



Posterior C2 Fixation Using Trans-C2 Inferior Articular Process Screws: A Case Series and Technical Note

Rui Zong¹, Teng Li¹, Lenian Lu², Guangyu Qiao¹, Xinguang Yu¹

■ **OBJECTIVE:** Upper cervical fixation with C2 pedicle screw insertion may predispose patients to vertebral artery injury, in particular, patients with craniovertebral junction anomalies. The aim of this study was to describe an alternative technique with trans-C2 inferior articular process screw (C2IAPS) insertion for rigid C2 fixation, which can be used to anchor the C2 vertebra for upper cervical fixation.

■ **METHODS:** Records of 19 patients who underwent posterior atlantoaxial fixation using C2IAPS combined with C1 lateral mass screw were retrospectively reviewed. Efficacy was assessed by postoperative imaging and Japanese Orthopaedic Association scores.

■ **RESULTS:** There were 22 C2IAPSs successfully implanted (3 on both sides and 16 on 1 side). With the exception of 2 screws that had intruded into the outlet of the intervertebral foramen, all screws were safely implanted. Average Japanese Orthopaedic Association scores improved from 11.8 ± 1.9 preoperatively to 15.3 ± 1.3 postoperatively. Bony fusion rate was 100%.

■ **CONCLUSIONS:** For patients who are not eligible for C2 pedicle screw fixation, C2IAPS fixation can be considered as an alternative technique for upper cervical fixation of C2.

INTRODUCTION

Instability of the upper cervical spine can be surgically treated using various techniques. The C1 lateral mass screw (C1LMS)–C2 pedicle screw (C2PS)–rod technique is one of

the most popular and effective techniques for atlantoaxial fixation.¹ This technique has many advantages, such as short segment involvement, lower screw shearing strength, and longer screw trajectory.² To improve the efficiency of reduction in the horizontal plane, we modified the C1LMS–C2PS–rod technique by developing an instrumental manipulation technique combined with a facet joint release technique to reduce the fixed atlantoaxial dislocation in a single posterior stage.^{3–6} However, application of the C1LMS–C2PS–rod technique is limited because the C2 pedicle in some patients is narrow and cannot accommodate a 3.5-mm screw. In such a situation, C2PS implantation increases the risk of vertebral artery (VA) injury. To anchor the C2 vertebra for upper cervical fixation, an alternative to C2PS implantation is required. This article introduces a salvage technique using a trans-C2 inferior articular process screw (C2IAPS) for anchoring the C2 vertebra in atlantoaxial fixation. In addition, we present a retrospective review of a series of 19 patients who were treated with the C2IAPS technique. The clinical outcomes are presented as preliminary evidence of the outcomes of this new technique.

MATERIALS AND METHODS

Patients

This retrospective study was approved by the Institutional Review Board of PLA General Hospital. Between 2013 and 2016, all patients who underwent posterior atlantoaxial complex stabilization with the C2IAPS technique were considered for inclusion. The indications for surgery included 1) diagnosis of congenital atlantoaxial dislocation; 2) presence of signs and symptoms of spinal cord dysfunction; and 3) narrow C2 pedicle (<4 mm), which was not suitable for implantation of the 3.5-mm screw.⁷ Patients with craniovertebral junction diseases involving neoplasms or

Key words

- Atlantoaxial dislocation
- Atlantoaxial instability
- C1 lateral mass screw
- C2 pedicle screw
- Congenital craniovertebral anomalies
- Trans-C2 inferior articular process screw
- Vertebral artery injury

Abbreviations and Acronyms

- C1LMS:** C1 lateral mass screw
C2IAPS: Trans-C2 inferior articular process screw
C2PS: C2 pedicle screw
CT: Computed tomography
VA: Vertebral artery

From the ¹Department of Neurosurgery, General Hospital of People's Liberation Army, Beijing; and ²Department of Neurosurgery, The First People's Hospital of Shunde, Foshan City, Guangdong Province, China

To whom correspondence should be addressed: Xinguang Yu, M.D., Ph.D.
 [E-mail: xinguang_yu@263.net]

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inflammation and patients who had undergone craniovertebral fixation/posterior decompression previously were excluded from this study. A total of 19 patients were finally recruited. If the patient had a unilateral narrow pedicle, the C2IAPS was inserted on only 1 side. The characteristics of this cohort are summarized in Table 1.

Surgical Technique

All patients were placed in the prone position. The head and cervical spine were maintained in the neutral position using the Sugita head fixation system. Intraoperative electrophysiologic monitoring was performed in all patients. A posterior midline incision was made, and the occipital muscles were dissected under the periosteum to expose the squamous part of the occipital bone, the posterior edge of the foramen magnum, and the posterior arch of the C1 and C2 lamina. In patients with occipitalization of the atlas, the posterior edge of the foramen magnum and

the posterior arch of the atlas were commonly fused. In the next step, the venous plexus around the C2 nerve root was coagulated. The C2 nerve root was then retracted with a small elbow-headed curette to expose the superior and inferior facets and the C2 isthmus. If the C2 nerve root hindered exposure of the posterior C1 lateral mass joint, it was cut to create adequate space for opening the joint. The C1-C2 facet joint capsules were opened, and scars, osteophytes, and the cartilage endplate were curetted and drilled to ensure C1-C2 mobility. The muscles around the spinous process were stripped, and the C2 inferior articular process facet was clearly exposed.

The entry point of the C1LMS was located at the midpoint of the posterior surface of the C1 facet (approximately 1 mm above the inferior facet edge). After a burr was made with a 3.0-mm hand drill, a 3.5-mm polyaxial screw (Vertex; Medtronic, Minneapolis, Minnesota, USA/Beijing Libeier Bio-Engineering Institute Co., Ltd., Beijing, China) was inserted approximately 15° inward and

Table 1. Radiologic Anomalies, Technique, and Clinical Outcomes

Patient	Age (years)/Sex	Associated Radiologic Anomalies	Surgical Technique	JOA Scores		Fusion Status	FU (months)
				Pre-op	Post-op		
1	41/female	OC, KF	C1LMS-C2PS + C2IAPS	13	17	FP	3
2	22/male	OC, KF, Sy	C1LMS-C3PS + C2IAPS	10	15	FP	3
3	29/female	OC, KF	C1LMS-C3PS + C2IAPS	12	16	FP + FIN	4
4	14/male	OC, KF	C1LMS-C2PS + C2IAPS	14	17	FP	3
5	28/male	OC, KF	C1LMS-C2PS + C2IAPS	12	13	FP + FIN	3
6	43/female	OC, CM	C1LMS-C2PS + C2IAPS	11	15	FP	3
7	24/male	OC, KF, Sy	C1LMS + C2IAPS	15	17	FIN	4
8	41/female	OC, KF, Sy, CM	C1LMS + C2IAPS	13	16	FP	3
9	36/female	OC, KF, Sy	C1LMS-C2PS + C2PS + C2IAPS	10	15	FP + FIN	3
10	25/male	OC, Sy	C1LMS-C2PS + C2IAPS	9	14	FP + FIN	6
11	56/female	OC, Sy	C1LMS-C2PS + C2IAPS	14	15	FP	3
12	59/male	OC, Sy, CM	C1LMS-C2PS + C2IAPS	12	15	FP	3
13	33/female	OC + KF	C1LMS-C2PS + C2IAPS	11	15	FP + FIN	3
14	49/male	OC + KF	C1LMS-C2PS + C2IAPS	15	17	FP + FIN	4
15	33/male	Os odontoides, KF	C1LMS-C2ParS + C2IAPS	13	16	FP	3
16	55/female	OC, KF, Sy	C1LMS + C2IAPS	11	15	FP	3
17	44/female	OC, KF	C1LMS-C2PS + C2IAPS	9	12	FIN	3
18	26/male	Platybasia	C1LMS-C2PS + C2IAPS	10	15	FP	3
19	22/male	OC, KF, Sy, CM	C1LMS-C2PS + C2IAPS	11	16	FP	4
Mean	35.8 ± 12.9			11.8 ± 1.9	15.3 ± 1.3*		3.4 ± 0.8

In case 7, 8, and 16, who was with KF, the screw was through the fused C3 inferior articular process on one side, and on the other side the C2IAPS was used. As the aim is to fix the C2, here, the trans-C3 inferior articular process screw is also called C2IAPS.

JOA, Japanese Orthopaedic Association; Pre-op, preoperative; Post-op, postoperative; FU, follow-up; OC, occipitalization; KF, Klippel-Feil syndrome with C2-C3 segmentation defect; C1LMS, C1 lateral mass screw; C2PS, C2 pedicle screw; C2IAPS, trans-C2 inferior articular process screw; FP, bone fusion between the posterior structure of the occiput, C1 and C2; Sy, syringomyelia; C3PS, C3 pedicle screw; FIN, bone fusion between superior and inferior facet of C1-C2 or C2-C3; CM, Chiari malformation; C2ParS, C2 pedicle pars screw.

**P* = 0.000.

15° upward. The screw length was 20 mm on average (range, 18–22 mm).⁶

For fixation of C2, a high-speed drill was used to create a small cortical window at the C2IAPS entry point, which was located at the midpoint of the posterior wall of the C2 inferior articular process. If the C2 was congenitally fused with the C3 vertebra, the entry point was located at the posterior wall of the fused C3 inferior articular process. As the aim was to fix the C2, the trans-C3 inferior articular process screw here is also called C2IAPS. With a hand drill, the inferior articular process was drilled. The trajectory was tilted approximately 45° caudally and 10° laterally so that it was nearly perpendicular to the inferior articular facet joint. As performed in the standard procedure, the C3 superior articular process was penetrated with a quadricortical screw. A ball probe was used to palpate the length of the trajectory. Then a 3.5-mm polyaxial screw

was inserted along the prearranged hole. The average length of the C2IAPS was 14 mm (range, 12–16 mm) (Figure 1).

After insertion of the screws, the head will be drawn to the cephalad, dorsal direction, and extension rotated to readjusted the head position to reduce the atlantoaxial dislocation. The degree of reduction and the position of the screws were examined using C-arm fluoroscopy. Then the right and left C2IAPS and C1LMS were connected ipsilaterally by a 3.5-mm titanium rod. The titanium rod and nuts were gradually fastened. Based on the height difference between the C1 and C2 screws, the horizontal dislocation could be further reduced by moving C2 forward.⁶ Cancellous bone was harvested from the posterior iliac crest and was stuffed into the distracted lateral mass joint space, the decorticated suboccipital and the atlantoaxial complex. A drainage tube was placed, and the wound was closed layer by layer.



Radiographic Evaluation and Follow-Up

All patients underwent reconstructive computed tomography (CT) scan of the cervical spine 2–3 days after the surgery. The patients had outpatient follow-up at 3 months. CT and magnetic resonance imaging examinations were performed at follow-up, and neurologic function was evaluated by Japanese Orthopaedic Association score. Bony fusion was defined by the presence of bridging trabecular bone between the posterior structure of the occiput, C1, and C2 and/or the inner superior or inferior facet of C1–C2 or C2–C3.

Statistical Analysis

All results were expressed as mean \pm SD values. A paired *t* test was performed to compare preoperative and postoperative Japanese Orthopaedic Association scores using SPSS for Windows Version 17.0 (SPSS, Inc., Chicago, Illinois, USA). A *P* value of < 0.05 was considered to indicate statistical significance.

RESULTS

Clinical Outcomes

All screws were inserted without incident, and no technical problems occurred during the procedures. There were no cases of death, VA injury, neurologic deterioration, cerebrospinal fluid leakage, or infection after the surgery. There were 22 C2IAPs (3 on both sides and 16 on 1 side) with 14 C2PSs, 2 C3 pedicle screws, 1 C2 par screw, and 38 C1LMSs carefully inserted. Extubation was delayed in 2 patients because of postoperative dyspnea.

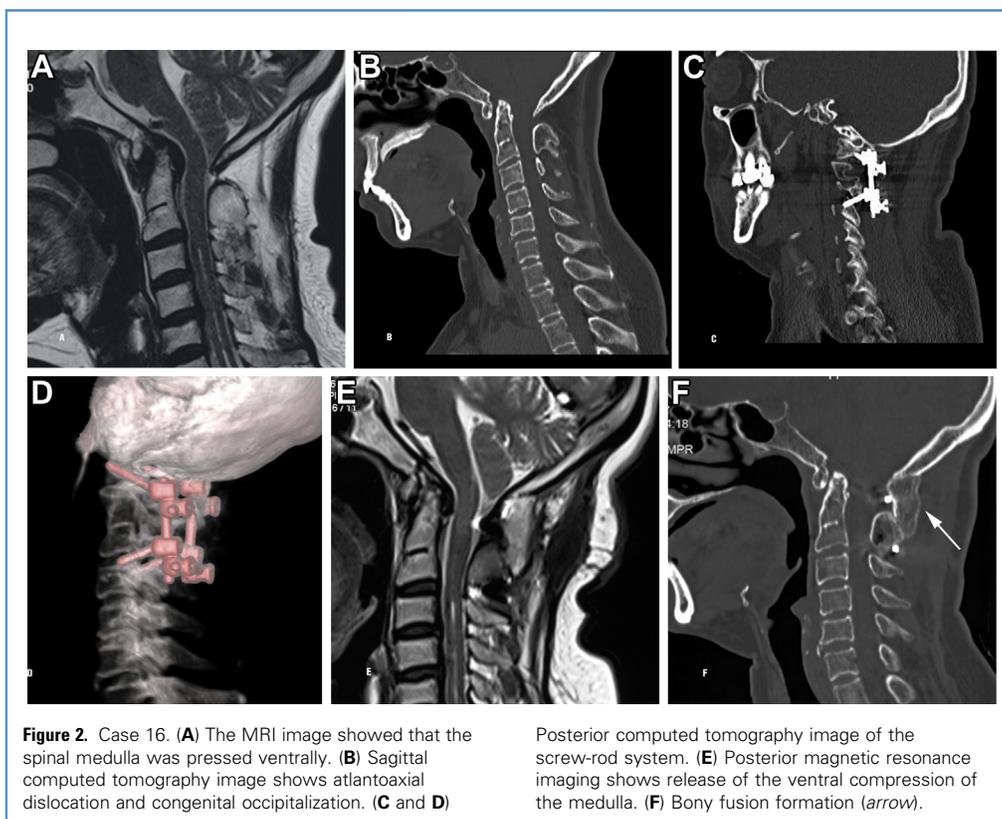
The patients were extubated on the fifth day after surgery, when they had recovered and showed normal cough reflex and swallow function.

Radiographic Assessment

Posterior CT scans obtained immediately after the procedure showed that 20 C2IAPs were accurately implanted. The tips of 2 C2IAPs had slightly protruded into the outlet of the intervertebral foramen (< 1 mm), but this did not cause nerve root neuralgia. Furthermore, with the exception of 1 C2PS that broke the lateral cortex of the pedicle (< 1 mm, without narrowing of the VA), all the other screws were safely and accurately implanted.

Follow-Up Findings

Follow-up duration was 3–6 months (mean \pm SD, 3.4 ± 0.8 months). Mean postoperative Japanese Orthopaedic Association score (3 months after surgery) was 15.3 ± 1.3 , which was significantly higher than the mean preoperative score of 11.8 ± 1.9 ($P = 0.000$). Three-dimensional CT demonstrated that all patients (100%) achieved bony fusion; 15 patients showed bony fusion between the occipital and cervical vertebrae. Moreover, 8 patients showed signs of intra-facet joint bony fusion (Figure 2). Long-term follow-up (mean 50.3 months) was available for 11 patients. Two patients (patients 2 and 4, 4 months and 3 months after upper C1–C2 fusion, respectively) underwent transoral odontoidectomy because of inadequate posterior reduction; 1 patient (patient 13, 4 months after upper cervical fusion) underwent posterior



laminoplasty owing to subaxial cervical degeneration. The other 8 patients showed stable clinical status over long-term follow-up.

DISCUSSION

Limitation of Using C2PS

The C1LMS-C2PS plate fixation technique was first described by Goel and Laheri⁸ in 1994. In 2001, Harm and Melcher⁹ reported the technique of using C1LMS-C2PS with polyaxial screws and rod fixation instruments. Since then, this technique has become popular because immediate significant stiffness and up to a 100% fusion rate can be achieved with this method.^{1,3,4} The C1LMS-C2PS technique can provide perfect biomechanical stability in the flexion/extension, lateral bending, and axial rotation dimensions.^{2,10,11} Compared with occipital-cervical fixation, C1LMS-C2PS fixation has the advantages of short segment involvement, lower screw shearing force, and absence of neural and vascular compromise associated with intracranial intrusion of occipital screws.^{12,13} Furthermore, we have modified this system to achieve direct atlantoaxial reduction by instrument manipulation in a single posterior procedure.³⁻⁶

When the C2 pedicle is narrow, the application of C2PS is limited by the risk of VA injury. Anatomic studies showed that 7%–17.8% of pedicles were unsuitable for the 3.5-mm screw.^{7,14,15} Although there have not been any studies comprising large series of patients with craniovertebral junction malformation, the proportion of narrow C2 pedicles may be higher than in normal patients. Aoyama et al.¹⁶ found that in patients with occipitalization of the atlas, the C2

pedicle was significantly narrower than in the control group (5.21 mm vs. 7.17 mm). Wang et al.¹⁷ reported that in patients with the Klippel-Feil syndrome, the width of the C2 pedicles in 39.6% of patients was <4.5 mm. In addition, in a series of C2-C3 fusion cases, Xiu et al.¹⁸ reported that the diameter of 54.8% of the C2 pedicles was <4 mm. In a study by Moon et al.,¹⁹ 13 of 48 patients (27.1%) in the congenital skeletal anomaly group had a high-riding VA. Thus, the use of 3.5-mm C2PSs in patients with craniovertebral junction malformation may be limited. In cases with a narrow C2 pedicle, an alternative technique is required for anchoring the C2 vertebra (Figure 3).

Alternative Techniques to C2PS

In the setting of congenital C2-C3 fusion, the C3 pedicle screw could be used for fixation of C2-C3 vertebra. Xiu et al.¹⁸ reported a series of 42 cases of C2-C3 fusion in which 81.0% of the C3 pedicles could be fixed with 3.5-mm screws. However, C3 pedicle screw insertion is unsafe without the assistance of navigation, and some patients with C2-C3 fusion have contraindications for C3 pedicle screw fixation.

In 2004, Wright²⁰ reported a new technique involving bilateral C2 laminar cross-screw fixation, which reduces the risk to the VA and provides good biomechanical stability. Later, Matsubara et al.,²¹ Zhou et al.,²² and Meyer et al.²³ presented their experiences with using the C2 laminar screw as an anchor for occipitocervical reconstruction and showed good clinical results. The C2 laminar screw can be used across a broader group of patients than C2PSs: it is estimated that the 3.5-mm screw can

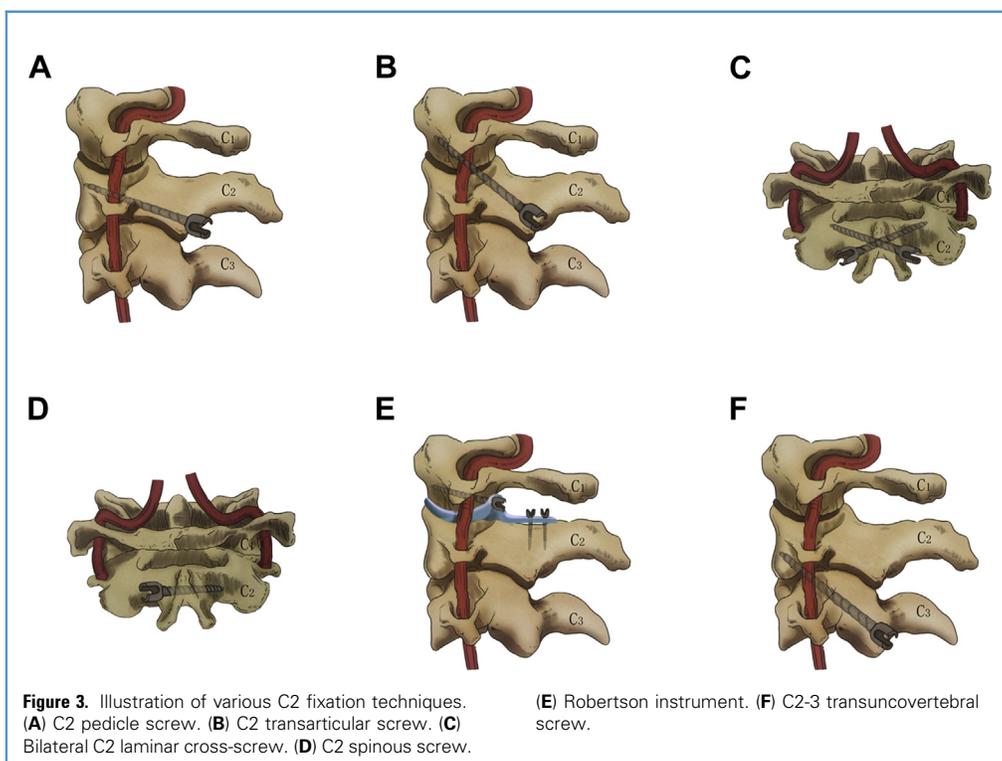


Figure 3. Illustration of various C2 fixation techniques. (A) C2 pedicle screw. (B) C2 transarticular screw. (C) Bilateral C2 laminar cross-screw. (D) C2 spinous screw.

(E) Robertson instrument. (F) C2-3 transuncovertebral screw.

be used in 92.6% of cases of normal cervical segmentation.²⁴ However, a meta-analysis has shown that the bending resistance of the laminar screw is less than that of the transarticular and pedicle screw in the case of atlantoaxial fixation.² Moreover, the titanium rod should be acute bending to connect the laminar fixation points, which will also increase the manipulation difficulty. In addition, it carries the risk of the screw intruding into the spinal canal. Furthermore, in patients with craniovertebral junction anomalies, it is common for the C2 lamina to be too narrow for the 3.5-mm screw.

Some other techniques for anchoring C2 have been reported. For example, Wang et al.²⁵ introduced a fixation method using a thinner C2 pedicle screw (3.0 mm) combined with a cable tied to the C3 spinous process. However, the 3.0-mm screw might be not strong enough to sustain the shearing force that it is subject to, as was evident in a case of screw abruption reported by Wang et al.²⁵ In another study, Robertson et al.²⁶ designed a novel device that integrated an intra-articular blade inserted into the lateral mass joint with an oblique posterior blade that allowed the screw to be fixed to the C2 lamina. Biomechanical analysis showed that this instrument has similar stability to the C1-C2 screw rod instrument. However, as there is no screw cap present that can be used as a “handle,” it may be difficult to manipulate this instrument during the operation. In addition, the shape of this screw plate may not be suitable for fixing bony malformations involving the C2 superior facet either.

Yet another alternative technique was reported by Nagata et al.,²⁷ who reported that a C2 spinous screw can be used for bicortical horizontal reduction. The biomechanical study showed that the spinous process screws provide comparable pullout strength to the C2PS.²⁸ However, clinical reports of this technique are rare, and this screw can be used on only 1 side. According to another alternative method reported by Takigawa et al.,²⁹ a C2-C3 transuncovertebral screw is inserted through the cervical pedicle and the uncovertebral joint via a posterior approach. The trajectory is similar to that of the subaxial cervical pedicle screw, and the cephalad-to-caudal relationship is similar to that of the C1-C2 transarticular screw. The screw penetrates through the C2-C3 uncovertebral joint into the C2 vertebral body in a tricortical fashion, is incorporated with C2, and provides an anchor at C3 for posterior fixation. However, uncovertebral screw placement is technically difficult and may result in VA injury or spinal cord injury. Moreover, navigation guidance is necessary to assist the screw insertion.

Experience of Using C2IAPS

To overcome the drawbacks of the above-mentioned C2 fixation techniques, we developed the C2IAPS technique as an alternative to atlantoaxial immobilization. In the current series, in cases in which the preoperative radiologic evaluation demonstrated that the C2 pedicle was not suitable for the 3.5-mm screw, we used the

C2IAPS to anchor the C2 vertebra. After thorough exposure of the C2 inferior articular process, we inserted the C2IAPS under manual observation. The trajectory was directed outward so that the screw did not intrude into the spinal canal or injure the VA. The procedure is relatively simple and safe. Although the length of the screw is shorter than that of the C2PS, the trajectory of the C2IAPS passes through the C2 inferior articular process and the C3 superior articular process. Therefore, fixation of a quadricortical screw can be achieved, and it would contribute to immediate rigid stabilization and help with bony fusion. Although this series is small, the outcome is satisfactory, as the follow-up results showed a 100% bony fusion rate.

For C2IAPS fixation involving the C2-C3 segment, 1 more cervical segmentation is involved than C2PS fixation required. Considering that the C2-C3 segment contributes little to the entire cervical movement range,³⁰ we presume that the negative impact on cervical movement is limited. This negative influence is acceptable compared with the risk of VA injury. In our cohort, 16 of 19 patients had pedicle pars screw inserted on 1 side and C2IAPS on the other side. Although the C2IAPS was in the opposite direction to the pedicle screw, their entry points were at relatively the same height as C2. We did not find any difficulty in fastening the rods to the screws or any influence on positioning of the rods. However, this mixed instrument may have a complex and uncertain biomechanical characteristic. In this cohort, 2 screws encroached into the outlet of the intervertebral foramen. Therefore, it is essential to access the trajectory preoperatively and carefully explore it during the procedure to prevent any misplacement of the screw into the intervertebral foramen and to avoid nerve root injury.

Study Limitations

This study has 2 limitations. First, we did not obtain any biomechanical data to quantitatively evaluate the strength of C2IAPS and its influence on cervical movement. Further biomechanical research and a large-scale cohort study are necessary to determine the efficacy of this technique. Second, this is a retrospective study with no control group. As the incidence of craniovertebral junction anomalies is low, it is difficult to obtain a control group. However, to overcome these limitations, a future clinical study is required.

CONCLUSIONS

Although C2PS is an effective method for C1-C2 fixation, its application is limited in patients with a narrow C2 pedicle. This article introduces a salvage technique using C2IAPS for anchoring the C2 vertebra in atlantoaxial fixation. The preliminary results show a promising clinical outcome. For patients who are not eligible for C2PS fixation, C2IAPS fixation can be considered as an alternative technique for upper cervical fixation of C2.

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