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Original Article

Treatment for odontoid fracture with C1 lateral mass and C2 pedicle screws using intraoperative orbic-3-dimensional navigation

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Abstract: *Objective:* To assess the technical advantages of intraoperative orbic-3-dimensional navigation in the treatment of odontoid fractures. *Material and methods:* Twelve male patients with type II or rostral type III odontoid fractures were treated with posterior C1LM-C2P screws fixation using the orbic-3D fluoroscopic navigation. The follow-up period ranged from 12 to 24 months with a mean of 19.2 months. Clinical and radiological follow-up was achieved in all patients. Indexes of patients were recorded, including operation time, complications, VAS and NDI. *Results:* 95.8% screws had no pedicle perforation. There were no postoperative injuries to the vertebral artery, nerve, or spinal cord. At the final follow-up, the healing rate of odontoid fracture was 83.3%. The odontoid fracture in the patient without bone graft achieved union. There was no mobile odontoid nonunion or instability of the C1-C2 articulation. The average NDI score before surgery and at the final follow-up was 75.5 ± 6.88% and 17.5 ± 6.72%, respectively. Patients who achieved odontoid fracture healing was with NDI scores of 17.4 ± 7.36% at the final follow-up (6% to 30%), while two patients of nonunion was with NDI scores of 18.0 ± 2.82% (16% to 30%) Clinical symptoms abated significantly in all patients. *Conclusion:* Posterior C1LM-C2P screw fixation using intraoperative Orbic-3D navigation should be considered as a treatment option for certain cases with type II or rostral type III odontoid fractures.

Keywords: Odontoid fracture, screw fixation, 3-dimensional navigation

Introduction

Odontoid fractures, which account for 10-15% of cervical fractures [1], can lead to serious consequences such as atlantoaxial instability and cervical spinal cord injury [2, 3]. For Anderson-D'Alonzo type I and III odontoid fractures [2], conservative therapy can often achieve a good outcome. However, for type II and rostral type III odontoid fractures, surgery is a better choice, owing to high nonunion rates with external immobilization. In recent years, anterior screw fixation has been used in the management of odontoid fractures. However, for specific types of odontoid fracture, such as a comminuting fracture of odontoid, transverse ligament rupture, or nonreducible fractures, anterior screw fixation remains contraindicated [4, 5]. Posterior technique is preferred when there is any contraindication for anterior fixation [6]. Atlantoaxial fusion by using C1 lateral mass and C2 pedicle (C1LM-C2P) screws was first described by Goel and Laheri in 1994 [10], then further modified and popularized by Harms and Melcher [7] in 2001. At present, posterior C1-C2 fixation with C1LM-C2P screws is an increasingly popular posterior surgical method [7]. In 2013, Yang et al. [8] treated 12 patients with posterior C1LM-C2P screw fixation with conventional C-arm fluoroscopy for atlantoaxial instability. However, this technique with conventional C-arm fluoroscopy has disadvantages, such as the possibility of penetrative, vertebral artery, or spinal cord injury following [8]. Computer-assisted technique was introduced to spine surgery in the 1990s [9]. Many studies have shown that a 3-dimensional navigation system can optimize surgical procedures, enhance the accuracy and safety of implantations, and reduce surgical complications. For

Table 1. Demographics of the patients with odontoid fractures

Case	Age (y)	Sex	Classification and characters of fracture	Clinical sympotems	ASIA Scale	NDI	VAS
1	46	M	Type II Comminuting fracture	Neck pain and motion restricted	E	74%	6
2	47	M	Type II Atlantoaxial instability	Neck pain, torticollis and motion restricted	E	78%	7
3	32	M	Type II Osteosclerosis of proximal fractures	Headache, neck pain and motion restricted	E	82%	7
4	46	M	Type II Delayed fracture (>8 w)	Headache, neck pain and motion restricted	E	78%	6
5	44	M	Type II (IIc) Oblique fracture	Neck pain and motion restricted	E	70%	6
6	35	M	Type II Atlantoaxial instability	Headache, neck pain, torticollis and motion restricted	E	86%	8
7	28	M	Type II Osteosclerosis of proximal fractures	Neck pain and motion restricted	E	60%	5
8	25	M	Type II Comminuting fracture	Headache, neck pain and motion restricted	E	78%	6
9	18	M	Type II Oblique fracture	Neck pain and motion restricted	E	74%	7
10	42	M	Rostral-type III Atlantoaxial instability	Headache, neck pain, torticollis and motion restricted	E	82%	7
11	47	M	Type II Cervicothoracic kyphosis	Neck pain and motion restricted	E	70%	6
12	39	M	Type II Comminuting fracture	Neck pain and motion restricted	E	74%	6

ASIA scale indicates the American Spine Injury Association impairment scale. NDI indicates the neck disability index. NDI = (The sum of each item scores/Total number of items completed × 5) × 100%. VAS indicates Visua Analogue Scale.

example, in 2011, Yang et al. [3] found that using isocentric C-arm 3-dimensional navigation for the treatment of atlantoaxial instability can significantly improve the accuracy of screw placement and decrease intraoperative fluoroscopic time and blood loss. In 2015, Yang et al. [10] also found that using isocentric C-arm 3D navigation can improve accuracy of the C1-C2 transarticular screws. However, to date, there have been few reports on the use of C1LM-C2P screw fixation with the guidance of 3D navigation for the repair of odontoid fractures. The aim of this study was to present a surgical experience of posterior C1LM-C2P screw fixation with Orbic-3D fluoroscopic navigation for repairing odontoid fractures and evaluate the clinical and radiographic outcomes.

Materials and methods

Patients

Twelve male patients with type II or rostral type III odontoid fractures had been hospitalized between September 2012 and February 2014. They were all treated with posterior C1LM-C2P screw fixation using the Orbic-3D fluoroscopic navigation (Siemens Healthcare, Erlangen, Germany). The fractures were defined according to the Anderson-D'Alonzo classification [2]. The characteristics of the odontoid fractures among these 12 patients were shown in **Table 1**: comminuting fractures of odontoid (3 cases), atlantoaxial instability (3 cases), osteosclerosis of proximal fracture (2 cases), fracture line from posteriosuperior to anterioinferior at the base of the dens (2 cases), delayed (>8 weeks) odontoid fracture (1 case) and cervicothoracic kyphosis (1 case). The demographic data and clinical characteristics of the patients were also presented in **Table 1**. The patients presented with different degrees of posterior neck pain, torticollis, and activity limitation. The preoperative neurologic status of the patients was rated E (Normal: motor and sensory functions) according to the American Spine Injury Association (ASIA) impairment scale.

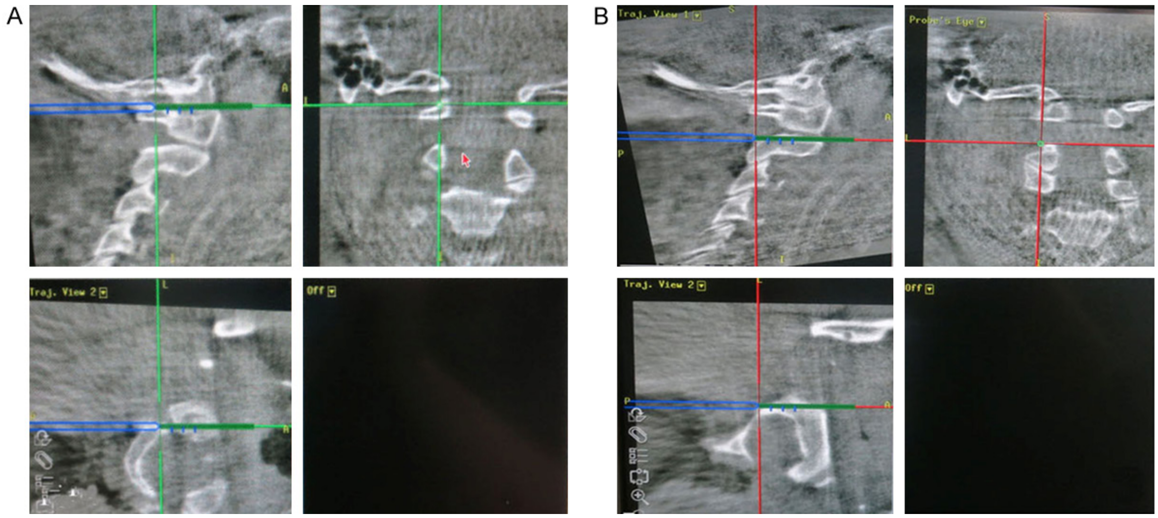

Figure 1. Reconstructed multiplanar images acquired by the Orbic C-arm and used for imaged-guided navigation during C1 lateral mass (A) and C2 pedicle screws (B) placement in the sagittal, coronal, and axial trajectory planes.

Written informed consent was required for participation in the trial.

Preoperative evaluation

Preoperative radiologic evaluation included anteroposterior (AP) and lateral plain radiographs, cervical computed tomography (CT) scans and magnetic resonance imaging scans. All displaced odontoid fracture were reduced by skull traction in each patient preoperatively.

Surgical technique

The operation was performed by a senior spinal surgeon using a standard procedure with the Orbic-3D navigation system. Patients were placed in the prone position with a radiolucent head frame in place.

Patients who underwent general endotracheal anesthesia were injected with 1:500,000 epinephrine solutions for hemostasis. A midline longitudinal skin incision was made from the posterior cranial fossa to the spinous process of C4. The posterior elements were exposed subperiosteally. The posterior arch of C1 was identified at the lateral mass. The vessels and nerve roots of C2 were then pulled cephalad to expose the medial border of the pars interarticularis of C2. The locus of entry points for C1LM-C2P screws was identified.

The image guidance dynamic reference array was then fixed tightly to the spinous process of vertebra C4. Vertebrae C1 and C2 were attuned to the center on the AP and lateral images of the Orbic-3D fluoroscope. During scanning, the C-arm continuously automatically rotated 190°. One hundred images were obtained and transferred to a Stealth Station Treatment Guidance Platform System, where the data was reconstructed to provide real-time multiplanar images [11]. The probe, drill, and tractor of the navigation system were registered so that these instruments could be recognized and tracked by the system. With the help of the navigator and 3D fluoroscopic real-time images, the entry points and directions of the C1LM-C2P screws were determined (**Figure 1**). The optimal trajectories of the screws were determined according to the anatomic structures of the surgical region. A high-speed drill was used to mark the entry points to prevent slippage. Using the imaging data, an insertion hole was prepared at each screw insertion point using a 2.5-mm drill that was calibrated to the 3D navigation system. Throughout the drilling process, the accuracy of the screw trajectory was checked using the tool and a probe. After all the holes were drilled, the accuracy of the trajectories of the screws was confirmed once again by the C-arm scan. Next, two lateral mass screws were placed into C1 lateral masses and two pedicle screws were placed into C2 pedicles along the trajectories. The positions of the screws could be observed immediately in the sagittal (**Figure 2A** and **2B**), axial (**Figure 2C**), and coronal planes (**Figure 2D**) through the

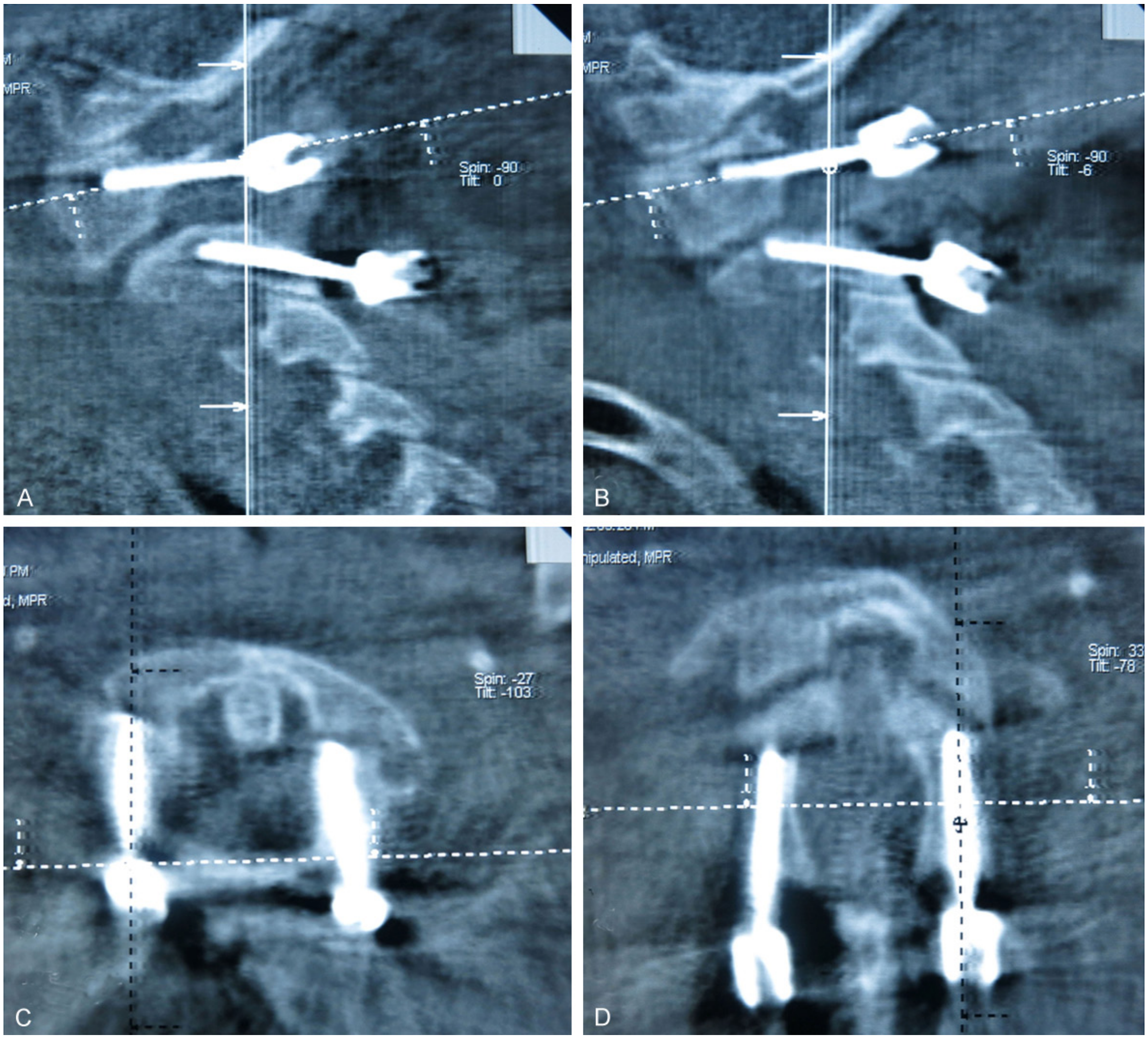

Figure 2. The positions of the screws could be observed immediately through the Orbic C-arm in the operation after the screws inserted (A, B. Sagittal plane; C. Axial plane; D. Coronal plane).

Orbic C-arm. Rods of appropriate lengths were then fixed, and morselized autogenous cancellous iliac grafts were placed on the surface of the posterior arches of both the atlas and axis after grinding the bone surface of the atlanto-axial vertebral arch (**Figure 3**).

The follow-up period ranged from 12 to 24 months with an average follow-up of 19.2 months. Additionally, clinical examination and functional outcomes were assessed at the time of ultimate follow-up.

Postoperative evaluation

Postoperative screw position, fracture union and stability, neurologic status, and long-term functional outcomes were assessed over the follow-up interval.

Cervical CT images were obtained to evaluate the positions of the screws after surgery [8, 12]. At the time of the final follow-up, plain radiographs, flexion-extension dynamic radiographs, and CT scans were used to assess union and stability. Fracture union was defined by the evidence of bone trabeculae crossing the fracture site and the absence of sclerotic borders adjacent to the fracture site [13]. Stability was indicated by the absence of secondary displacement [14]. The C1-C2 fusion was characterized by a bony trabecular bridge between the graft and the adjacent posterior elements on imaging and no motion at the C1-C2 joint complex on flexion-extension radiographs [15, 16].

Neurologic status was assessed by the ASIA impairment scale. The Neck Disability Index

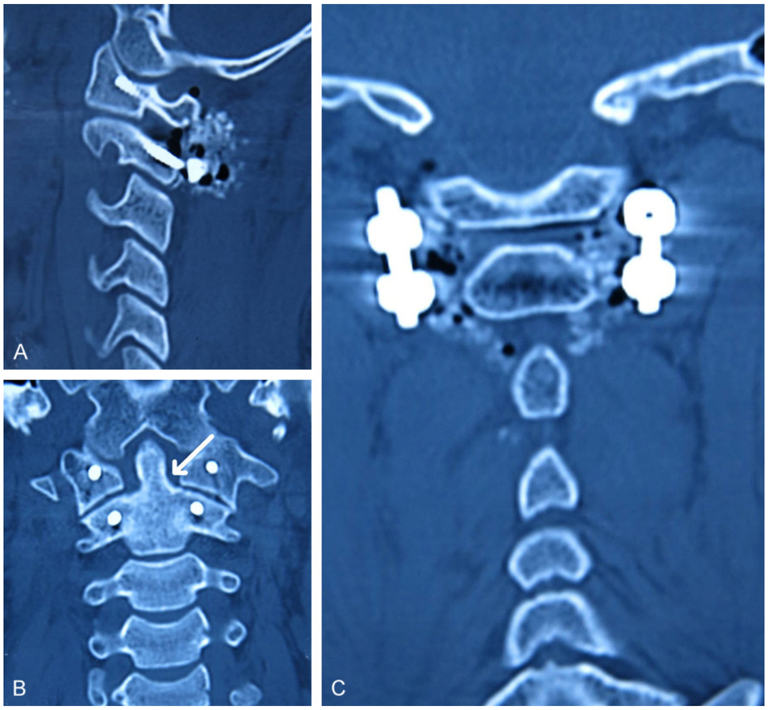

Figure 3. A 35-year-old patient with odontoid fracture combined with atlantoaxial instability was treated with posterior C1LM-C2P screws fixation using Orbic-3D navigation. The postoperative CT images showed the bone trabeculae crossing the fracture site (white arrows) and bony trabecular bridge between the graft and the adjacent posterior elements (A. Sagittal plane; B. Axial plane; C. Coronal plane).

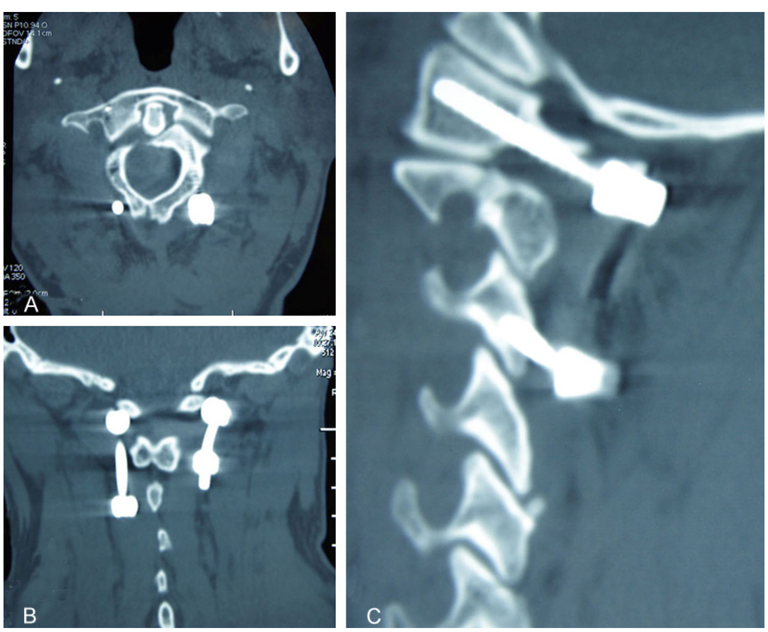

Figure 4. CT scans in axial planes showed that the right C2 pedicle screw was not placed for one patient. The C2 right pedicle of the patient was dysplasia (A), a C3 lateral mass screw was used to replace the C2 pedicle screw for fixation (B, C).

(NDI) [17] and Visual Analog Scale (VAS) were used to evaluate the functional outcomes.

Statistical analysis

Statistical analysis was performed using SPSS 13.0 statistical software (SPSS Inc, Chicago, IL, USA). All data were expressed as mean ± standard deviation. The NDI and VAS scores before and after surgery were compared using Student's *t* test; NDI and VAS between the patients who achieved odontoid fracture healing and those who did not were also compared using the Student's *t* test. For each test, $P \leq 0.05$ was considered significant.

Results

Operative time and complications

One of the patients was not treated with pedicle screw, because during the operation we found that the right pedicle of C2 was dysplastic in this patient (**Figure 4A**). Instead, we used a C3 lateral mass screw to replace the original C2 pedicle screw for fixation (**Figure 4B** and **4C**). Bone grafting was not performed in a young patient (**Figure 5**); the internal implantation would be removed after the fracture healed to aid the recovery of upper cervical rotation.

The mean operative time of C1LM-C2P screw fixation was 117.3 ± 15.5 min (92-146 min), blood loss was 255.8 ± 87.4 mL (110-410 mL) and the fluoroscopic time was 41.2 ± 13.3 s (30-78 s). No procedure-related deaths occurred. There was no vertebral artery, nerve or spinal cord injury (**Table 2**).

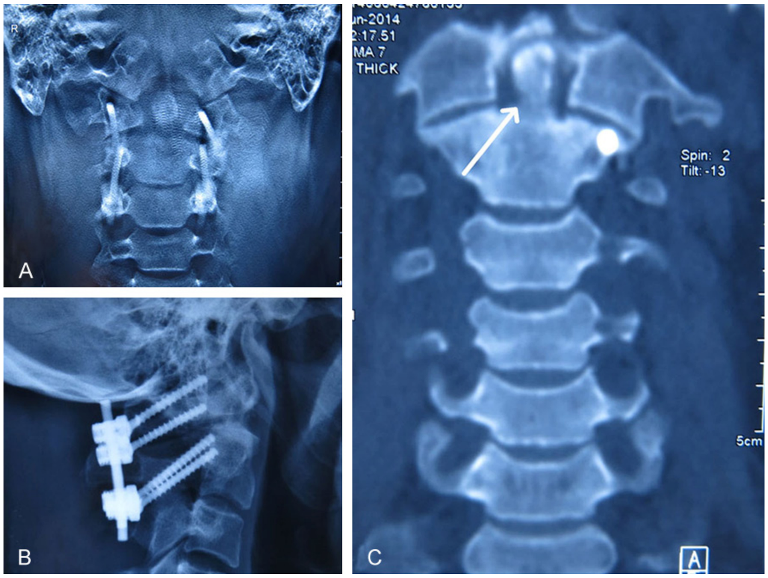

Figure 5. A 18-year-old patient with oblique fracture of odontoid underwent posterior C1LM-C2P screws fixation with Orbic-3D navigation without bone graft. The cervical anteroposterior (AP) and lateral radiographs at ultimate follow-up showed that the odontoid fracture was union (white arrow) (A. Anterior; B. Lateral; C. Posterior).

Table 2. The operative records of the patients

Case	Operative Time (minute)	Blood loss (ml)	Fluoroscopic time (second)	Vessel or spine injury
1	112	220	32	No
2	141	360	48	No
3	146	410	78	No
4	120	370	36	No
5	108	210	33	No
6	126	300	46	No
7	92	110	30	No
8	98	180	32	No
9	112	210	35	No
10	115	230	34	No
11	122	250	48	No
12	116	220	43	No

Radiologic assessment

Positions of screws: In this study, 95.8% (46/48) of the screws placement was graded as 0. One C2 pedicle screw that breached through the pedicle wall (**Figure 6A**) and one C1 lateral mass screw that perforated were classified as grade 1 (**Figure 6B**). However, the stability of the two screws was good, and no new neurologic deficit occurred after surgery.

Odontoid fracture healing and stability: Radiologic evaluation demonstrated that the healing rate of odontoid fracture was 83.3%. Solid union of the odontoid fractures was achieved in 10 of the 12 patients during the follow-up period (**Table 3**). But, two patients with odontoid nonunion did not demonstrate any motion at the fracture site on flexion-extension radiography, and did not develop a spinal cord injury during follow-up. There was no internal fixation rupture or mobility. C1-C2 fusion was observed in 11 of the 12 cases at the final follow-up, except the young patient without the bone graft (**Figure 6**).

Neurologic status: The neurologic status of all patients after surgery and at the time of the last follow-up was E (Normal: motor and sensory functions) according to the ASIA impairment scale (**Table 3**). No patients suffered neurologic impairment.

Functional outcomes

The average NDI score before surgery and at the final follow-up was 75.5 ± 6.88% and 17.5 ± 6.72%, respectively. The neck disability has been greatly improved (**Table 3**). The difference in average NDI scores before and after surgery was statistically significant ($P < 0.001$, *t* test).

Patients who achieved odontoid fracture healing was with NDI scores of 17.4 ± 7.36% at the final follow-up (6% to 30%), while two patients of nonunion was with NDI scores of 18.0 ± 2.82% (16% to 30%) (**Table 3**). The difference in NDI scores between the patients who achieved fracture healing and those with nonunion was not statistically significant ($P = 0.915$).

VAS with a range from 0 (no pain) to 10 (maximal pain) was used to describe the degree of pain. The mean VAS score was 6.4 ± 0.79 (range 5-8) points before surgery and 2.3 ± 0.78 (1-3) points at the last follow-up (**Table 3**). There was a statistically significant difference in VAS scores before and after surgery ($P < 0.001$).

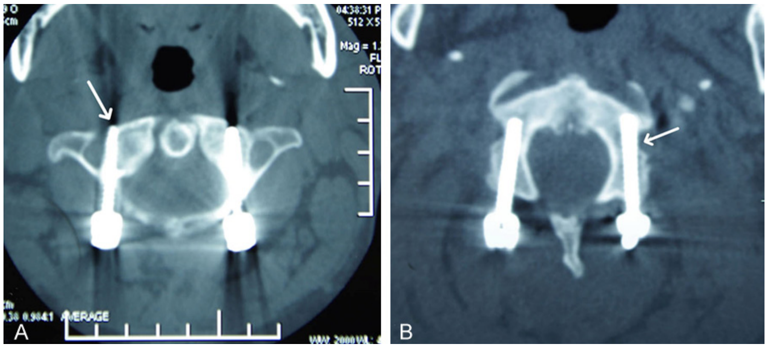

Figure 6. Postoperative CT scans showed the position of the C1 lateral mass and C2 pedicle screws in two different patients. The right C1 lateral mass screw (B) and the left C2 pedicle screw (A) breached out of the cortical wall.

Table 3. Outcomes of the patients with C1LM-C2P screws fixation under Orbic-3D navigation system

Case	Follow-up period	ASIA scale	Internal fixation rupture or mobility	Odontoid union	Atlantoaxial fusion	Final NDI	Final VAS
1	24 M	E	No	Yes	Yes	6%	1
2	24 M	E	No	Yes	Yes	18%	3
3	22 M	E	No	Yes	Yes	14%	2
4	21 M	E	No	No	Yes	16%	2
5	22 M	E	No	Yes	Yes	10%	2
6	24 M	E	No	Yes	Yes	16%	3
7	22 M	E	No	No	Yes	12%	1
8	16 M	E	No	Yes	Yes	22%	3
9	15 M	E	No	Yes	No	20%	3
10	15 M	E	No	Yes	Yes	20%	2
11	14 M	E	No	Yes	Yes	30%	3
12	12 M	E	No	Yes	Yes	26%	3

ASIA scale indicates the American Spine Injury Association impairment scale. NDI indicates the neck disability index. NDI = (The sum of each item scores/Total number of items completed × 5) × 100%. VAS indicates Visua Analogue Scale.

The average VAS score at the time of final follow-up for the patients with odontoid fracture union and those with nonunion was 2.3 ± 0.82 (1-3) and 2.5 ± 0.71 (2-3) points, respectively (**Table 3**). There was no statistically significant difference in VAS scores between the patients who achieved odontoid healing and those who did not ($P = 0.757$).

Discussion

At present, there is no consensus on which treatment is the most efficacious to manage the patients with type II odontoid fractures because of the high nonunion rate for this type of fracture. Various treatment methods ranging from conservative therapy to surgery have been reported [18]. In recent decades, surgical fixation has obtained satisfactory results, which has popularized surgical intervention in the treatment of type II odontoid fractures [19, 20]. Historically, the placement of a pedicle or lateral mass screw was completed with the help of conventional C-arm fluoroscopy for which only 2-dimensional images were available, which was inadequate for screw fixation in the C1-C2 complex. It is difficult to display the C1-C2 complex clearly on AP and lateral views of conventional Carm fluoroscopy, which leads to a high rate of screw breach.

In our study, we used 3D navigation system instead of C-arm fluoroscopy to provide accurate 3D images similar to postoperative CT scans [21]. With the help of the 3D images reconstructed by the navigation system, the surgeon can detect the screw position using the registered probe during the operation. Using detailed mapping of slice planes, a route to insert the screw can be found in transverse section, coronal section as well as vertical section, even in cases where screw insertion appears difficult. During surgery, we can regulate the direction of nails according to the images generated by Navigation System. Compared to the traditional scan methods, the 3D Navigation System significantly reduced the surgical time and radiation time, which are safer and more effective in treatment of patients with odontoid fracture. In a comparative study of cervical pedicle screw insertion using conventional fluoroscopy and the computerized navigation technique, the rate of pedicle wall perforation was significantly lower in the computer-assisted group [22]. A study in 2013 [8] reported 12 patients treated with posterior C1LM-C2P screw fixation with conventional fluoroscopy for atlantoaxial instability.

The mean operative time, mean blood loss, fluoroscopic time, and screw perforation rate were 145.0 ± 6.5 min, 462.5 ± 55.4 mL, 64.0 ± 3,0 s, and 16.7% (8/48), respectively, versus 117.3 ± 15.5 min, 255.8 ± 87.4 mL, 41.2 ± 13.3 s, and 4.2% (2/48) in our present study with the Orbic-3D navigation system. In our study, the C1-C2 articulation was stable in all of the patients despite odontoid nonunion in two of them. Radiographically we did not observe motion at the odontoid fracture site or at the C1-C2 junction. The accuracy of the posterior C1LM-C2P screw fixation procedure was improved with the use of the Orbic-3D navigation system, in addition to substantial relief of clinical symptoms. Moreover, there were no operative complications, the cervical function recovered well, and the clinical symptoms of the patients abated. The navigation system proved to be a useful support device for improving the accuracy and safety of surgical procedures.

However, while focusing on the innovation and improvement in orthopedic surgery brought about by computer navigation technology, we must also take account of their inherent drawbacks [23]: the learning curve of the technology is considerable, and thorough training and practice are needed to master the technology; the images are affected by many factors during the operation and so on. The surgeon should be familiar with the principle and manipulation of the guidance system, and have rich experience in freehand screw insertion, thus to achieve optimum synergy between navigation and freehand screw insertion during the operation and ensure the accuracy of screw placement.

Other limitations should be pointed out. Firstly, in our study, we did not design comparison series that we do not know if the surgical times are longer with navigation. Secondly, the sample size was small and the follow-up period was short. Owing to the limitations of our study, our experience should be confirmed by further studies with larger cohorts and long-term follow-up.

In summary, the treatment of odontoid fractures with C1LM-C2P screws and intraoperative 3D navigation promises to enhance the accuracy and safety of implantation, and significantly improve the surgical efficacy. Future improvement and development of such navigation systems are warranted. Therefore, posterior C1LM-C2P screw fixation with intraoperative Orbic-3D navigation should be considered as a treatment option for some type II and rostral type III odontoid fractures. 3D navigation is an effective support device, and the technique can be safely extended to include technically difficult in pedicle screw insertion.

Disclosure of conflict of interest

None.

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