lies snugly in the arterial groove; therefore, this process requires careful operation and only use the raspatory at the inferior border of the groove to prevent injury to the vertebral artery. And then the separation and protection of C2 nerve root and epidural venous plexus were performed with the help of another raspatory to confirm the location of inferior border of C1 “pedicle” (see Fig. 2, Supplemental Content, which demonstrates the way to probe the inferior border of C1 “pedicle.”, <http://links.lww.com/MD/B749>). Subsequently, the medial border of the C1 vertebral pedicle, using a hook, was palpated along the vertebral surface of the posterior arch from inside to outside (see Fig. 3, Supplemental Content, which demonstrates the way to probe the medial border of C1 “pedicle.”, <http://links.lww.com/MD/B749>). Additionally, the borders of C1 vertebral pedicle were “located” (see Video1, Supplemental Video1, which records the way to locate the borders of C1 “pedicle.”, <http://links.lww.com/MD/B750>). The entry point of C1 vertebral pedicle screw was marked at the center of a vertebral pedicle. The cortical bone of C1 was grinded off with the help of high-speed burr, and subsequently, a pilot hole was made with a battery-powered drill under “direct vision” in an anterior-posterior (AP) direction, at 5–10° angle cranially (see Video2, Supplemental Video2, which records the way to make a pilot hole of C1 “pedicle.” <http://links.lww.com/MD/B751>). Consecutively, the hole was enlarged with abrasive drilling in the same direction. After fluoroscopy had confirmed the position of the drill, the hole was taped to ensure that all the borders were intact, and subsequently, Vertex screws (Medtronic Sofamor Danek) were inserted. Before the insertion of C2 vertebral pedicle screw, the medial border of the vertebral pedicle, using a hook, was probed and separated along the superior border of the vertebral plate from inside to outside (see Fig. 4, Supplemental Content, which demonstrates the way to probe the medial border of C2 pedicle., <http://links.lww.com/MD/B749>). The entry point was at the point of intersection at a distance of 4 mm from the medial border of the vertebral pedicle and 5 mm from the superior border of the vertebral lamina, in a convergent direction at an angle of 15–20° and at an angle of 20–25° cranially (Fig. 2) (see Video3, Supplemental Video 3, which records the way to make a pilot hole of C2 pedicle.,

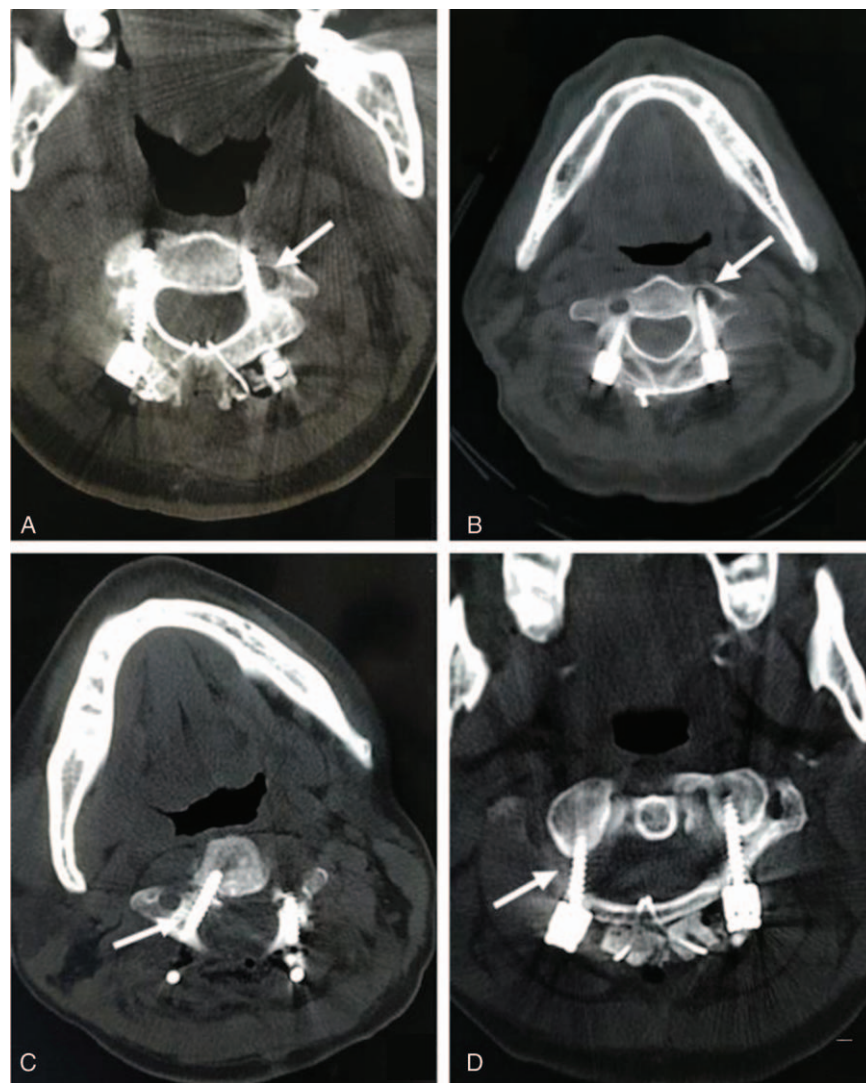


Figure 1. Screw placement; lateral breach: screw exposure (A) and pedicle perforation (B); medial breach: screw exposure (C), and pedicle perforation (D) in axial CT scans.

<http://links.lww.com/MD/B752>). Then, vertex screws were inserted after the hole was treated with the tape. Consecutively, the lateral and AP view was conducted under image intensifier to ensure the position of the screws; connecting rods were then applied and fastened by inner nuts, the iliac bone graft shaped appropriately was implanted over the surfaces of posterior atlantal arch (see Fig. 5, Supplemental Content, which demonstrates the way to mould the graft bone, <http://links.lww.com/MD/B749>) with the cancellous bone side down, after axial vertebral plate decorticated with high-speed burr (see Fig 6, Supplemental Content, which demonstrates the preparation process of decorticating the cortex, <http://links.lww.com/MD/B749>) and fixed with a titanium cable (Medtronic Sofamor Danek) (see Fig. 7, Supplemental Content, which shows the positions of screws and graft, <http://links.lww.com/MD/B749>). Another lateral and anterior-posterior view under image intensifier are seen to ensure the position of screws and graft, (see Fig 8, Supplemental Content, which shows the position of screws and cable., <http://links.lww.com/MD/B749>) and reconstruct the end point of the suboccipital group on the spinous process of C2. Then, the wound was closed in layers, with a negative pressure drainage inserted.

The antibiotic was used conventionally on the first postoperative day, and ambulation was permitted on the second day after surgery under the protection of cervical gear. In consideration of the controversy of methylpredisolone in these years,^[21–23] low dose of it was used on the patients with a spinal neurological deficit on the first 3 days after surgery in our center for the fear of higher risks of wound and respiratory infections,^[24] combined with appropriate dose of mannitol and moderate ganglioside. Imaging a plain x-ray and CT at regular intervals was necessary, and cervical gear could be removed after graft fusion.

3. Results

A total of 92 patients diagnosed with unstable atlantoaxial fractures were recorded. However, only 87 patients treated with this technique were included, which consisted of 32 unstable atlas fractures with transverse ligament injuries, 13 complex atlantoaxial fractures, and 43 odontoid fractures including thirty odontoid II fractures and 12 old odontoid fractures.^[2,25–31] All the surgery were completed by 1 surgeon at a single institution. The mean age of the patients was 39.2 years (range: 25–55 years),

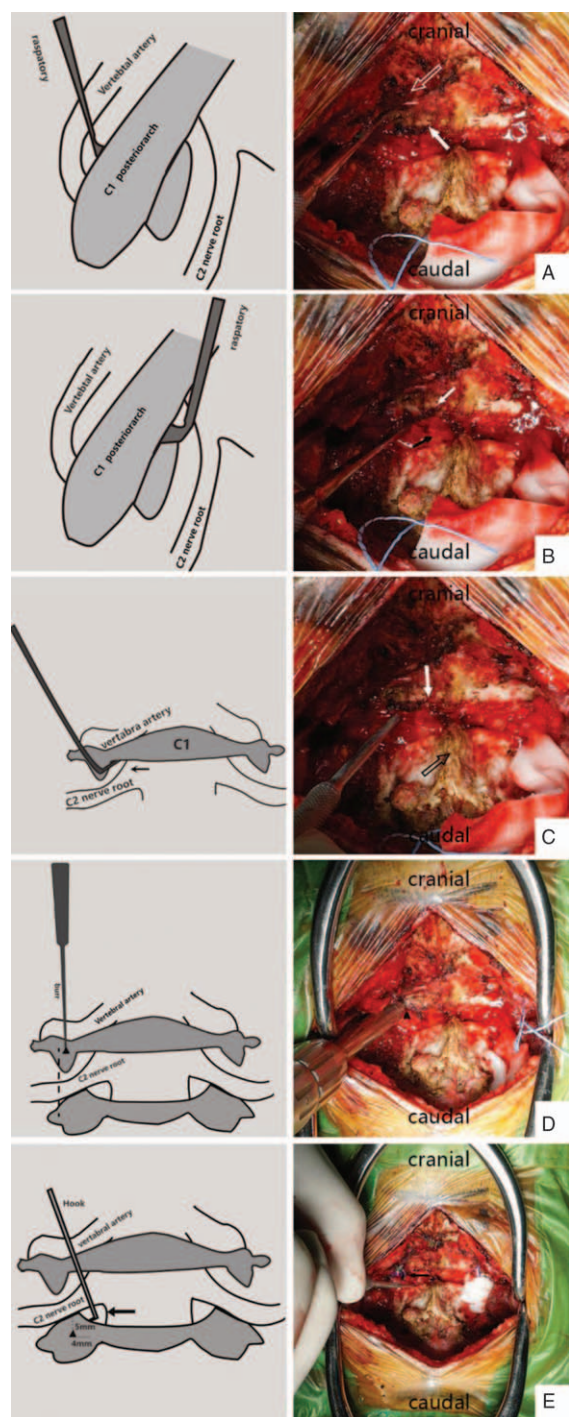


Figure 2. The superior border of C1 posterior arch (A) and bottom of the groove for vertebral artery (B) are probed respectively with raspator. The black arrow, faint white arrow, and solid white arrow represent C2 nerve root, vertebral artery, and C1 posterior arch, respectively. (C) The medial border of C1 vertebral pedicle is palpated along the vertebral surface of posterior arch from inside to outside with a hook. The faint black arrow represents the C2 spinous process. (D) The lateral border of C1 vertebral pedicle (dash line) was paralleled to the lateral border of C2 lateral mass anatomically. Then, the entry point (black triangle) located at the center of the borders, and a pilot hole is created with high-speed burr and abrasive drill. (E) The medial border of C2 vertebral pedicle was identified with the help of a hook. The entry point of C2 (black triangle) is located at the point of intersection at a distance of 4mm from the medial border of the vertebral pedicle and 5mm from the superior border of the vertebral lamina.

and all were followed up for >12 months. The mechanisms of injury were falling accident in 36 cases, bruises in 24, and a vehicle accident in 27 cases. In total 70 patients underwent with skull traction for 2 to 3 days routinely, 6 patients coupling spinal injury presented within 72 hours, operations were performed in 6 patients with associated chest injury 4 weeks later, and 5 injuries was 2-months-old because of severe craniocerebral trauma (Table 1). The duration of operation ranged from 115 to 160 minutes, with an average of 145 minutes. The intraoperative estimated blood loss ranged from 150–350 mL, with an average of 242 mL. Twenty-one patients with C1 single-side lateral mass comminuted fractures had unilateral screw placement. A total of 306 atlantoaxial pedicle screws were inserted in 87 patients; the length of the screws 24–28 mm, and diameter 3.5–4.0 mm, which was selected by the preoperative CT scans and intraoperative lateral radiographs. According to the modified classification of Gertzbein and Robbins, 264 (about 86.27%) screws were grade 1, and 42 (about 13.73%) screws were grade 2, among which 12 screws protruded into medial walls of the pedicles, 4 screw breached the vertebral artery groove, and 26 lateral breaches were seen on postoperative CT scans. These violations were not taped intraoperatively or detected on postoperative plain radiographs (Table 2). However, none of them demonstrated new-onset neurological signs, and the clinical symptoms of all the patients had improved without any complication, such as dura mater tear or vertebral artery injury. Six cases presented bilateral upper extremities numbness and lower extremities weakness, and were classified by the American Spine Injury Association (ASIA) classification: 1 patient as ASIA C and 5 patients as ASIA D. These patients improved after surgery: 1 patient with ASIA C and 5 patients with ASIA D improved to ASIA E, respectively. The follow-up CT scans showed fusion in all the patients. There was no screw breakage or displacement. (Fig. 3) The pain of occipitocervical region was significantly relieved, with the VOA scores ranging 2.0–3.5 (average 2.2) and JOA scores ranging from 13 to 16 (average 13.8) at discharge, as shown in Table 3.

Table 1

Patient clinical characteristics.

Clinical characteristic	N (patients/screws)
Fracture characteristics	
Unstable atlas fractures	32/87
Complex atlantoaxial fractures	13/87
Odontoid II fractures	30/87
Old odontoid fractures	12/87
Mechanisms of injury	
Falling accident	36/87
Bruise	24/87
Vehicle accident	27/87
Combined injury	
Chest injury	6/87
Craniocerebral trauma	5/87
Spinal cord injury	6/87
Improvement	
Pain Relief	87/87
Neurological function	6/6
Accuracy of screws	
Penetration	264/306
Status of fusion	87/87
Complication	0/87

Table 2**Breach rates.**

	Number of screws	C1			C2		All breaches (%)
		Vertebral artery groove	Medial breaches	Lateral breaches	Medial breaches	Lateral breaches	
Left side	160	3	4	8	1	3	19
Right side	146	1	6	13	1	2	23
Total	306	4	10	21	2	5	42 (13.73%)

4. Discussion

The most important point of treatment for atlantoaxial fracture is to reduce and stabilize the injured segment for preventing further neurological injury. The TL and muscles play vital roles in maintaining the stability of atlantoaxial joints.^[32] The injuries of TL frequently cause serious instability of the upper cervical spine. The surgical treatment is always required for the patients combined with bilateral anterior and posterior arch fractures, comminuted atlas fractures, and unstable fractures with TL of atlas injury. The nonunion rate of type II and type IIA fractures is over 40%,^[33,34] which rises up to 80% when combined with >4 mm of fracture

ends shifting.^[35] The old odontoid fracture heals with difficulty and necessitates surgical aid. Subsequently, several groups worldwide conducted the in-depth studies on anatomic characteristics of atlantoaxial pedicle and technology of transpedicular screw insertion. These studies manifested that the dimension of the C2 posterior arch under the vertebral artery groove is capable of accommodating 3.5 to 4.0 mm diameter screws.^[29–31] Compared to the other techniques of C1–C2 fixations such as the C1–C2 lateral mass screw, the transarticular screw technique as well as the posterior wiring techniques, atlantoaxial transpedicular screw fixation has shown superiority in increased range of motion,



Figure 3. The preoperative CT scans and plain radiographs of a 57-year-old man showed complex atlantoaxial fractures. (A) Preoperative mouth-open views revealed lateral atlanto-dental space asymmetry and atlantoaxial joint instability. (B) Preoperative sagittal CT image showed the odontoid II fractures. (C) Preoperative horizontal CT scan showed the comminuted fracture of C1 anterior and posterior arches. (D) The preoperative CT scans showed the correction of rotation of C1 anterior ring after instrumentation. (E) Sagittal CT image showed the exact screw trajectory without posterior arch penetration and reduction of the dislocated C1 fracture. (F) The anteroposterior and lateral x-ray showed the exact position of screws and rigid fixation. CT= computed tomography.

Table 3
Pre- and postoperative VAS and JOA scores.

	Preoperative	Discharge	3-month	1-year	Final time-point
VAS score	7.4±1.02	2.6±0.51*	2.4±0.62*	2.2±0.68*	1.8±0.76*
JOA score	10.8±1.62	14.8±1.03†	14.9±0.99†	14.9±1.01†	15.2±0.68†

Note: *†Compared with preoperative values respectively using ANOVA and posthoc test, $P < .05$. JOA=Japan Department of Orthopedics Association, VAS=visual analog score.

excellent biomechanical stability,^[8,10] and minimal rate of complications of neurovascular injury symptoms.^[36–39] Thus, the C1 pedicle screw combined with C2 pedicle screw fixation, first described by Resnick and Benzel in 2002,^[40] has become the most popular fixation technique.^[11]

The complexity of the upper cervical region that courses the medulla oblongata, vertebral artery, and other extremely critical structures contribute towards the restrictive application of this technique. With the advances and usage of the navigation system, the increased safety and accuracy of atlantoaxial transpedicular screw insertion is achieved compared to the other manual techniques.^[41] Nevertheless, cost-burden and inconvenience of registration limit its wide application widely at present. Respiration and movement of the neck would mislead the navigation. Compared to the other techniques^[14,15,42] that also can help C1–C2 pedicle screw insertion safely, this technique supported location of entry point and the borders of C1 pedicle, the direction of insertion, and isolation and protection of these vital structures. The key of this technology lies in conforming the medial, lateral, superior, and inferior borders of C1 pedicle precisely with probe before screws insertion, the entry point location at the center of C1 pedicle that we have probed. And whenever probing the superior border of C1, careful operation is required because the vertebral artery lies snugly in the arterial groove, and when the inferior border of the groove is probed, without deliberately dissecting the vertebral artery, the superior border of C1 “pedicle” is conformed. And then inserting the screws on a sagittal plane with 5–10° in a cephalad direction. The key point of C2 transpedicular screw insertion is to conform the medial border of the pedicle. The entry point locates at the intersection, at a distance of 4 mm from the medial border of C2 pedicle guided by raspatory and 4 mm from the superior rim of C2. The direction of the screw trajectory was determined to be 15 to 20° in a medial direction and 20 to 25° in a cephalad direction. Since the study began in 2012, 22 patients with traumatic atlantoaxial instability have been treated with atlantoaxial transpedicular screw fixation under “direct vision” by 1 surgeon who is experienced with C1–C2 lateral mass screw insertion but no experience with placing the C1–C2 transpedicular screws insertion previously; nonetheless, all the patients received satisfactory clinical effect.

Combined with our clinical experience, successful screw insertion under “direct vision” still needs attention as described below: (1) in addition to the x-ray films and mouth-open films, thin layer CT scanning and 3-dimensional reconstruction is especially critical for ascertaining the entry points, direction, diameter, and length of screws before surgery. (2) Given that cortical bone covers the posterior arch of atlas and vertebral lamina of the axis, the high-speed burr is suggested to mark a drill point before obtaining the pilot trajectory. Then, the pilot hole was prepared by drilling, and after blunt probe verifies the integrity of the hole, screws are inserted subsequently. (3) The deliberate exposure of C2 nerve root and paravertebral venous plexus is unnecessary; the purpose is to locate the interior of the

posterior arch of atlas and lateral mass of axis. (4) The posterior arch of atlas and lamina of axis, with the side of the cancellous bone down, should be decorticated with high-speed burr carefully before grafting. The autologous iliac bone is suggested as a bone graft material, which requires an appropriate shape and fixation with titanium cable. (5) The maximal safe diameter and length of screws should be pursued to obtain the best effect of internal fixation. (6) This technique cannot be applied to the narrow C1 posterior arch at the vertebral artery measuring <3.5 mm and “high-riding” vertebral artery reflected on the preoperative CT scans, and unilateral pedicle screw fixation or other internal fixation methods should be preferred in these cases.

5. Limitations

In the present study, although most screws were inserted accurately, the defect due to lack of sufficient samples persists. The artifacts on postoperative CT scans would also affect the identification of screws misplacement. In addition, randomized controlled trials are a prerequisite for further studies on this technique.

6. Conclusions

In this study, atlantoaxial transpedicular screw fixation under “direct vision” has been performed safely and efficiently. Although cases with a thickness of C1 posterior arch and “high-riding” axis arch is a “restricted zone” for this technique, when armed with sufficient anatomical study of the upper cervical region, careful operation, and proficiency in operation, the C1–C2 fixation technique can be proposed for popularization.

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