Morphometric Measurements of the C1 Lateral Mass with Congenital Occipitalization of the Atlas

Hua-wei Wang, Yi-heng Yin, Ya-zhou Jin, Rui Zong, Teng Li, Xin-guang Yu, Guang-yu Qiao

■ OBJECTIVE: **Unfamiliarity with the morphometry of the assimilated C1 lateral mass (C1LM) could make screw placement dangerous. In the present study, we defined the morphometric dimensions of the occipitalized C1LM to provide surgeons with valuable information for preoperative planning.**

■ METHODS: **Thin-slice computed tomography scanning data from 131 patients with occipitalization of the atlas (OA) and 50 control cases were imported into Mimics software for analysis. The widths and heights of the C1LM were fully measured in the different planes. The ideal inward angulation and the safe maximum cephalic angulation of C1 screw trajectory were evaluated.**

■ RESULTS: **Except for the medial height, all the widths and heights of C1LM were significantly shorter in the OA group than those in the control group. The ideal inward angle (α) was significantly larger in the OA group (23.8° ± 8.3°) than that (15.3° ± 3.8°) in the control group; the corresponding screw length was also significantly longer in the OA group (20.9 ± 2.9 mm). The safe maximum cephalic angles (β) of the screw trajectory did not reach a significant difference between the 2 groups. All the widths and heights were shorter in the females than those in the males. The α angle also did not reach a significant difference between the sexes; however, the β angles in the males (35.9° ± 10.4°) was significantly larger than that in the females (32.0° ± 9.4°).**

■ CONCLUSIONS: **Although the hypoplastic C1LM brings limitations to screw insertion to some extent, it is still broad enough to accommodate a screw safely in both female and male patients. Considering the irregularity of the C1LM in patients with OA, the preoperative imaging assessment is critical, and C1LM screw placement should be performed individually.**

INTRODUCTION

Occipitalization of the atlas (OA) is 1 of the most common skeletal anomalies involving the craniocervical junction (CVJ), with a reported prevalence ranging from 0.08% to 2.76%.[1,2] Clinically, OA is often associated with basilar invagination (BI) and atlantoaxial dislocation (AAD), which are usually considered irreducible using skeletal traction.[3,4] These anomalies can cause progressive cervicomedullary compression and neurological deficits.[3-6] Eventually, surgical intervention will be required.

Key words
- Anatomy
- Atlantoaxial dislocation
- C1 lateral mass
- Computed tomography
- Craniocervical junction
- Occipitalization of the atlas

Abbreviations and Acronyms
AAD: Atlantoaxial dislocation
AADI: Anterior atlantodental interval
AW: Anterior width
BI: Basilar invagination
C1LM: C1 lateral mass
CIA: Coronal inferior C-1 facet angle
CT: Computed tomography
CVJ: Craniocervical junction
MH: Medial height
MW: Medial width
OA: Occipitalization of the atlas
PH: Posterior height
PW: Posterior width
SIA: Sagittal inferior C-1 facet angle
SL: Screw length
VA: Vertebral artery

Department of Neurosurgery, PLA General Hospital, Beijing, China

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

Hua-wei Wang and Yi-heng Yin contributed equally to this work.

Citation: World Neurosurg. (2019) 121:e1-e7.
https://doi.org/10.1016/j.wneu.2018.08.016

*Journal homepage: **www.journals.elsevier.com/world-neurosurgery***

*Available online: **www.sciencedirect.com***

1878-8750/$ - see front matter

Various surgical techniques for AAD and BI have been described. Among them, C1-C2 screw–rod instrumentation has obtained promising biomechanical and clinical effects.[7,8] Even in patients with OA, Goel et al.[9,10] have achieved satisfying effect using the C1-C2 plate–screw technique. Recently, both Yin et al.[3,5,11] and Salunke et al.[12] have also attained excellent results in patients with OA using a modified C1-C2 screw–rod technique. However, unfamiliarity with the morphometry of an assimilated C1 lateral mass (C1LM) could make screw placement dangerous. To date, a paucity of data is available pertaining to morphometric measurements of the occipitalized C1LM.

In the present study, using thin-slice computed tomography (CT) scanning data from 131 patients with OA, we have defined the morphometric dimensions of occipitalized C1LM to provide surgeons with valuable information for preoperative planning.

METHODS

Data Collection

We retrospectively reviewed 131 consecutive patients with OA who were treated in our institute from January 2014 to January 2017. Thin-slice (0.625-mm) preoperative CT scanning data were collected and imported into Mimics software, version 15.0 (Materialise, Leuven, Belgium). Patients were excluded if they had any evidence of tumor, infection, inflammatory disease, or fracture or surgical history at the CVJ. Additionally, 50 control patients were randomly chosen from the same review period, for whom cervical CT scanning had been performed for injury screening after a minor head collision but the radiological results had shown no abnormal findings. Electronic medical document and outpatient follow-up records were also reviewed to further confirm that no injury had been present.

Morphometric Measurement

For standardization, 3-dimensional reconstruction was performed subtly and then resliced by defining the Frankfort horizontal plane as the standard axial plane. Based on the 3-dimensional image, the fusion extent was recorded according to the anatomic part of the atlas defined by Gholve et al.[13] Thus, the anterior arch was defined as zone 1, the lateral masses as zone 2, and the posterior arch as zone 3. Other associated anomalies, such as the Klippel-Feil syndrome, BI, and AAD, were also recorded.

To reduce the effects of boundary irregularity on morphometric measurements, the C1LM was divided evenly into 3 parts in axial plane, and the anterior width (AW), medial width (MW), and posterior width (PW) were measured at the centerline of each part (Figure 1A). In the sagittal plane, the anterior height was defined as the vertical distance between the anterior exit canal of the hypoglossal nerve (anterosuperior C1 facet in the control group) and C1 inferior facet. The posterior height (PH) was measured

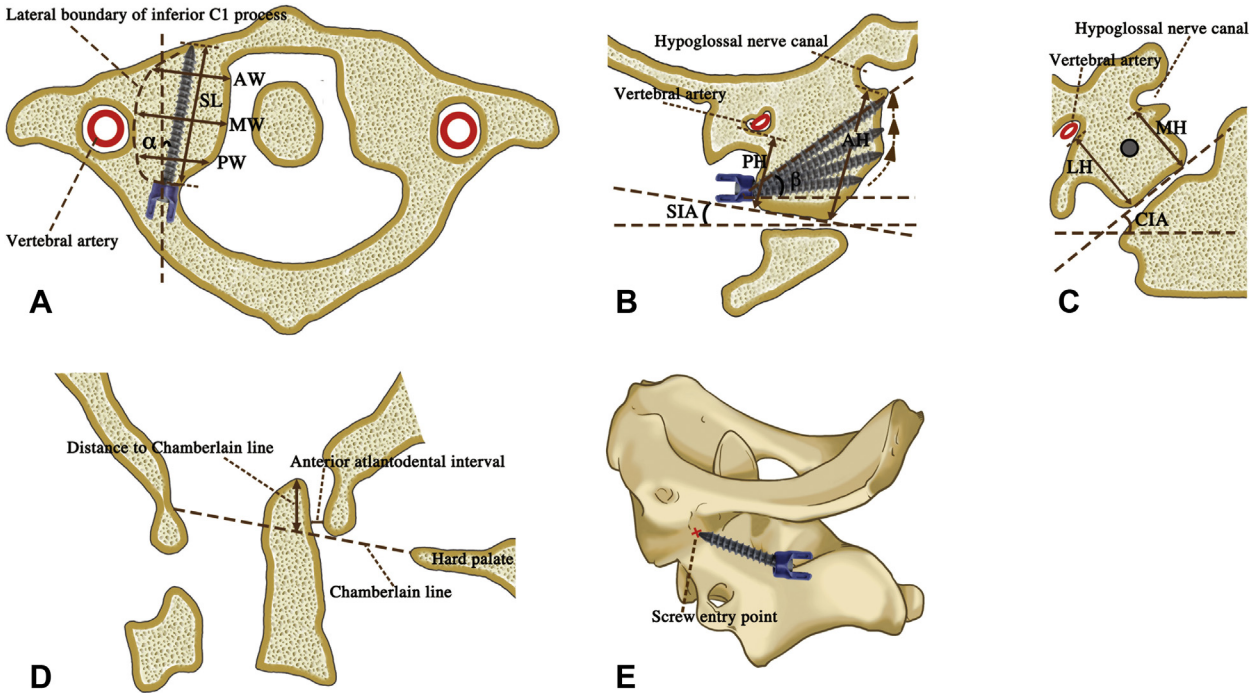

Figure 1. Schematic diagram showing various measurements in a patients with occipitalization of the atlas patient. (**A**) The anterior width (AW), medial width (MW), posterior width (PW), ideal inward angle of the screw (α), and corresponding screw length (SL) were measured in the axial plane. (**B**) The anterior height (AH), posterior height (PH), safe maximum cephalic angle of the screw (β), and sagittal inferior C-1 facet angle (SIA) were evaluated in the sagittal plane. (**C**) The medial height (MH), lateral height (LH), and coronal inferior C-1 facet angle (CIA) were measured in the coronal plane. (**D**) Measurements of the distance to the Chamberlain line and the anterior atlantoaxial interval help in the diagnosis of basilar invasion (BI) and atlantoaxial dislocation (AAD), respectively. (**E**) Three-dimensional image showing the dual screw entry point.

as the vertical distance between the vertebral artery (VA) canal (or groove) and the C1 inferior facet (Figure 1B). Similarly, the medial height (MH) and lateral height were measured in the coronal plane (Figure 1C). In addition, the sagittal inferior C-1 facet angle (SIA) and the coronal inferior C-1 facet angle (CIA) were measured in the sagittal and coronal plane, respectively (Figure 1B, C). Both the SIA and the CIA were formed as a line extending from the C1 facet and a horizontal line. In addition, the anterior atlantodental interval (AADI) and Chamberlain line were used as references for the diagnosis of AAD and BI respectively (Figure 1D).

To further provide surgeons with quantitative information for preoperative planning, a C1 screw insertion was simulated. According to the clinical series reported by Yin et al,[3,5,11] in OA cases, the midpoint of the posterior surface of the C1LM (1 mm above the facet) would be the ideal entry point for the C1 screw (Figure 1E). In contrast, in the control group, the ideal screw entry point was determined by referring to the study by Harms and Melcher.[8] In the axial plane, the ideal screw trajectory was determined to be the line connecting the ideal entry point and the midpoint of the MW, extending to the anterior cortical bone. Next, the inward oblique angle (α) and theoretical screw length (SL) were measured (Figure 1A). To obtain the greatest purchase in the C1LM, the screw must be angled as far cephalically as possible in the sagittal plane. However, to avoid violating the hypoglossal nerve canal (OA case) or the Co-C1 joint (control case), a C1LM screw should $\geq$2 mm below them. In this extreme condition, the safe maximum cephalic angle (β) of screw trajectory were evaluated (Figure 1B).

Statistical Analysis

All the quantitative measurements were performed by 2 operators and then averaged. The data are presented as the mean $\pm$ standard deviation. Because the average value of each measurement parameter was very close between the left and right side, for simplicity, we pooled them for analysis. Statistical analysis was performed using the SPSS, version 17.0, software (IBM Corp., Armonk, New York, USA). An independent sample t test was performed to compare the measurements between the 2 groups and between the sexes. Differences were considered statistically significant at $P < 0.05$.

RESULTS

Clinical Features

The results are summarized in Table 1. The mean age was 44.08 $\pm$ 15.9 years in the control group and 35.14 $\pm$ 11.99 years in the OA group. Of the 131 patients in the OA group, 81 were women and 50 were men. Of the 50 patients in the control group, 30 were women and 20 were men. Although fusion of the C1LM (zone 2) was confirmed in all cases (262 sides), only 87 revealed total fusion (zone 1 plus zone 2 plus zone 3) of the atlas. Zone 2 and zone 3 were fused in 32 cases, zone 1 and zone 2 in 9 cases, and only zone 2 in 3 cases. Klippel-Feil syndrome was confirmed in 33 cases, with C2-C3 fusion in 29, C3-C4 in 2, and C4-C5 fusion in 2. In the OA group, 126 cases were associated with BI and 104 with AAD. Neither BI nor AAD was discovered in the control group.

Table 1. Morphological Evaluation and Concomitant Anomalies in Occipitalization of the Atlas

Variable	Patients (*n*, %)
Sex	
Female	81 (61.4)
Male	50 (38.6)
BI	126 (96.2)
AAD	104 (79.4)
Fusion extent	
Total	87 (66.4)
Anterior arch excluded	32 (24.4)
Posterior arch excluded	9 (6.9)
Only lateral mass	3 (2.3)
K-F syndrome	
C2-C3	29 (22.1)
C3-C4	2 (1.5)
C5-C6	2 (1.5)

BI, basilar invagination; AAD, atlantoaxial dislocation; K-F syndrome, Klippel-Feil syndrome.

Morphometric Measurements

Except for the MH, all the widths and heights of the C1LM were significantly shorter in the OA group than those in the control group (Table 2). However, the values revealed a wide variation for all measurements. Specially, the PW was calculated as 10.7 $\pm$ 1.9 mm (range, 7.2–20.6) in the OA group and 11.4 $\pm$ 1.4 mm (range, 7.6–15.0) in the control group. The PW was not <3.5 mm in either group. The PH was >3.5 mm on 242 sides (92.4%) in the OA group and 100 sides (100%) in the control group. In addition, the CIA and SIA were significantly steeper in the OA group than those in the control group. Screw insertion simulation showed that the ideal inward angle (α) was significantly larger in the OA group (23.8° $\pm$ 8.3°) than that (15.3° $\pm$ 3.8°) in the control group. The corresponding SL was also significantly longer in the OA group (20.9 $\pm$ 2.9 mm) compared with the control group. In the sagittal plane, the safe maximum cephalic angle (β) of screw trajectory did not reach a significant difference between the 2 groups.

A subgroup analysis between the sexes was also performed. All the widths and heights were shorter in the women than those in the men; however, the PH did not reach a statistically significant difference. Both the CIA and SIA showed no differences between the sexes. The α angle also did not reach a significant difference between the sexes; however, the corresponding SL in the men (20.2 $\pm$ 2.8 mm) was significantly longer than that in the women (22.1 $\pm$ 2.8 mm). In addition, the β angles in the men (35.9° $\pm$ 10.4°) were significantly larger than those in the women (32.0° $\pm$ 9.4°).

DISCUSSION

OA, also known as atlanto-occipital fusion, assimilation of the atlas, or occipito-cervical synostosis, represents 1 of the most

Table 2. Comparison of Morphometric Measurements Between Occipitalization of the Atlas and Control Groups and Between Women and Men in Former Group

	Group			OA Group		
Variable	OA	Control	*P* Value	Female	Male	*P* Value
Axial						
AW (mm)	9.6 ± 1.6 (5.7–17.8)	10.9 ± 1.3 (8.0–15.3)	<0.001	9.1 ± 1.3	10.3 ± 1.7	<0.001
MW (mm)	12.7 ± 2.0 (7.7–21.6)	13.1 ± 1.3 (9.9–16.5)	0.019	12.2 ± 1.7	13.5 ± 2.1	<0.001
PW (mm)	10.7 ± 1.9 (7.2–20.6)	11.4 ± 1.4 (7.6–15.0)	<0.001	10.3 ± 1.5	11.3 ± 2.2	<0.001
SL (mm)	20.9 ± 2.9 (12.9–29.2)	18.3 ± 1.6 (13.8–23.7)	<0.001	20.2 ± 2.8	22.1 ± 2.8	<0.001
α Angle (°)	23.8 ± 8.3 (5.4–48.1)	15.3 ± 3.8 (6.9–27.5)	<0.001	24.5 ± 8.5	22.7 ± 7.9	0.09
Sagittal						
AH (mm)	11.6 ± 2.6 (6.5–24.3)	16.7 ± 1.8 (12.2–20.7)	<0.001	11.3 ± 2.3	12.0 ± 3.1	0.045
PH (mm)	5.4 ± 1.8 (1.6–11.6)	9.1 ± 1.1 (6.6–12.7)	<0.001	5.3 ± 1.6	5.6 ± 2.1	0.202
SIA (°)	21.4 ± 16.2 (−28.5 to 58.5)	0.3 ± 7.3 (−13.1 to 17.1)	<0.001	22.3 ± 15.7	20.1 ± 17.1	0.288
β Angle (°)	33.5 ± 9.9 (8.1–67.5)	32.9 ± 6.6 (16.0–44.8)	0.491	32.0 ± 9.4	35.9 ± 10.4	0.002
Coronal						
MH (mm)	12.0 ± 1.9 (7.3–21.7)	11.4 ± 1.7 (7.8–18.6)	0.012	11.7 ± 1.7	12.5 ± 2.1	<0.001
LH (mm)	11.2 ± 2.4 (5.2–22.7)	15.7 ± 2.0 (10.6–20.6)	<0.001	10.9 ± 2.1	11.8 ± 2.7	0.001
CIA (°)	26.0 ± 13.2 (0.1–64.3)	22.4 ± 4.2 (7.1–32.0)	<0.001	26.1 ± 1.1	25.7 ± 13.1	0.825

Data presented as mean ± standard deviation (range).
OA, occipitalization of the atlas; AW, anterior width; MW, medial width; PW, posterior width; SL, screw length; α, inward angle of screw trajectory; AH, anterior height; PH, posterior height; SIA, sagittal inferior C1 facet angle; β, safe maximum cephalic angle of screw trajectory; MH, medial height; LH, lateral height; CIA, coronal inferior C1 facet angle.

common anomalies involving the CVJ. This deformity is caused by failure of segmentation between the fourth occipital sclerotome and the first cervical sclerotome in the embryonic stage.[14,15] Female gender has been reported to be predominant in patients with OA among the Chinese population.[2,3,16] Consistently, females have accounted for 61.38% of cases of OA. The fusion extent of the atlas varies individually. In the present study, although all the C1LMs had fused with the occipital condyles, only 66.41% of the atlases had revealed total fusion with the occipital bone.

Concomitant deformities are very common in patients with OA.[3,17] In the present study, BI and AAD were confirmed in 96.2% and 76.4% of those with OA, respectively, with none in the control group. This could be attributed to the steeper CIAs and SIAs in the patients with OA (mean, 26° and 21.4°, respectively) than those in the controls (mean, 22.4° and 0.3°, respectively). A steeper CIA will result in a greater probability for vertical dislocation (BI).[18] The anteversion of C1 over the C2 facet (steeper SIA) will result in overstress on the transverse ligament, which will progressively result in AAD.[19] In addition, the Klippel-Feil syndrome was very common in the OA group (25.2%), similar to that reported by Gholve et al.[13] (20%) and Goel and Shah[20] (25.89%).

Traditionally, posterior occipitocervical fixation with or without transoral surgery has been generally accepted for the treatment of AAD in patients with OA.[21,22] However, this procedure has several crucial drawbacks. First, in patients with OA, the occipital squama will always be small, thin, and asymptotic,[17] rendering the suboccipital screw purchase insufficient. Second, the misalignment and acute angle between the occipital plate and C2 screw can result in an overshearing force on the instrumentation. A report by Salunke et al.[23] has indicated that AAD can occur after occipito-cervical fusion owing to a cantilever effect.

Recently, reduction and fixation were achieved simultaneously by Yin et al[3,11] using the modified version of the C1-C2 screw–rod technique after thorough posterior facet joint release without transoral odontoidectomy (**Figure 2**). With this technique, all the previously reported drawbacks with occipito-cervical fixation can be overcome. However, the occipitalized C1LM is often considered to be hypoplastic and irregular. Without a full understanding of the occipitalized C1LM, a surgeon could place the VA, hypoglossal nerve, contents of the spinal canal, and, even, the carotid artery at risk during surgery. Therefore, the morphometry of fused C1LM should be familiar to surgeons who specialize in CVJ disorders.

In the present study, we performed a quantitative evaluation of occipitalized C1LMs with 131 patients with OA (262 sides) and compared the measurements between the OA group and control group (50 patients; 100 sides). The results showed that no width (AW, MW, and PW) would bring a substantial impediment to a 3.5-mm screw in either group (no value was <3.5 mm), although all the widths were significantly narrower in the OA group compared with those in the control group.

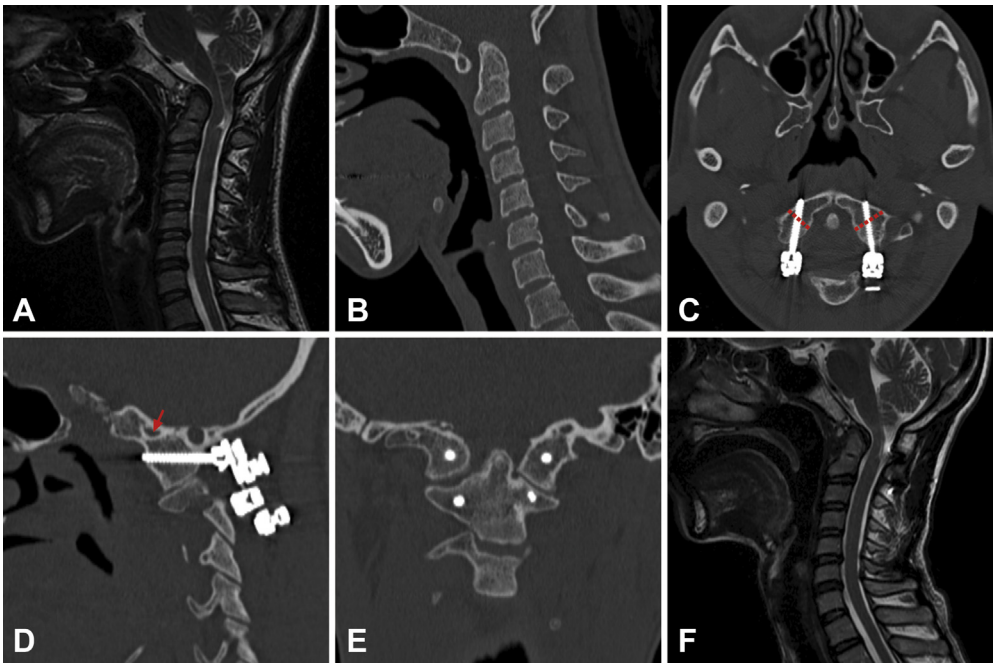

Figure 2. A 40-year-old female patient who presented with a history of headache and progressive weakness and paresthesia of the upper extremities. Preoperative (**A**) magnetic resonance imaging and (**B**) computed tomography showed occipitalization of the atlas, basilar invagination, atlantoaxial dislocation, tonsillar herniation, and compression of the cervicomedullary junction. Reduction and fixation were performed using a posterior C1-C2 screw–rod technique. (**C**) The C1 screw trajectory approximately connected the entry point and the midpoint of the medial width (*red dashed line*), directing inward to the anterior cortical bone in the axial plane. (**D**) The posterior height was enough for screw insertion, with the screw directed cephalically but inferior to the hypoglossal canal (*red arrow*). (**E**) Reconstructed coronal image showing the screws centered in the occipitalized C1 lateral mass. (**F**) At the 1-year follow-up examination, posterior magnetic resonance imaging showed retraction of the herniated tonsils and relief of cervicomedullary compression.

The PH has always been another constraining parameter for screw insertion.[3,21,24] Clinically, a part of the fused atlas in patients with OA or the posterior C1 arch in the control patients could be drilled to provide more space for screw insertion when necessary.[3,5,7] Therefore, in the present study, the PH was defined as the valid height of C1LM that was inferior to the VA. The results showed that the mean PH was 5.4 ± 1.8 mm in the OA group. In ~242 sides (92.4%), the PH was >3.5 mm. Therefore, a screw with a diameter of 3.5 mm would probably be acceptable in most patients with OA. However, the VA in the CVJ is highly variable in patients with OA.[2] Although the PW and PH were wide and high enough to contain a 3.5-mm screw, the anomalous VA will be highly prone to injury during dissection around the C1-C2 facets and the placement of screws. Therefore, the preoperative CT images should be studied carefully, and the screw entry point should be individualized to avoid VA injury. In addition, the intraoperative VA could be dissected away from the surgical field for application of fixation screws in some cases.[25]

The results also showed that the anterior height (11.6 ± 2.6 mm) was much greater than the PH; thus, the occipitalized C1LM resembles a wedge in the sagittal plane, which was consistent with the findings by Jian et al.[16] A wedge-shaped C1LM could make it possible to obtain a relatively free and safe range for screw trajectory (Figure 1B). In addition, both the MH (12.0 ± 1.9 mm; range, 7.3–21.7) and lateral height (11.2 ± 2.4 mm; range 5.2–22.7) did not result in any restrictions for screw insertion in the patients with OA.

The inward and cephalic angulation are critical references for safe and appropriate screw placement (Figures 1A and 2C). Based on our measurements, the ideal inward (α) angle in the OA group (23.8° ± 8.3°) was significantly more medial than that in the control group (15.3° ± 3.8°). The change could be ascribed to the fusion of the C1LM, making its long axis fit to that of occipital condyle, which has been reported to be 33.5° inward.[26] Because the hypoglossal nerve and internal carotid artery lie nearly ahead of the anterior aspect of C1LM,[27,28] a more medially angled screw could reduce the risk of hypoglossal nerve and internal carotid artery injury. With the ideal α angle, the SL was determined to be 20.9 ± 2.9 mm in the OA cases, which was coincided with reports of clinical series (range, 18–24 mm).[3,5] Although the SL value had a broad variation (range, 12.9–29.2 mm), even the smallest value (12.9 mm) was still enough to hold a screw firmly and was longer than the occipital bone screw (<10 mm).

To obtain the greatest purchase in the C1LM, a screw must be angled as far cephalically as possible. Injury to the hypoglossal canal (OA case) or Co-C1 joint (control case) is the main concern

when determining the cephalic angle of the C1 screw. To avoid violation, a screw should ≥2 mm below the hypoglossal angle or Co-C1 joint (**Figures 1B** and **2D**). With this principle, we evaluated the safe maximum cephalic angles (β) for C1 screw trajectory. Although no significant difference was found for the average value between the OA group (33.5° ± 9.9°) and control group (32.9° ± 6.6°), the range was much wider in the OA group (range, 8.1°–67.5°) than that in the control group (range, 16.0°–44.8°). Therefore, the safe and ideal cephalic angle of the C1 screw should be evaluated individually and carefully with sagittal CT reconstruction before surgery.

A study by Zong et al.[17] showed that most morphological measurements pertaining to the CVJ will be significantly smaller in females than in males. In the present study, all the widths and heights of the C1LM and SL were also significantly shorter in the women than in the men, although the difference in the PH did not reach statistical significance. However, no difference was found in the α angle between the sexes. In contrast, the safe maximum β angle was significantly larger in the men (35.9° ± 10.4°) than in the women (32.0° ± 9.4°), which could be attributed to the shorter PH of the C1LM in the women compared with the men. The smaller β angle makes the hypoglossal nerve more vulnerable for women than for men when performing screw insertion. These results highlight that when considering screw insertion, more attention should be given to cases in women, and a relatively short screw might be preferred to avoid excessive screw penetration.

The present study had 2 limitations. First, the measurements were only taken from a Chinese population, which could have led to a selection bias. Although we provided usable morphometric information on the C1LM with OA, we could not perform a thorough comparison with other studies owing to the rarity of the associated data. Therefore, more studies from other populations are required before definite conclusions can be drawn. Second, we performed a retrospective study using data from the medical records and CT images, which could have resulted in selection and measurement bias.

CONCLUSIONS

The present study represents the largest series of detailed morphometric measurements of the C1LM in patients with OA. Although the hypoplastic C1LM results in limitations to screw insertion to some extent, it will still be broad enough to accommodate a screw safely in both female and male patients. Considering the irregularity of the C1LM in patients with OA, the preoperative imaging assessment will be critical and C1LM screw placement should be performed individually. We have provided valuable information for surgeons who treat AAD and BI in patients with OA.

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Conflict of interest statement: This research was supported by the National Natural Science Foundation of China (grant 81571350) and the Beijing Science and Technology Nova Program Project (grant Z171100001117106).

Received 21 January 2018; accepted 2 August 2018

Citation: World Neurosurg. (2019) 121:e1-e7.
https://doi.org/10.1016/j.wneu.2018.08.016

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