The importance of atlantoaxial fixation after odontoidectomy

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OBJECTIVE Although anterior odontoidectomy has been widely accepted as a procedure for decompression of the craniovertebral junction (CVJ), postoperative biomechanical instability has not been well addressed. There is a paucity of data on the necessity for and choice of fixation.

METHODS The authors conducted a retrospective review of consecutively treated patients with basilar invagination who underwent anterior odontoidectomy and various types of posterior fixation. Posterior fixation included 1 of 3 kinds of constructs: occipitocervical (OC) fusion with atlantoaxial (AA) fixation, OC fusion without AA fixation, or AA-only (without OC) fixation. On the basis of the use or nonuse of AA fixation, these patients were assigned to either the AA group, in which the posterior fixation surgery involved both the atlas and axis simultaneously, regardless of whether the patient underwent OC fusion, or the non-AA group, in which the OC fusion construct spared the atlas, axis, or both. Clinical outcomes and neurological function were compared. Radiological results at each time point (i.e., before and after odontoidectomy and after fixation) were assessed by calculating the triangular area causing ventral indentation of the brainstem in the CVJ.

RESULTS Data obtained in 14 consecutively treated patients with basilar invagination were analyzed in this series; the mean follow-up time was 5.75 years. The mean age was 53.58 years; there were 7 males and 7 females. The AA and non-AA groups consisted of 7 patients each. The demographic data of both groups were similar. Overall, there was significant improvement in neurological function after the operation ($p = 0.03$), and there were no differences in the postoperative Nurick grades between the 2 groups ($p = 1.00$). According to radiological measurements, significant decompression of the ventral brainstem was achieved stepwise in both groups by anterior odontoidectomy and posterior fixation; the mean ventral triangular area improved from $3.00 \pm 0.86 \text{ cm}^2$ to $2.08 \pm 0.51 \text{ cm}^2$ to $1.68 \pm 0.59 \text{ cm}^2$ (before and after odontoidectomy and after fixation, respectively; $p < 0.05$). The decompression gained by odontoidectomy (i.e., reduction of the ventral triangular area) was similar in the AA and non-AA groups ($0.66 \pm 0.42 \text{ cm}^2$ vs $1.17 \pm 1.42 \text{ cm}^2$, respectively; $p = 0.38$). However, the decompression achieved by posterior fixation was significantly greater in the AA group than in the non-AA group ($0.64 \pm 0.39 \text{ cm}^2$ vs $0.17 \pm 0.16 \text{ cm}^2$, respectively; $p = 0.01$).

CONCLUSIONS Anterior odontoidectomy alone provides significant decompression at the CVJ. Adjuvant posterior fixation further enhances the extent of decompression after the odontoidectomy. Moreover, posterior fixation that involves AA fixation yields significantly more decompression of the ventral brainstem than OC fusion that spares AA fixation.

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KEY WORDS atlantoaxial fixation; odontoidectomy; occipitocervical fixation; craniovertebral junction; cervical

ANTERIOR odontoidectomy has been widely accepted as the surgical approach for decompression at the craniovertebral junction (CVJ).^{6–8,21,23,36,38,39,42–45} Several reports have demonstrated the clinical effectiveness of combined posterior fixation and odontoidectomy in

the management of basilar invagination (BI).^{2,3,5,9,10,14,20,23,29–32,34} A spectrum of anomalies of the CVJ, including os odontoides, platybasia, clival hypoplasia, and atlanto-occipital hypoplasia, can cause various degrees of ventral compression at the brainstem and malalignment of the

ABBREVIATIONS AA = atlantoaxial; BI = basilar invagination; CVJ = craniovertebral junction; OC = occipitocervical.

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CVJ.^{14,15,18,22,24,28–34,40} These deformities might require both anterior decompression and posterior fixation to achieve adequate correction.^{12,44–46} Despite the innovation of various routes for odontoidectomy (e.g., transnasal, transoral, transcervical, and combined), there is a paucity of data addressing biomechanical instability after odontoidectomy. The best timing and choices of and the necessity for occipitocervical (OC) or atlantoaxial (AA) fusion after odontoidectomy are still not clear.

In this study, we analyzed images of a series of patient preoperation, postodontoidectomy, and postfixation CT or MR images. To our knowledge, this is the first study aimed at evaluating the effectiveness of odontoidectomy and fixation.

Methods

In this retrospective study, we reviewed the clinical and radiological data obtained in a series of consecutively treated adult patients with BI who underwent anterior odontoidectomy and posterior fixation. The anterior odontoidectomies were achieved via the standard transoral or endoscopic transnasal approach. The posterior fixations were composed of an OC or AA fusion construct. The indication for surgery was progressive quadriparesis or other myelopathy symptoms caused by ventral compression at the CVJ.

Perioperative Management and Operative Techniques

Halo traction was routinely performed for every patient before the operation. The entire traction process was done in an intensive care unit. Fluoroscopy/lateral radiography was performed after traction for the evaluation of stability and alignment at the CVJ. In general, the traction force was initiated from a weight of 3 lbs and increased gradually to a maximum of 12 lbs. Adjustment of the direction of traction was made to optimize alignment and reduce the displaced bony structures at the CVJ before the operation. If the reduction result from the halo traction was limited and the ventral compression was still prominent, as was the case in our series of patients, the treatment was carried on to the next step (i.e., 2-phased surgery).

The 2-phased surgical management involved anterior odontoidectomy and posterior fixation. The interval between these 2 approaches was approximately 3–7 days. For anterior odontoidectomy, the patient was placed supine after the induction of general anesthesia with either halo-ring traction or halo-vest immobilization. The odontoidectomy was achieved via the endoscopic transnasal or transoral approach with fluoroscopy and navigation guidance. The choice of surgical approach was tailored to each person's anatomical features seen on the preoperative MR images. The palatine line was adopted to differentiate the location of BI as high, intermediate, or low,¹³ and either the transnasal or transoral route was chosen. Detailed surgical procedures were described previously by us.^{44,45} After the first operation (i.e., anterior odontoidectomy), the patient was sent back to the intensive care unit. Subsequent radiographs and postoperative CT scans were obtained before the second operation to confirm the degree of decompression and to plan for the posterior fixation surgery.

Within 1 week, each patient was taken back to the operating room for the second-stage surgery (i.e., posterior fixation). Patients without evident deformity at the CVJ after odontoidectomy underwent AA fixation; for those with evident deformity, OC fixation was performed for further distraction and correction of the anomaly at the CVJ. After the fixation surgery, the halo vest was removed in the operating room and substituted with a Miami collar for postoperative support.

Follow-Up Evaluations

Standard anteroposterior, lateral, and open-mouth radiographs were obtained before the anterior odontoidectomy, between the odontoidectomy and posterior fixation, after the posterior fixation, and at the 3-, 6-, 12-, and 24-month follow-up visits. Multidetector thin-section coronal and sagittal CT reconstructions were also performed before the anterior odontoidectomy, between the odontoidectomy and posterior fixation, immediately after the posterior fixation, and 12 months after surgery. Furthermore, MRI was performed before the operation and 6 months afterward. Additional radiological follow-up was arranged at clinical visits annually. Clinical outcomes were assessed by using the Nurick grade.³⁷ Preoperative and postoperative assessments were undertaken by the treating neurosurgeons at the clinical visits.

Triangular Area at the Ventral CVJ

In the sagittal plane images of each patient, a triangular area ventral to the brainstem was delineated (Fig. 1). The 3 points of this triangle were defined by the lowest point of the clivus, the posterior-inferior point of the C-2 vertebral body (axis), and the most dorsal indentation point in the ventral aspect of the brainstem (e.g., pannus formation [rheumatoid arthritis], os odontoides, and the most cephalad-dorsal point [BI]).

The area of this triangle was measured and analyzed at each stage (i.e., before and after odontoidectomy and after

FIG. 1. Proposed assessment of ventral compression at the CVJ by using a simulated triangle. The 3 points of the triangle are the lowest point of the clivus (C), the posterior-inferior point of the axial vertebral body (E), and the most indenting point of the pathology (D). The triangular area can be calculated as follows: $(a \times b)/2$. After 2 operations (i.e., odontoidectomy and posterior fixation), the postoperative triangle area (B) was smaller than the preoperative triangular area (A).

fixation), as illustrated in Fig. 1. Measurements were completed by using quantitative analyzing software (Smart-Iris, Taiwan Electronic Data Processing Co.).

Statistical Analysis

Independent t-tests and paired t-tests were used to analyze continuous variables with Excel (Microsoft) software. A p value of 0.05 was considered statistically significant. In the text and tables, mean values are presented $\pm$ SD.

Results

Demographics and Clinical Evaluations

Between September 2004 and April 2013, 14 consecutively treated patients with BI who underwent anterior odontoidectomy with posterior fixation were enrolled for this analysis. The mean follow-up period for the series was 5.75 ± 2.70 years. There were 7 female and 7 male patients. Their mean age at the time of surgery was 53.38 ± 14.28 years. The etiologies of BI included rheumatoid arthritis ($n = 6$), chronic odontoid fractures ($n = 4$), os odontoidum ($n = 3$), and seronegative spondyloarthropathy ($n = 1$). Concomitant congenital anomalies included platybasia ($n = 2$) and atlantooccipital hypoplasia ($n = 6$). The mean preoperative Nurick grade was 4.07 ± 1.20 , which improved to 3.00 ± 1.30 after the operations. The average improvement expressed by the Nurick grade was 1.07 (Table 1).

Among the 14 patients, 1 underwent transoral odontoidectomy, whereas the others underwent transnasal odontoidectomy for anterior decompression at the CVJ. Each of the 14 patients underwent subsequent posterior fixation, including OC (10) or AA (4) fixation. There was no definite deformity at the CVJ in the 4 patients whose fixation was confined to the C1–2 junction (Table 1, AA-only fixation without OC fusion). The other 10 patients underwent OC fixation surgery, among whom 3 had a fixation construct that involved both the axis and atlas (Table 1, OC fusion with AA fixation [OC+AA]); the axis, atlas, or both were omitted for the remaining 7 patients (Table 1, OC fusion without AA fixation [OC-AA]) for various reasons.

The mean triangular area (calculation demonstrated in

Fig. 1) before surgery was 3.00 ± 0.86 cm². After anterior odontoidectomy, the average triangular area decreased to 2.08 ± 0.51 cm² ($p = 0.002$, compared with the preoperative value) and decreased further to 1.68 ± 0.59 cm² after the stage-2 posterior fixation surgery ($p = 0.00007$, compared with the preoperative value, as illustrated in Fig. 2). The mean reduction in this triangular area (i.e., decompression gained by anterior odontoidectomy) was 0.92 ± 1.04 cm², and 0.40 ± 1.04 cm² was gained by posterior fixation surgery.

AA Versus Non-AA Fixation

Based on the segments involved in the posterior fixation surgeries, the 14 patients were assigned to 1 of 2 groups; the AA group consisted of 7 patients who underwent fixation that involved both the axis and atlas simultaneously, and the non-AA group consisted of the other 7 patients whose fixation surgery spared the axis, atlas, or both (Fig. 3). Thus, there was a 1-to-1 comparison of patients with fixation of the AA joint (i.e., the AA group) with those patients whose fixation excluded the AA joint (i.e., the non-AA group).

The demographic data between the AA and non-AA groups were similar (Table 2). The mean age of patients in the AA group was 55.91 ± 17.57 years, which is similar to that of the non-AA group (51.25 ± 10.96 years; $p = 0.56$). Clinical evaluations suggested that the mean preoperative Nurick grade was 4.14 ± 0.90 in the AA group, which was similar to that in the non-AA group (4.00 ± 1.53 ; $p = 0.83$). After surgery, both groups demonstrated similar improvements in Nurick grades (AA vs non-AA group, 3.00 ± 1.41 vs 3.00 ± 1.29 , respectively; $p = 1.00$); the mean improvement was approximately 1 grade in both groups (1.14 ± 1.07 [AA group] and 1.00 ± 1.15 [non-AA group]; $p = 0.81$). It is worth noting that every patient experienced neurological improvement with or without a change in the Nurick grade.

Radiological assessments of the patients in both groups revealed significant decompression of the brainstem (a decrease of the triangular area at the ventral CVJ). In the AA group, the ventral triangular area improved from 2.8

FIG. 2. Overall changes in the triangular area (in cm²) at different stages of management in this series. Odontoidectomy significantly reduced the ventral triangular area, and posterior fixation enhanced this reduction further.

TABLE 1. Demographic and clinical data

Pt No.	Age, Sex	Preop Mobility	RA	Seronegative Spondyloarthropathy	Os	Chronic Odontoid Fracture	Platybasia	AO Hypoplasia	BI Type	Preop Triangular Area (cm ²)	Reduction of Area by Odontoidectomy*	Type of Fixation†	Pseudarthrosis/Reops	Reduction of Area by Fixation‡	Preop Nurick Grade	Nurick Grade Improvement
1	41, M		+						1	2.33	0.20	OC-AA	-	0.11	4	+1
2	59, M		+					+	1	3.30	2.03	OC-AA	-	0.36	1	0
3	32, M					+		+	1	3.08	0.45	OC-AA	+	0.09	5	+1
4	23, M			+				+	1	3.45	1.04	OC+AA	-	0.56	5	+2
5	51, F	+			+		+	+	2	2.31	0.24	AA only	+	1.36	3	+1
6	54, F		+						1	2.73	0.39	OC-AA	-	0.08	5	+3
7	54, F	+	+				+		2	5.40	4.01	OC-AA	-	0.41	3	0
8	72, F		+					+	1	2.38	1.09	OC+AA	-	0.15	5	+1
9	70, M					+			1	3.31	1.07	OC+AA	-	0.89	5	0
10	65, F					+			1	2.87	0.06	AA only	-	0.68	4	0
11	43, F				+			+	2	3.04	0.61	AA only	-	0.43	3	+1
12	50, F					+			1	3.54	0.99	OC-AA	-	0.14	5	0
13	64, M		+						1	1.82	0.08	OC-AA	-	-0.02	5	+2
14§	64, M				+				1	2.37	0.52	AA only	-	0.39	4	+3

AA only = C1-2 fixation without OC fusion; AO = atlantooccipital; OC-AA = OC fusion without C1-2 fixation; OC+AA = OC fusion with C1-2 fixation; os = os odontoides; Pt = patient; RA = rheumatoid arthritis; + = present.

* Triangular area difference before and after the first operation (i.e., odontoidectomy).

† Demineralized bone matrix mixed with local bone autograft was routinely used in every patient for fusion, and no patient required reoperation as a result of pseudarthrosis.

‡ Triangular area difference before and after the second operation (i.e., posterior fixation).

§ The only patient who underwent transoral odontoidectomy; all others had endoscopic transnasal odontoidectomy.

FIG. 3. A: Postoperative lateral radiograph of a 23-year-old man (from the AA group) who underwent posterior occipitotlantoaxial fixation; this is the same patient shown in Fig. 1. **B:** Postoperative lateral radiograph of a 41-year-old man (from the non-AA group) who underwent posterior fixation in which hardware was placed in the occiput, axis, C-3 vertebra, and C-4 vertebra.

to 2.2 to 1.5 cm² (before and after odontoidectomy and after fixation, respectively; $p < 0.05$). In the non-AA group, the ventral triangular area improved from 3.2 to 2.0 to 1.8 cm² (before and after odontoidectomy and after fixation, respectively; $p < 0.05$). The triangular areas at the ventral CVJ were similar at each stage of management (Table 3).

Both the AA and non-AA groups experienced stepwise decompression of the brainstem as a result of anterior odontoidectomy and then posterior fixation. The mean preoperative triangular areas were 2.82 ± 0.48 cm² in the AA group and 3.17 ± 1.15 cm² in the non-AA group. After anterior odontoidectomy, the triangular areas were 2.16 ± 0.49 and 2.01 ± 0.55 cm², respectively. Both groups had significant reductions after the 2 staged operations compared with preoperative values ($p = 0.02$ [AA group] and 0.03 [non-AA group]). After the 2 staged operations, the areas were 1.52 ± 0.51 cm² in the AA group ($p = 0.003$ compared with the preoperative area) and 1.84 ± 0.66 cm² in the non-AA group ($p = 0.02$ compared with the preoperative area).

Both anterior odontoidectomy and posterior fixation contributed to decompression of the brainstem (reduction of the triangular area at the ventral CVJ). The mean reductions of the triangular area gained by anterior odontoidectomy

were similar in both groups (0.66 ± 0.42 vs 1.17 ± 1.42 cm², respectively; $p > 0.05$). However, the AA group gained more decompression of the brainstem as a result of posterior fixation surgery than the non-AA group (0.64 ± 0.39 vs 0.17 ± 0.16 cm², respectively; $p = 0.0127$). Therefore, patients with AA fixation gained more decompression than the patients of the non-AA group after anterior odontoidectomy (Table 3).

In this study, there were no postoperative hematomas, wound infections, or new-onset neurological deficits. There were no patients in this series who required a permanent feeding tube except 1 patient (7.14%) with preexisting mechanical ventilator dependence. However, despite neurological improvement soon after the operation, 1 patient developed sepsis with multiple organ failure and died on postoperative Day 10.

Subgroup Analysis

The AA group was further broken down into 2 subgroups: the OC-with-AA group and the AA-only (without OC) group. The radiological measurements of all 3 groups, the OC-without-AA, OC-with-AA, and AA-only (without OC) groups, were compared (Table 3). The ventral triangular areas were similar before and after odontoidectomy and after fixation (Table 4).

Patients whose posterior fixation construct involved AA fixation (both the OC-with-AA and AA-only groups) experienced a statistically significant reduction in the triangular area ($p = 0.047$ and 0.015 , respectively) when compared with the patients without AA fixation (the OC without AA group). There were no significant differences between the OC-with-AA and AA-only groups ($p = 0.61$). Therefore, there was further reduction of the ventral triangular area at the CVJ as a result of AA fixation after odontoidectomy. This enhanced decompression was found in patients in the OC-with-AA and AA-only groups (Table 4).

Discussion

In this study, we focused on the clinical implication of AA involvement in posterior fixation surgery after odontoidectomy. We proposed a new measurement for assess-

TABLE 2. Demographic comparisons

Demographic	Pt Group (mean $\pm$ SD)		p Value $\ddagger$
	AA*	Non-AA†	
No. of pts	7	7	
Sex (M/F)	3:4	4:3	
Age (yrs)	55.91 ± 17.57	51.25 ± 10.96	0.56
Radiographic follow-up (yrs)	1.50 ± 2.05	2.96 ± 3.28	0.37
Clinical follow-up (yrs)	5.21 ± 1.96	6.34 ± 3.02	0.45
Preop Nurick grade	4.14 ± 0.90	4.00 ± 1.53	0.83
Postop Nurick grade	3.00 ± 1.41	3.00 ± 1.29	1.00
Nurick grade improvement	1.14 ± 1.07	1.00 ± 1.15	0.81

* Posterior fixation involved AA fixation (both C-1 and C-2), including OC fusion with C1–2 fixation and C1–2 fixation without OC fusion.

† Posterior fixation included OC fusion without AA fixation and involved either C-1 or C-2 only or neither.

‡ Comparison between the AA and non-AA groups.

TABLE 3. Radiographic outcomes

Outcome	Pt Group (mean $\pm$ SD)		p Value (if <0.05)
	AA*	Non-AA†	
Preop area (cm ²)	2.82 $\pm$ 0.48	3.17 $\pm$ 1.15	
Postodontoidectomy area (cm ²)	2.16 $\pm$ 0.49	2.01 $\pm$ 0.55	
Postfixation area (cm ²)	1.52 $\pm$ 0.51	1.84 $\pm$ 0.66	
First reduction (cm ²)‡	0.66 $\pm$ 0.42	1.17 $\pm$ 1.42	
Second reduction (cm ²)§	0.64 $\pm$ 0.39	0.17 $\pm$ 0.16	0.0127

* Posterior fixation involved AA fixation (both C-1 and C-2), including OC fusion with C1–2 fixation and C1–2 fixation without OC fusion.

† The posterior fixation involved either C-1 or C-2 only or neither (OC fusion without AA fixation).

‡ The triangular area difference before and after the first operation (i.e., odontoidectomy).

§ The triangular area difference before and after the second operation (i.e., posterior fixation surgery).

ing ventral compression at the CVJ. By using a simulated triangle (Fig. 1) defined by 3 points—the lowest point of the clivus, the posterior-inferior point of the C-2 vertebral body, and the most dorsal indentation point in the ventral aspect of the brainstem—the compression to the brainstem was quantified. This study retrospectively analyzed 14 consecutive patients with irreducible BI treated by anterior odontoidectomy and subsequent posterior fixation surgery. The patients were assigned to 1 of 2 groups: the AA group, in which the posterior fusion surgery included AA fixation, or the non-AA group, in which the OC fusion surgery skipped AA fixation. A significant decrease of the triangular area at the CVJ, which suggests successful decompression of the brainstem, was found in this series of patients after anterior odontoidectomy and after posterior fixation. The improvements in neurological function and clinical evaluation results also corroborate the effectiveness of the 2-staged operations in an average follow-up period of 5.75 years. Both the AA and non-AA groups experienced similar significant decompression of the brainstem as a result of odontoidectomy. However, significantly more decompression (further reduction of the triangular area at the ventral CVJ) was gained after posterior fixation by the AA group than by the non-AA group (0.64 vs 0.17 cm², respectively; $p = 0.0127$). Therefore, this study demonstrated that adjuvant posterior fixation after odontoidectomy further enhances the extent of decompression, even after successful odontoidectomy. Furthermore, posterior fixation

that involved AA fixation yielded significantly more decompression of the ventral brainstem than OC fusion that spared AA fixation. This is the first report to quantitatively suggest that AA fixation be included in posterior fixation surgery after anterior odontoidectomy.

The biomechanics and anomalies of the CVJ are of great complexity and have been addressed less commonly in the literature. These anomalies can be categorized as congenital or developmental/acquired (i.e., acquired through trauma, infection, or neoplasm).³³ For the optimal treatment options, one should consider the etiology of the pathology, the segmental instability and reducibility, the mechanics of compression, and the direction of encroachment.³¹ Menezes³¹ proposed a treatment algorithm for craniovertebral abnormalities with a primary goal of relieving compression. For reducible lesions, the main purpose of treatment is to stabilize and maintain the proper neural structure. For irreducible lesions, decompression is required at the site at which the encroachment of neural tissue has occurred. The concept of management was straightforward and convincing based on the extensive clinical data published by Menezes et al.^{28–30,32,34,35,41} In our study, all the included patients had irreducible BI, in which case odontoidectomy was necessary, in addition to posterior fixation. The problem was determining which segments of the posterior fixation anchor would yield the most optimal outcome.

Currently, there are no guidelines for posterior fusion

TABLE 4. Radiographic outcomes (subdivision of the AA group in Table 3)

Outcome	OC w/o AA*	OC w/ AA*	AA Only*	p Value (if <0.05)
No. of pts	7	3	4	
Preop area (cm ²)	3.17 $\pm$ 1.15	3.05 $\pm$ 0.58	2.65 $\pm$ 0.37	
Postodontoidectomy area (cm ²)	2.01 $\pm$ 0.55	1.98 $\pm$ 0.61	2.29 $\pm$ 0.43	
Postfixation area (cm ²)	1.84 $\pm$ 0.66	1.44 $\pm$ 0.36	1.57 $\pm$ 0.65	
First reduction (cm ²)†	1.17 $\pm$ 1.42	1.07 $\pm$ 0.03	0.36 $\pm$ 0.25	
Second reduction (cm ²)‡	0.17 $\pm$ 0.16	0.54 $\pm$ 0.37	0.71 $\pm$ 0.44	§

* Values represent the mean $\pm$ SD. OC w/o AA = posterior OC fixation involved either C-1 or C-2 only or neither; OC w/ AA = posterior OC fixation involved both C-1 and C-2; AA only (without OC) = posterior fixation involved C-1 and C-2 only.

† The triangular area difference before and after the first operation (i.e., odontoidectomy).

‡ The triangular area difference before and after the second operation (i.e., posterior fixation surgery).

§ Patients whose posterior fixation construct involved AA fixation, both the OC w/ AA and the AA-only groups, experienced a statistically significant reduction in the triangular area ($p = 0.047$ and 0.015 , respectively) when compared with the patients without AA fixation (the OC w/o AA group). There was no significant difference between the OC w/AA group and the AA-only group ($p = 0.61$).

after odontoidectomy. In 2008, Ahmed et al.¹ reported results of a study of a series of more than 750 pediatric OC fusions with good clinical outcomes. The patients were treated with OC fixation for severe reducible BI, unstable dystopic os odontoideum, unilateral C-1 assimilation, or traumatic OC dislocation or after transoral CVJ decompression. Conversely, Goel¹⁴ reviewed his institutional and personal 25-year experience of BI and proposed a new classification (Types A and B), in which the categorization was based on the relative alignment of the clivus, the axis, and atlas. In his classification, Type A BI indicated that there was a fixed AA dislocation and the tip of the odontoid process invaginated into the foramen magnum, whereas Type B meant that the odontoid process and clivus remained aligned despite the presence of BI. The classifications correlated with the treatment options. The author proposed a posterior fixation surgery for Type A BI, which consisted of wide AA exposure, excision of the AA facet capsule, and distraction in addition to AA fixation with screws and plates.^{15,17–19} For Type B BI, the treatment was foramen magnum decompression. In this theory, no anterior decompression was required, and the clinical outcomes were satisfying. However, perfectly reduced AA dislocation might not always be achievable in regular practice. It was generally agreed that irreducible BI would benefit from anterior decompression followed by posterior fixation. However, the successful clinical experience of Goel et al.^{14–20} suggests that the biomechanics of the AA complex was intriguingly beyond our understanding. Thus, we focused on the effectiveness of involving AA fixation in the posterior fixation and its synergic benefit after anterior odontoidectomy.

The optimal timing of, approach to, and instrumentation for OC fusion were still not clear. Reports have shown that the risk of nonunion obviously increases when the construct of AA fixation is extended to the OC fixation.^{11,26} Although arthrodesis at the CVJ is beneficial for the correction of deformity between the clivus and cervical spine, it inevitably limits the direction of gaze, oropharyngeal musculature, and head motion.^{4,25,27} The patient is usually placed in a prone position during the posterior OC fixation; thus, it is sometimes problematic determining the angle for fusion. An inadvertently aligned OC construct can cause postoperative dysphagia or dyspnea. In other words, OC fusion should be reserved for patients whose deformity in the CVJ requires fixation or in which instability exists, and a thorough preoperative plan is mandatory. However, in clinical practice, there is a lack of standard evaluation for segmental instability of the atlantooccipital joints.

Our study shows that posterior fixation after odontoidectomy provided indirect decompression to the brainstem, and this effect was more prominent in the patients with AA fixation than those who underwent OC fusion without AA fixation. These results suggest the importance of including AA fixation in the fusion construct simultaneously. Although it is reasonable to infer that involving AA fixation provides strong anchoring of the screws and better correction of the deformity that exists in the CVJ, additional studies are needed. For instance, this phenomenon could also be caused by the pooling of those suboptimal OC fixations. Fixation and correction of deformity limited

to the AA complex is definitely more predictable than that performed at the OC complex. The proposed measurement of this series, using the triangular area, might assist in evaluating for and predicting the results of OC fixation. Furthermore, the biomechanics of the AA complex after odontoidectomy has been addressed even less commonly. The results from our series also indicated that AA fixation might not be avoidable. However, this theory requires additional investigation.

There were limitations in this current study. It was a nonrandomized retrospective study of a relatively small sample size. Study of a greater number of patients with OC and AA fixation is required to determine the actual outcomes of fixation after odontoidectomy. Although the AA and non-AA groups in our series were allocated by the surgeons, there was little difference in the demographic data between the 2 groups (Table 2). The results of this study actually merit the proposal that direct measurement of the degree of compression (triangular area in the ventral CVJ) be done by calculating the triangular area differences in the preoperation, postodontoidectomy, and postfixation images (i.e., CT and MRI images). We also specifically analyzed the images obtained between the 2 staged operations to differentiate the effectiveness of anterior decompression and posterior fixation. Furthermore, the triangular area adopted in this current study may have merely measured the mass effect at the CVJ in the sagittal plane, and we might have overlooked rotational and coronal deformity. The measurement was also insufficient for depicting the alignment of the clivus and AA joint complex. We also neglected the causes of skipping AA fixation in the posterior fusion surgery. In some early cases in the series, AA fixation was avoided intentionally because of technical difficulties, anatomical variances, or surgeon preference. Nevertheless, this study provides quantification of the decompression after each stage of the operations.

Conclusions

Anterior odontoidectomy alone provides significant decompression at the CVJ. Adjuvant posterior fixation further enhances the extent of decompression after odontoidectomy. Moreover, posterior fixation that involves AA fixation yields significantly more decompression of the ventral brainstem than OC fusion that spares AA fixation. Although the clinical improvements in neurological function were similar in this study, AA fixation is advocated after anterior odontoidectomy to achieve better outcomes.

References

1. Ahmed R, Traynelis VC, Menezes AH: Fusions at the craniovertebral junction. *Childs Nerv Syst* 24:1209–1224, 2008
2. Anderson RC, Kan P, Gluf WM, Brockmeyer DL: Long-term maintenance of cervical alignment after occipitocervical and atlantoaxial screw fixation in young children. *J Neurosurg* 105 (1 Suppl):55–61, 2006
3. Baaj AA, Vrionis FD: Atlantoaxial stabilization utilizing atlas translaminar fixation. *J Clin Neurosci* 17:1578–1580, 2010
4. Bagley CA, Witham TF, Pindrik JA, Davis RF, Bydon A, Gokaslan ZL, et al: Assuring optimal physiologic craniocervical alignment. *J Neurosurg* 113:100–108, 2010

- vical alignment and avoidance of swallowing-related complications after occipitocervical fusion by preoperative halo vest placement. **J Spinal Disord Tech** 22:170–176, 2009
5. Brockmeyer DL, Apfelbaum RI: A new occipitocervical fusion construct in pediatric patients with occipitocervical instability. Technical note. **J Neurosurg** 90 (2 Suppl):271–275, 1999
 6. Cornelius JF, Kania R, Bostelmann R, Herman P, George B: Transnasal endoscopic odontoidectomy after occipito-cervical fusion during the same operative setting—technical note. **Neurosurg Rev** 34:115–121, 2011
 7. Crockard HA: The transoral approach to the base of the brain and upper cervical cord. **Ann R Coll Surg Engl** 67:321–325, 1985
 8. Crockard HA: Transoral surgery: some lessons learned. **Br J Neurosurg** 9:283–293, 1995
 9. Crockard HA, Calder I, Ransford AO: One-stage transoral decompression and posterior fixation in rheumatoid atlanto-axial subluxation. **J Bone Joint Surg Br** 72:682–685, 1990
 10. Crockard HA, Pozo JL, Ransford AO, Stevens JM, Kendall BE, Essigman WK: Transoral decompression and posterior fusion for rheumatoid atlanto-axial subluxation. **J Bone Joint Surg Br** 68:350–356, 1986
 11. Deutsch H, Haid RW Jr, Rodts GE Jr, Mummaneni PV: Occipitocervical fixation: long-term results. **Spine (Phila Pa 1976)** 30:530–535, 2005
 12. Dickman CA, Kalani MY: Resolution of cervical syringomyelia after transoral odontoidectomy and occipitocervical fusion in a patient with basilar invagination and Type I Chiari malformation. **J Clin Neurosci** 19:1726–1728, 2012
 13. El-Sayed IH, Wu JC, Ames CP, Balamurali G, Mummaneni PV: Combined transnasal and transoral endoscopic approaches to the craniocervical junction. **J Craniocervical Junction** 1:44–48, 2010
 14. Goel A: Basilar invagination, Chiari malformation, syringomyelia: a review. **Neurol India** 57:235–246, 2009
 15. Goel A: Is atlantoaxial instability the cause of Chiari malformation? Outcome analysis of 65 patients treated by atlanto-axial fixation. **J Neurosurg Spine** 22:116–127, 2015
 16. Goel A: Occipitocervical fixation: is it necessary? **J Neurosurg Spine** 13:1–2, 2010
 17. Goel A: Treatment of basilar invagination by atlantoaxial joint distraction and direct lateral mass fixation. **J Neurosurg Spine** 1:281–286, 2004
 18. Goel A, Desai KI, Muzumdar DP: Atlantoaxial fixation using plate and screw method: a report of 160 treated patients. **Neurosurgery** 51:1351–1357, 2002
 19. Goel A, Shah A: Atlantoaxial facet locking: treatment by facet manipulation and fixation. Experience in 14 cases. **J Neurosurg Spine** 14:3–9, 2011
 20. Goel A, Sharma P: Craniocervical junction realignment for the treatment of basilar invagination with syringomyelia: preliminary report of 12 cases. **Neurol Med Chir (Tokyo)** 45:512–518, 2005
 21. Hadley MN, Spetzler RF, Sonntag VK: The transoral approach to the superior cervical spine. A review of 53 cases of extradural cervicomedullary compression. **J Neurosurg** 71:16–23, 1989
 22. Hwang SW, Gressot LV, Chern JJ, Relyea K, Jea A: Complications of occipital screw placement for occipitocervical fusion in children. **J Neurosurg Pediatr** 9:586–593, 2012
 23. Hwang SW, Heilman CB, Riesenburger RI, Kryzanski J: C1–C2 arthrodesis after transoral odontoidectomy and suboccipital craniectomy for ventral brain stem compression in Chiari I patients. **Eur Spine J** 17:1211–1217, 2008
 24. Karam YR, Menezes AH, Traynelis VC: Posterolateral approaches to the craniocervical junction. **Neurosurgery** 66 (3 Suppl):135–140, 2010
 25. Lall R, Patel NJ, Resnick DK: A review of complications associated with craniocervical fusion surgery. **Neurosurgery** 67:1396–1402, 2010
 26. Lu DC, Roeser AC, Mummaneni VP, Mummaneni PV: Nuances of occipitocervical fixation. **Neurosurgery** 66 (3 Suppl):141–146, 2010
 27. Mazur MD, Sivakumar W, Riva-Cambrin J, Jones J, Brockmeyer DL: Avoiding early complications and reoperation during occipitocervical fusion in pediatric patients. **J Neurosurg Pediatr** 14:465–475, 2014
 28. Menezes AH: Clival and craniocervical junction chordomas. **World Neurosurg** 81:690–692, 2014
 29. Menezes AH: Craniocervical junction abnormalities with hindbrain herniation and syringomyelia: regression of syringomyelia after removal of ventral craniocervical junction compression. **J Neurosurg** 116:301–309, 2012
 30. Menezes AH: Craniocervical junction anomalies: diagnosis and management. **Semin Pediatr Neurol** 4:209–223, 1997
 31. Menezes AH: Craniocervical junction database analysis: incidence, classification, presentation, and treatment algorithms. **Childs Nerv Syst** 24:1101–1108, 2008
 32. Menezes AH: Craniocervical junction neoplasms in the pediatric population. **Childs Nerv Syst** 24:1173–1186, 2008
 33. Menezes AH: Editorial on “The craniocervical junction and its abnormalities”. **Childs Nerv Syst** 24:1089–1090, 2008
 34. Menezes AH, Sonntag VK, Wang MY: The management of craniocervical junction disorders. Foreword. **Neurosurgery** 66 (3 Suppl):1, 2010
 35. Menezes AH, Traynelis VC, Gantz BJ: Surgical approaches to the craniocervical junction. **Clin Neurosurg** 41:187–203, 1994
 36. Mummaneni PV, Haid RW: Transoral odontoidectomy. **Neurosurgery** 56:1045–1050, 2005
 37. Nurick S: The pathogenesis of the spinal cord disorder associated with cervical spondylosis. **Brain** 95:87–100, 1972
 38. Patel AJ, Boatey J, Muns J, Bollo RJ, Whitehead WE, Giannoni CM, et al: Endoscopic endonasal odontoidectomy in a child with chronic Type 3 atlantoaxial rotatory fixation: case report and literature review. **Childs Nerv Syst** 28:1971–1975, 2012
 39. Ponce-Gómez JA, Ortega-Porcayo LA, Soriano-Barón HE, Sotomayor-González A, Arriada-Mendicoa N, Gómez-Amador JL, et al: Evolution from microscopic transoral to endoscopic endonasal odontoidectomy. **Neurosurg Focus** 37(4):E15, 2014
 40. Savage JG, Fulkerson DH, Sen AN, Thomas JG, Jea A: Fixation with C-2 laminar screws in occipitocervical or C1–2 constructs in children 5 years of age or younger: a series of 18 patients. **J Neurosurg Pediatr** 14:87–93, 2014
 41. Taggard DA, Menezes AH, Ryken TC: Instability of the craniocervical junction and treatment outcomes in patients with Down's syndrome. **Neurosurg Focus** 6(6):e3, 1999
 42. Tun K, Kaptanoglu E, Cemil B, Karahan ST, Esmer AF, Elhan A: A neurosurgical view of anatomical evaluation of anterior C1–C2 for safer transoral odontoidectomy. **Eur Spine J** 17:853–856, 2008
 43. Wolinsky JP, Sciubba DM, Suk I, Gokaslan ZL: Endoscopic image-guided odontoidectomy for decompression of basilar invagination via a standard anterior cervical approach. Technical note. **J Neurosurg Spine** 6:184–191, 2007
 44. Wu JC, Huang WC, Cheng H, Liang ML, Ho CY, Wong TT, et al: Endoscopic transnasal transclival odontoidectomy: a new approach to decompression: technical case report. **Neurosurgery** 63:ONSE92–ONSE94, 2008
 45. Yen YS, Chang PY, Huang WC, Wu JC, Liang ML, Tu TH, et al: Endoscopic transnasal odontoidectomy without resection of nasal turbinates: clinical outcomes of 13 patients. **J Neurosurg Spine** 21:929–937, 2014
 46. Zileli M, Cagli S: Combined anterior and posterior approach for managing basilar invagination associated with Type I

Chiari malformation. **J Spinal Disord Tech** 15:284–289, 2002

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: JC Wu, PY Chang. Acquisition of data: JC Wu, PY Chang. Analysis and interpretation of data: JC Wu, PY Chang, HK Chang. Drafting the article: JC Wu, PY Chang,

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