

Clinical Study

Effects of transverse connector on reduction and fixation of atlantoaxial dislocation and basilar invagination using posterior C1–C2 screw-rod technique

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Abstract

BACKGROUND CONTEXT: The mechanical strength provided by internal fixation is crucial for maintaining reduction and facilitating bony fusion. Though satisfactory results with the C1–C2 technique have been acquired in most clinical reports, the related problems of fusion delay and pseudarthrosis still exist. To increase the chance of bony fusion, a transverse connector (TC) is frequently used to augment torsional stiffness of thoracolumbar screw/rod constructs. Nevertheless, the clinical implication of TC in the management of atlantoaxial dislocation (AAD) and basilar invagination (BI) remains largely unknown.

PURPOSE: To evaluate the effects of TC application on C1–C2 screw-rod constructs based on consecutive adult patients with AAD and BI in a single institution over a 10-year period.

STUDY DESIGN: A retrospective study.

PATIENT SAMPLE: Patients with AAD and BI, who were treated with posterior C1–C2 screw-rod technique with or without TC usage from June 2007 to June 2017 at a single institution.

OUTCOME MEASURES: The radiological measurements included the anterior atlantodental interval (AADI), posterior atlantodental interval (PADI), height of odontoid process above Chamberlain line, and cervicomedullary angle (CMA). Patients' neurologic status was evaluated with the Japanese Orthopaedic Association (JOA) score. Fusion status was evaluated at different follow-up periods.

METHODS: We compared the difference of clinical, radiological, and surgical outcomes between the TC and NTC groups postoperatively.

RESULTS: In total, there were 149 consecutive patients in the TC group and 168 patients in the NTC group. On average, 1.2 TCs per patient were used in the TC group. No significant differences were identified for operative time and blood loss between groups. There was also no statistical difference in the radiological measurements of AADI, PADI, Chamberlain line, and CMA between the TC and NTC groups preoperatively and postoperatively. A significantly higher JOA score was obtained in the TC group than that in the NTC group postoperatively. The fusion rates were higher in the TC group than those in the NTC group at the early stage postoperatively (3 and 6 months; $p < .01$).

CONCLUSIONS: Use of TCs seems to improve bony fusion and neurologic outcomes in the treatment of AAD and BI with C1–C2 screw-rod technique. © 2019 Elsevier Inc. All rights reserved.

Keywords:

Atlantoaxial dislocation; Basilar invagination; Biomechanical stability; Bone fusion; C1–C2 fixation; Craniovertebral junction; Transverse connector

FDA device/drug status: Approved (C1–C2 screw-rods and transverse connectors fixation system (Vertex, Medtronic Sofamor Danek, Minneapolis, MN).

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Introduction

Congenital or developmental bony anomalies at the craniovertebral junction (CVJ) are complex and primarily consist of atlantoaxial dislocation (AAD) and basilar invagination (BI), both of which could give rise to progressive cervicomedullary compression [1–4]. Decompression/reduction, internal fixation, and bony fusion are currently the widely accepted treatments for AAD and BI. The mechanical strength provided by internal fixation is crucial for maintaining reduction and facilitating bony fusion [5]. Over the past three decades, various instrumentation techniques have been developed for CVJ fixation [6]. Among them, the C1 lateral mass combined with C2 pedicle/pars (C1–C2) screw plate-rod technique, first reported by Goel et al. [7] and then populated by Harms et al. [8], has been recognized as the standard technique in a variety of clinical circumstances, including AAD and BI [3,9–13]. Compared with the occipitocervical fixation, the C1–C2 screw-rod technique has the merits of long C1 screw trajectory, small rod shearing force, flexible instrumentation operation, and low intracranial injury risk associated with occipital screws [3,10,14]. Though satisfactory results with the C1–C2 technique have been acquired in most clinical reports, related problems of fusion delay and pseudarthrosis still exist [1,3,15].

Stronger fixation instrumentation has been deemed to benefit earlier bony fusion. To increase the efficiency of bony fusion, transverse connectors (TC) are frequently used to augment torsional stiffness of long-segment thoracolumbar screw/rod construct [16–19]. A biomechanical study by Wahba et al. [20] also shows an obvious rotatory stiffness improvement for short-segment instrumentation by adding TCs. Unlike the subaxial spine, anatomically and biomechanically, the CVJ is inherently rotationally unstable. At the same time, the frequent concomitant torticollis and asymmetrical lateral atlantoaxial joints in CVJ anomalies could expose the instrumentation to chronic rotatory torque post reduction. In such a setting, application of a TC would increase the stability of a C1–C2 screw-rod construct. Nevertheless, the clinical implication of TC in the management of CVJ anomalies remains largely unknown.

Supplementing the C1–C2 screw-rod construct with TC has been regularly performed in our institution since 2012 in the management of AAD and BI. To our knowledge, there is a paucity of clinical reports on such usage. Consequently, no sufficient information exists to determine the effects of supplementing TC on C1–C2 screw-rod construct in the treatment of CVJ anomalies. In this retrospective study, we primarily aim to evaluate the effects of TC application on C1–C2 screw-rod construct based on consecutive adult patients with AAD and BI in a single center over a 10-year period.

Materials and methods

Patients and data collection

After being approved by the institutional ethics committee, we retrospectively reviewed the patients with AAD and

BI who were treated with standalone posterior C1–C2 screw-rod technique in our department between June 2007 and June 2017. This technique had been regularly used in our institute since 2007 when we realized that it was safe and feasible in patients with CVJ anomalies. A thorough morphologic assessment of C1 lateral mass was performed based on reconstructed thin-slice computed tomography (CT) preoperatively, and only the patients with enough dimension of C1 lateral mass for holding the C1 screw (3.5 mm in diameter) were treated with C1–C2 screw-rod technique. Otherwise, the occipitocervical fusion technique would be programmed. Besides, if the abnormal course of vertebral artery or abundance of venous plexus prevented the proper exposure of C1 lateral mass during surgical dissection, the C1–C2 screw-rod technique had also to be modified to occipitocervical fusion.

Only the patients who were followed for more than 12 months were included. Patients were excluded if they had any evidence of tumor, infection, inflammatory diseases, fracture, or surgical history at the CVJ. Patients less than 12 years old were also excluded because of incomplete osteogenesis. Two groups of patients were identified: the TC group in which the posterior instrumentation was reinforced with one or two TCs and the NTC group in which no TC was added to the instrumentation. Each patient's electronic medical record data were reviewed carefully. Data collection included demographics features, clinical presentations, surgery details such as instrumentation technique, estimated blood loss, operative time, and perioperative complications.

Surgical procedures

All patients underwent posterior atlantoaxial facet joint release and C1–C2 screw-rods reduction fixation. The indications for surgery were presence of signs and symptoms of spinal cord dysfunction. The detailed surgical procedure had been described previously by Yin et al. [3,9]. In brief, a posterior midline incision was made to expose the posterior edge of the foramen magnum, the fused C1 lateral mass, C2 lamina, and C2 pars. The C1–C2 joint capsules were opened, and scars, osteophytes, and the cartilage endplate were curetted and drilled to ensure full C1–C2 mobility. After the C1 and C2 screws (18–24 mm; Vertex, Medtronic Sofamor Danek, Minneapolis, MN) were inserted, bilateral rods were placed and gradually fastened by tightening the nut, during which the distraction force drew C1 backward and pushed C2 downward and forward, thus, achieving reduction of the AAD and BI. Then, initiating from 2012, depending on the space available at the surgical site post reduction and fixation, one or two TCs were placed to augment the structural stiffness. At last, morselized cancellous bone harvested from the posterior iliac bone was placed over the decorticated bones. After the surgery, a hard cervical collar was worn for 3 months.

Radiological and neurologic evaluation

All patients underwent thin-slice CT, magnetic resonance imaging (MRI), and dynamic plain radiography examinations before surgery and at discharge. Follow-ups were programmed at 3, 6, and 12 months postoperatively and then according to the individual's radiological and neurologic conditions. During the follow-up, the CT was repeated until confirmation of solid bony fusion and the MRI was repeated every time. Meanwhile, possible instrumentation-related complications such as wound infections, late operative-site pain, implant failure and pseudarthrosis were also recorded. Bony fusion was defined as definite osseous union between the C1/occiput and C2 lamina without any gap on CT scanning. Patients' neurologic status was evaluated by the Japanese Orthopaedic Association (JOA) score before surgery and at the 3-, 6-, and 12-month follow-ups.

All radiological measurements were performed with the preoperative, discharge and 3-month follow-up CT images. The anterior atlantodental interval (AADI) was measured to evaluate the horizontal dislocation of C1 over C2. The posterior atlantodental interval (PADI) was measured to evaluate the space available for the spinal cord. The Chamberlain line was measured on sagittal reconstructed CT scans to evaluate the extent of the basilar invagination. In most cases, the invaginated posterior margin of the foramen magnum was removed to provide adequate space for C1 screw placement. Therefore, the postoperative Chamberlain line was measured on the sagittal reconstructed CT imaging as proposed by Jian et al. [2] to evaluate the vertical dislocation. The cervicomedullary angle (CMA) was measured on the sagittal MRI scans to evaluate the ventral compression of the spinal cord and medulla.

Statistical analysis

Statistical analysis was performed using the SPSS 22.0 software (IBM; Chicago, IL). Differences between the TC and NTC groups were analyzed using the independent samples *t* test for quantitative data, and the Pearson's chi-squared test for categorical data. The paired student *t* test was performed to identify any statistical difference between the pre- and postoperative measurements in each group. A *p* value less than .05 was considered statistically significant.

Results*Clinical and surgical features*

Totally, there were 149 consecutive patients in the TC group and 168 patients in the NTC group. The clinical and surgical characteristics of these cases are summarized in Table 1. Statistically, no significant differences were identified both in sex composition and age distribution between the TC and NTC groups. In respect to the clinical presentations, the two most common presenting symptoms were extremities weakness and paresthesia, following by occiput/neck pain, ataxia and the others in both groups. Except the dyspnea was a little more common in the NTC group ($p=.04$), no other difference was found for the frequencies of symptoms between groups.

No major neurovascular injury occurred during the surgical operation. The mean operative time was slight longer in the TC group (187.2 ± 33.5 mL) than that in the NTC group (181.4 ± 35.3 mL), but the difference made no statistical significance ($p=.14$). There was no statistical difference between the TC (143.9 ± 110.7 mL) and NTC (138.1 ± 108.2 mL)

Table 1
The clinical and surgical characteristics of AAD and BI patients

Characteristic	TC group	NTC group	<i>p</i>
Sex/n (%)			.15
Male	46 (30.9%)	65 (38.7%)	
Female	103 (69.1%)	103 (61.3%)	
Age/y (range)	39.9±13.4 (13–74)	37.4±13.0 (13–73)	.10
Symptom presentation/n (%)			
Extremities weakness	141 (94.6%)	155 (92.3%)	.40
Paresthesia	125 (83.9%)	147 (87.5%)	.36
Occiput/neck pain	73 (49.0%)	94 (56.0%)	.22
Ataxia	59 (39.6%)	65 (38.7%)	.87
Dyspnea	34 (22.8%)	56 (33.3%)	.04
Others	53 (35.6%)	47 (28.0%)	.15
Operative time/min (range)	187.2±33.5 (112–268)	181.4±35.3 (109–264)	.14
Blood loss/ml (range)	143.9±110.7 (50–600)	138.1±108.2 (50–600)	.63
Number of TC usage/n (%)			
One TC	121 (81.2%)	NA	
Two TCs	28 (18.8%)	NA	
Postoperative complications/n (%)			.79
Pulmonary infections	4 (2.7%)	6 (3.6%)	
Deep vein thromboses	3 (2.0%)	3 (1.8%)	
Follow-up/months	28.6±11.8	35.8±13.6	<.01

TC, transverse connector; NTC, no transverse connector; Others, including sphincter disturbance, sleep apnea, hoarseness, bucking; NA, not applicable.

groups for the blood loss as well ($p=.63$). In the TC group, 1 TC was used in 121 patients (81.2%; Fig. 1) and 2 in 28 patients (18.8%; Fig. 2), resulting in the 1.2 TCs per patients on average. After surgery, a total of seven patients (4.7%) in the TC group and nine patients (5.4%) in the NTC group occurred nonsurgical-related complications ($p=.79$). Among them, four and six patients in the TC and NTC groups developed into severe pulmonary infections respectively, all of which were effectively treated with antibiotics. And in each group, deep vein thromboses occurred in three patients, who recovered well after anticoagulation therapy with heparin. In the TC group, the mean follow-up time was 28.6 ± 11.8 months, ranging from 12 to 56 months, which was shorter than that in the NTC group (35.8 ± 13.6 months, ranging from 12 to 63 months; $p<.01$).

Radiological and neurologic evaluation

These results are summarized in Table 2. There was no statistical difference in the radiological measurements of AADI, PADI, Chamberlain line, and CMA between the TC and NTC groups preoperatively. Significant improvements in these parameters were confirmed in both groups postoperatively, but still no significant difference was identified

between groups at the discharge and at the 3-month follow-up. Similarly, no difference was identified between groups with respect to the JOA score preoperatively ($p=.66$). The JOA score reached no statistical difference at 3- and 6-month follow-ups postoperatively, though the p value was in close proximity to .05 at 6 months. However, when turning to the evaluation at 12-month follow-up, a significantly higher JOA score was obtained in the TC group (15.17 ± 1.15) than that in the NTC group (14.36 ± 1.41 ; $p<.01$).

As for the bony fusion assessment, variable results were revealed according to the following duration. The fusion rates were much higher in the TC group than those in the NTC group at the early stage postoperatively (3 and 6 months; both $p<.01$). Though the rate gap between groups was narrowed at the 12-month period, statistical significance still existed, with 100% of fusion was obtained in the TC group and only 96.4% in the NTC group. Finally, six patients (3.6%) in the NTC group eventually got no bony fusion at the subsequent follow-up and the final fusions were achieved with a second operation for cancellous bone grafting. During the full follow-up period, no instances of neurologic deterioration, CSF leak, or hardware failure and other late complications were recognized in both groups.

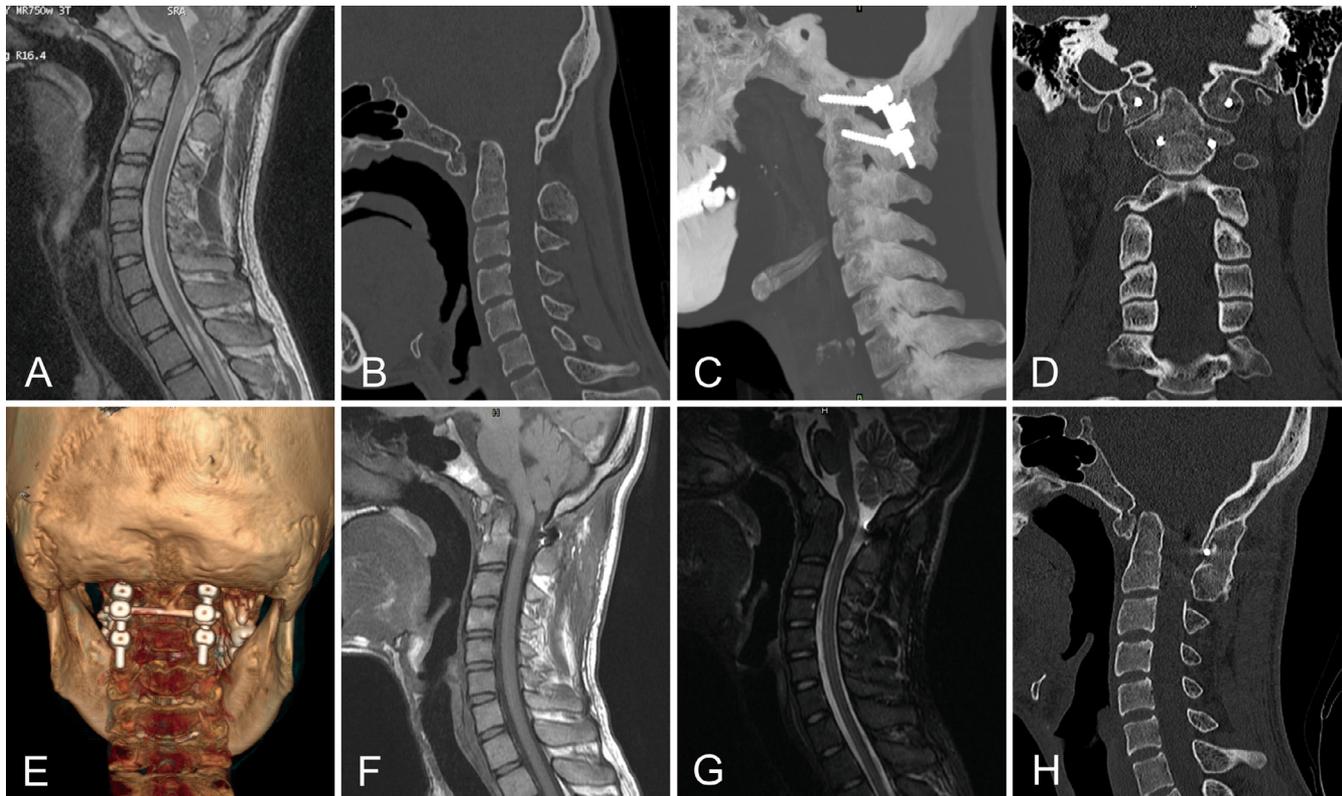


Fig. 1. A 19-year-old male presented with dizziness and progressive quadriparesis. The preoperative magnetic resonance imaging (MRI) showed cervicomedullary compression, Chiari malformation, and syringomyelia (A). The sagittal reconstructed computed tomography (CT) scanning showed severe atlantoaxial dislocation (AAD), basilar invagination (BI), and occipitalization of the atlas (OA) (B). The patient underwent reduction and fixation by the C1–C2 screw-rod technique (C,D). The three-dimensional reconstructed postoperative CT scanning demonstrated the bilateral rods were connected by one TC (E). The postoperative MRI showed the disappeared syringomyelia, regressed tonsils, and alleviated cervicomedullary compression (F,G). Solid bony fusion was confirmed by the formation of continuous cortical bone between the C0/C1 and C2 lamina on CT scanning at the 6-month follow-up (H).

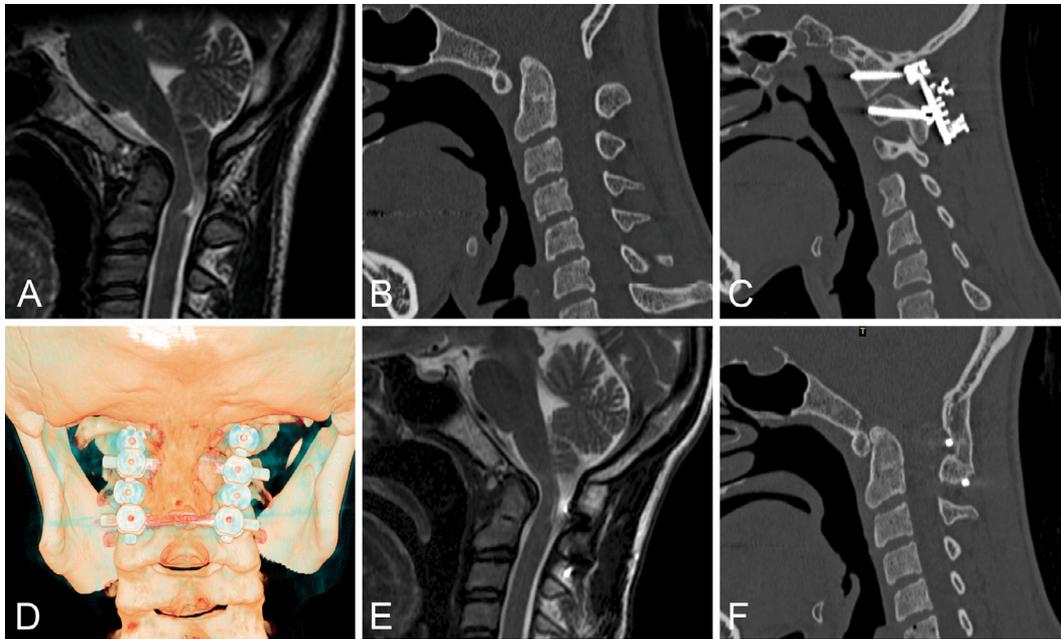


Fig. 2. A 40-year-old female presented with a history of headache and progressive weakness and paresthesia of the upper extremities. The preoperative magnetic resonance imaging (MRI) revealed compression of the cervicomedullary junction and Chiari malformation (A). The preoperative computed tomography (CT) showed occipitalization of the atlas (OA), atlantoaxial dislocation (AAD), and basilar invagination (BI) (B). Reduction and fixation were performed using a posterior C1–C2 screw-rod technique (C). The three-dimensional reconstructed postoperative CT scanning demonstrated the bilateral rods were connected by two TCs (D). At the 1-year follow-up, the MRI showed the retraction of the herniated tonsils and the relief of cervicomedullary compression (E). Solid bony fusion was also confirmed by the CT scanning (F).

Table 2
Comparisons between groups for pre- and postoperative radiological measurements and neurologic assessment

Items	NTC group	TC group	p
AADI/mm			
Before surgery	7.18±2.06	7.29±2.26	.64
At discharge	2.21±1.10	2.17±1.09	.74
3 mo	2.20±1.10	2.18±1.08	.82
PADI/mm			
Before surgery	11.41±2.30	11.53±2.43	.66
At discharge	18.68±2.33	18.66±2.33	.91
3 months	18.74±2.30	18.55±2.29	.48
Chamberlain line/mm			
Before surgery	12.06±2.90	11.96±2.94	.76
At discharge	2.56±1.82	2.52±1.82	.85
3 mo	2.52±1.84	2.49±1.68	.89
CMA/			
Before surgery	116.42±18.19	116.07±18.02	.86
At discharge	150.87±10.78	150.92±10.88	.97
3 mo	150.31±11.00	150.93±10.93	.61
JOA score			
Before surgery	10.92±2.19	11.03±2.22	.66
3 mo	13.27±2.16	13.51±2.14	.32
6 mo	14.00±1.72	14.38±1.70	.05
12 mo	14.36±1.41	15.17±1.15	<.01
Bony fusion/n (%)			
3 mo	23 (13.7%)	48 (32.2%)	<.01
6 mo	110 (65.5%)	129 (86.6%)	<.01
12 mo	162 (96.4%)	149 (100%)	.02
Final follow-up	168 (100%)	149 (100%)	NS

AADI, anterior atlantodental interval; NTC, none transverse connector; TC, transverse connector; PADI, posterior atlantodental interval; CMA, cervicomedullary angle; JOA, Japanese Orthopaedic Association; NS, not significant.

Discussion

To increase the biomechanical stability of instrumentation and achieve solid bony fusion, several novel techniques or modifications have been used for the reinforcement of C1–C2 screw-rod fixation. Harati et al. [21] introduced a technique of combining C1 lateral mass and C1–C2 transarticular screws connected by rod. Although this construct is likely to provide the strongest strength among all existing techniques, it may be confined by the requirement of reducibility of AAD preoperatively, which is not always possible in patients with CVJ anomalies. Tran et al. [22] found that reinforcing the C1–C2 constructs with supplemental posterior wiring could improve the final fusion rate but no significant differences were found. To decrease the risk of vertebral artery injury and increase the biomechanical stability of fixation, Lu et al. [23] extended the C1 lateral mass C2 short pedicle screw-rod construct to the C3 lateral masses. Their results indicated that the angular stiffness at all loading conditions were significantly improved compared with the standard C1–C2 screw-rod technique, but sacrificing the C2–C3 may result in additional motion and stress on the adjacent level.

Transverse connectors (TC) are frequently used to augment long-segment screw-rod construct. Though its efficacy in the thoracolumbar screw-rod system remains controversial in different loading modes, most of the biomechanical data have consistently demonstrated its role in enhancing torsional stiffness [16–20,24]. Different from the thoracolumbar spine, the unique morphology of

atlantoaxial complex provides the highest mobility of the cervical spine which is responsible for 50% of neck rotation [25]. Pathologic instability can result if the atlantoaxial complex is damaged by trauma, congenital defects, or iatrogenic reasons. Stronger fixation instrumentation would intuitively result in a higher chance of solid bony fusion. Adding TCs would potentially further improve the rotational stability of a C1–C2 screw-rod construct. A biomechanical study by Lehman et al. [26] has confirmed that the TC offered increased stability to the C1 lateral mass and C2 intralaminar construct, particularly in the axial rotation and lateral bending mode.

Atlantoaxial fixation using the C1 lateral mass combining with C2 pedicle/pars screw-rods technique is currently the predominant surgical technique in a variety of clinical circumstances, including AAD and BI (Figs. 1 and 2). Biomechanical tests have showed that the C1–C2 screw-rod structure provides improved atlantoaxial stability in contrast to the destabilized condition [27,28], and satisfactory clinical results have been reported with more than 95% fusion rate with this technique [3,7–13]. Considering this, the necessity for further increasing fixation structure stiffness is controversial. Most clinical studies report the fusion rate based on the last follow-up results without analyzing the time span required to achieve fusion. Recently, in a small series of patients, Mizutani et al. [29] found that solid bony fusion occurred earlier with atlantoaxial fixation using TCs than that without. However, the role of TC in the management of AAD and BI remains largely unknown.

As far as we know, this study is the first report of TC application in the management of AAD and BI. We did not find any significant differences in the major pre- and postoperative radiographic measurements of AADI, PADI, Chamberlain line, and CMA between the TC and NTC groups. This finding is similar to the reports that TC usage does not improve the radiological performance in the thoracolumbar spine [30,31]. These findings suggest that the TC does not function in deformity correction. Whereas, when it comes to bony fusion at different follow-up duration, a clear difference was confirmed between groups and the fusion rate was much higher at the early stage postoperatively in the TC group than that in the NTC group.

Many factors can contribute to the fusion delay among which biomechanical instability undoubtedly plays a dominant role [32]. The placement of paralleled rods in a disconnected mode predisposes the constructs to a quadrilateral shift [33]. Due to the high-frequency activities in the CVJ, the fixed atlantoaxial joint would sustain cyclical minimal movements. With TC usage, the rods are actually held together as a solid construct complex and increase the resistance to small, high-frequency motions. In a previous report from our institution [3], three patients (1.8%) had no bony fusion at last follow-up with this technique.

Satisfactory neurologic improvements were achieved postoperatively in both the TC and NTC groups. Despite that preoperative JOA scores and the major radiographic

measurements were not different between groups, interestingly, we still found that a significantly higher JOA score was obtained in the TC group than that in the NTC group at the 12-month follow-up, whereas no statistical difference was identified at 3- and 6-month follow-ups. The JOA scoring system is a semiquantitative evaluation criterion for spinal cord function and is susceptible to many subjective factors [34]. With the fusion delay, the patient undoubtedly would bear psychological burden during the follow-up period, which at least in part contributes to the lower JOA score in the NTC group. Similarly, in a cohort study on TC usage with pedicle screws in adolescent idiopathic scoliosis by Garg et al. [31], mental health domain increased more obviously in the TC group than that in the NTC group at the early postoperative period although it returned equal between groups at the 2-year follow-up. Meanwhile, the fusion delay might make the patients afraid or reluctant to take physical activities and rehabilitation training postoperatively, which altogether resulted in the lower JOA score in the NTC group than that in the TC group at the relative long follow-up period (12 months).

Concerns over increasing structural bulk and operational difficulty may arise when TC is added [35]. Unlike the bulk lumbar vertebra and imbricate thoracic vertebra, the atlas would not pose too much impediment for the placement of TC, especially when the invaginated posterior margin of the foramen magnum/fused atlas was removed in most cases with CVJ anomalies. At the same time, with the morselized cancellous bone being used, ample space was left surrounding the TC(s) without influencing the fusion (Figs. 1 and 2). Attachment of the TCs was placed very easily in all cases during the operation. Although an average 6 more minutes were used by adding the TC, no significant difference between groups was reached. Soft tissue reaction, metal corrosion, late-onset pain, and prominence have also been concerned related to TC usage [36,37]. However, these concerns are low due to the thick suboccipital soft tissue, and we did not have any reports of such complications so far in this series, although further follow-up is necessary.

Increased surgical expense is another concern. The cost for one TC is about 1,000 dollars in our center. On average, 1.2 TCs per patients were used in the TC group, which means roughly 1,200 more dollars were costed for each one averagely with the TC placement. However, based on the findings in the study, the prolonged fusion duration will undoubtedly increase the frequency of radiological examination as well during the follow-up. Obviously, the additional examinations would likewise give rise to an extra expense, and even radiation risk, let alone the concomitant psychological burden. Therefore, the differences in expense would be equivocal when all of the factors are taken as a whole.

This study was subject to selection bias due to the retrospective single-center analysis. Thus, a multicenter, large sample study is required in the future. Moreover, the follow-up period may not be long enough in the TC group to

evaluate the late complications related to TC usage and further follow-up is necessary. Additionally, biomechanical data quantitatively evaluating the strength provided by TC for the C1–C2 screw-rod construct are scant at present. Further biomechanical research is necessary to determine the best assembly concerning the number, location, and pattern of TCs.

Conclusion

TCs are beneficial in improving the clinical efficiency of C1–C2 screw-rod construct. Comparing with the NTC group, the usage in the TC group does not bring about additional operational difficulty and surgical complication at all. Although the TC plays no role in deformity correction, the increased torsional stiffness provided by the TC results in earlier solid bony fusion and better neurologic performance in the treatment of AAD and BI with C1–C2 screw-rod technique.

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