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ORIGINAL ARTICLE

Clival screw and plate fixation by the transoral approach for the craniovertebral junction: a CT-based feasibility study

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Abstract

Purpose A clivus screw and plate was invented and proved to strengthen the stability of the craniovertebral junction (CVJ). However, it is unclear whether the clivus screw and plate could be placed onto the CVJ by transoral approach. Therefore, the present study aims to evaluate the feasibility of clivus screw and plate placement by transoral approach and investigate its relative anatomic parameters.

Methods A total of 80 normal adults (40 males/40 females) with an average age of 60.4 ± 11.6 years old were enrolled in this study. All parameters were measured in a supposed maximums mouth-opening status on computed tomography images, where the vertex of lower incisor was defined as Point A. The vertical intersection from Point A to extracranial clivus was defined as Point B, and its distance to the bottom of clivus was measured as B length. Point B was considered as ideal screw entry point. All the cases were divided into three types based on the location of Point B: above the top portion (Type 1), between the top and bottom portion (Type 2), and below the bottom portion (Type 3) of extracranial clivus. The B Length was defined as a minus value if the case belonged to Type 3. The anterior skull base angle, the angles between tangent of extracranial clivus and the lines from Point A to different parts of clivus, and distances between Point A and clivus and C1-3 vertebra were also measured.

Results One in eighty cases (1.2%) belonged to Type 1 with a B Length of 32.12 mm. Most cases (61.3%) were Type 2 with a B Length of 8.7 mm, while Type 3's was −9.7 mm occupying for 37.5%. Significant statistic differences were found in anterior skull base angle between these three types (128.9°, 122.7° and 118.5° for Type 1, 2 and 3, respectively). The distances from Point A to the top and bottom portion of the clivus and the pharyngeal tubercle were 97.5, 96.0 and 96.8 mm, respectively. The angles between the tangent of the clivus and the lines from Point A to the above three structures were 75.7°, 92.3° and 84.0°, respectively. The distances from Point A to the middle point of anterior margin of C1 anterior tubercle, C2 vertebra and C3 vertebra were 79.1, 73.4 and 61.5 mm, respectively.

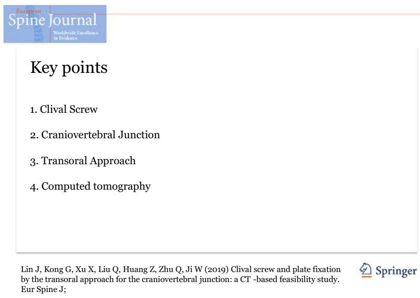
Conclusion The clivus screw and plate placement could be accomplished with optimal screw angle by transoral approach in most of patients. Mandibular splitting would be needed in patients with greater anterior skull angle.

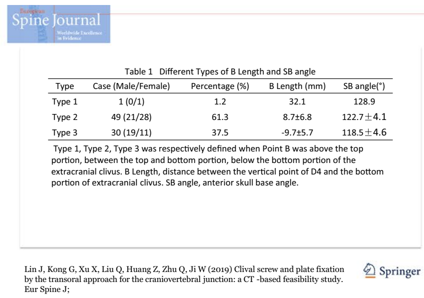
Electronic supplementary material The online version of this article (https://doi.org/10.1007/s00586-019-06039-5) contains supplementary material, which is available to authorized users.

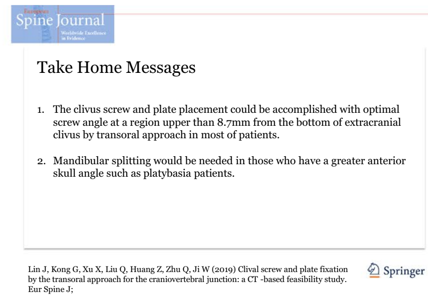
Extended author information available on the last page of the article

Graphic abstract

These slides can be retrieved under Electronic Supplementary Material.







Keywords Clival screw · Craniovertebral junction · Transoral approach · Computed tomography

Introduction

The craniovertebral junction (CVJ) is the region that connects crania and spine. Various lesions, such as inflammation, tumor, injury or congenital malformation, cause the CVJ extremely instable in structure, which might necessitate resection and reconstruction [1–3]. The complicated anatomical structures adjacent to clivus and cervical vertebra made these surgical challenging because any direct or indirect damage of the structures could be vital [4]. The trimmed titanium mesh cage is a commonly used instrument to regain the stability of CVJ after resecting the nidus [5, 6].

Innovatively, the present authors proposed clival screw fixation as a viable option for conventional surgical treatments by anatomic study and morphometric analysis [7, 8]. In our previous study, we designed a novel clivus plate fixation afterward as an alternative to conventional craniovertebral fixation techniques and demonstrated the device's function in strengthening the stability of the defected CVJ in cadaveric specimens when combined with posterior instrumentation [9]. Furthermore, it was proved that the clivus plate fixation system was biomechanically prior to the conventional fashioned mesh cage fixation techniques in range of motion of flexion, lateral bending and axial rotation [10].

Although new techniques were perfected and advanced instrument like endoscope was applied, the transoral–transpharyngeal approach and transoral–transpalatopharyngeal approach were conventional anterior approaches of surgical operations to get to the CVJ [11]. These transoral approaches were still considered effective routes to approach multifarious anterior extradural lesions of the CVJ [12], because the craniofacial osteotomy could be avoided to decrease the risks of postoperative complications. The clivus screw fixation system was proved to be functional in cadaveric specimens [9, 10]. However, it has not been confirmed that whether the clivus plate could be placed through transoral approach without hard palate or mandible splitting which could cause extra iatrogenic injury.

Therefore, in this study, a set of lengths and angles between the lower incisor and the clivus and cervical vertebra at the supposed maximus mouth-opening status on computed tomography (CT) images were measured to evaluate the feasibility of clival screw and plate placement by transoral approach.

Methods

Study design and inclusion criteria

This was an institutional review board-approved, retrospective analysis of patients of East Asian ancestry who presented to the department of orthopedics at our hospital between November 1, 2017 and January 30, 2018, requiring thin layer CT scanning of the head and cervical spine. The inclusion criteria were mainly: (1) age $\geq$ 18 years old; (2) with intact upper and lower incisor at the midsagittal CT image; (3) with completed clivus; (4) without spinal or clival congenital deformity; (5) without cervical or clival trauma or tumors; and (6) without internal fixation or surgical history on the CVJ. A total of 80 adult patients (40 male and 40 female) with a mean age of 60.4 ± 11.6 years old were finally enrolled for CT measurement, while 7 cases did not meet the inclusion criteria (1 case with atlas assimilation, 1 cases with vertebral compression fracture, 4 cases with absent lower incisor, 1 case with scoliosis).

Morphological features analysis

CT images were obtained using Philips Brilliance 16 computed tomographic scan machine (Philips Medical Systems, Eindhoven, Netherlands) with a layer thickness of

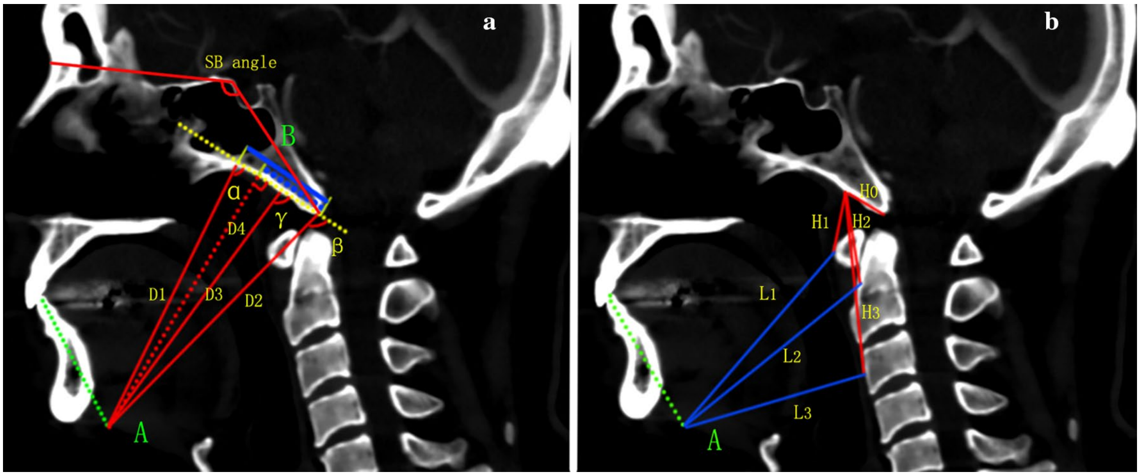


Fig. 1 Parameters of clivus and cervical vertebras on CT midsagittal image. Green dotted line represents maximum mouth opening. Yellow dotted line represents the tangent of extracranial clivus. Point A represents the vertex of lower incisor. **a** α, β, and γ are defined as the angle between the tangent of extracranial clivus and D1, D2, and D3, respectively. D1, D2, and D3 are defined as the distance between Point A and the top portion of the extracranial clivus, the bottom portion of the extracranial clivus, and the pharyngeal tubercle, respectively. D4 represents the perpendicular distance from Point A to the tangent of extracranial clivus, and Point B is defined as the vertical point. The blue full line represents the clival length, while the blue dotted line represents the B Length, the distance between Point B and the bottom portion of extracranial clivus. SB angle represents the anterior skull base angle. **b** H0, H1, H2, and H3 represent the distance between the pharyngeal tubercle and the foramen magnum, the middle point of anterior margin of C1 anterior tubercle, C2 vertebra, and C3 vertebra, respectively. L1, L2, and L3 represent the distance between Point A and the middle point of anterior margin of C1 anterior tubercle, C2 vertebra, and C3 vertebra, respectively

1.0–2.0 mm, pitch of 0.7 mm (120 kV, 180 mA, 512 × 512 matrix) and reconstruction level of 1 mm. Images of the sagittal and axial planes of the craniovertebral region were obtained after multiplanar reconstruction on the workstation (MXV, Philips). Angles and lines were drawn and measured using Star PACS (INFINITT, Seoul, South Korea) in bone windows.

On the midsagittal image of the CVJ, a line of 52 mm [13] in length from the vertex of lower incisor along the axis of mandible was drawn, representing for the maximum mouth opening of Chinese normal adults, and the end point of the line was defined as Point A. Additionally, a perpendicular line from Point A to the tangent of extracranial clivus was drawn, and the vertical intersection was defined as Point B. Point B was considered as ideal screw entry point. Besides, we divided all the cases into different types when Point B was above the top portion (Type 1), between the top and bottom portion (Type 2), and below the bottom portion (Type 3) of extracranial clivus, respectively.

Therefore, on the midsagittal image of the CVJ, the measured variables included (1) the B Length, defined as the length between Point B and the bottom portion of extracranial clivus (Fig. 1a). The B Length was defined as a minus value if the case belonged to Type 3, (2) the anterior skull base angle (SB angle), measured from nasion to midsella to basion [14] (Fig. 1a), (3) the clival length, defined as a maximal distance between the top and bottom portions of extracranial clivus (Fig. 1a), (4) the distances between Point A and the top portion of extracranial clivus (D1), the bottom portion of extracranial clivus (D2) and the pharyngeal tubercle (D3), respectively (Fig. 1a), (5) the angles between the tangent of extracranial clivus and D1 (α), D2 (β) and D3 (γ), respectively (Fig. 1a), (6) the perpendicular distance from Point A to the tangent of extracranial clivus (D4) (Fig. 1a), (7) the distances between the pharyngeal tubercle and the foramen magnum (H0), the middle point of anterior margin of C1 anterior tubercle (H1), C2 vertebra (H2) and C3 vertebra (H3), respectively (Fig. 1b), (8) the distances between Point A and the middle point of anterior margin of C1 anterior tubercle (L1), C2 vertebra (L2) and C3 vertebra (L3), respectively (Fig. 1b).

On the axial image of the CVJ, the diameter of extracranial clivus was measured at the level of the top portion (W1), bottom portion (W2) and pharyngeal tubercle (W3), respectively (Fig. 2). The distances from the medial margin of left and right transverse foramen to the midsagittal line of vertebra were also measured (TF) in C1, C2 and C3 (Fig. 2).

Statistical analysis

The statistical analyses were conducted using SPSS (version 19.0, Chicago, IL). The independent-samples *T* test and Wilcoxon signed-rank test were used to analyze these variables between different genders. The results were presented as mean ± standard deviation (SD). Statistically significant differences were set at a $p < 0.05$.

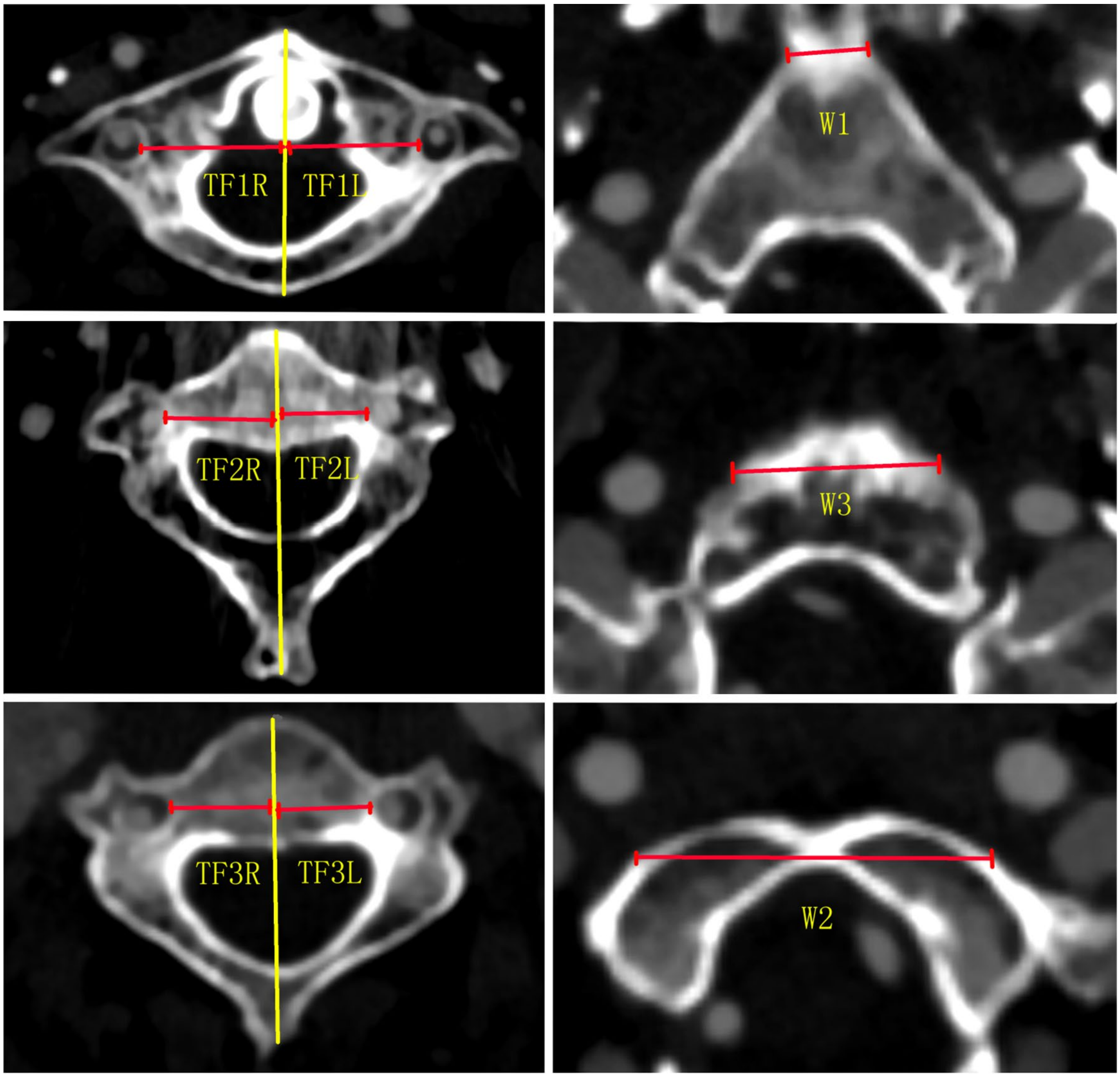


Fig. 2 Parameters of clivus and cervical vertebra on CT axial images. W1, W2, and W3 represent the diameter of the extracranial clivus at the level of the top portion, bottom portion, and pharyngeal tubercle, respectively. TF1L, TF1R, TF2L, TF2R, TF3L, and TF3R represent the distance from the medial margin of left and right transverse foramen to the midsagittal line of the vertebra of C1, C2 and C3, respectively

Table 1 Different types of B length and SB angle

Type	Case (male/female)	Percentage (%)	B Length (mm)	SB angle (°)
Type 1	1 (0/1)	1.2	32.1	128.9
Type 2	49 (21/28)	61.3	8.7 ± 6.8	122.7 ± 4.1
Type 3	30 (19/11)	37.5	−9.7 ± 5.7	118.5 ± 4.6

Type 1, Type 2, Type 3 are, respectively, defined when Point B is above the top portion, between the top and bottom portion, below the bottom portion of the extracranial clivus. B Length, distance between the vertical point of D4 and the bottom portion of extracranial clivus. SB angle, anterior skull base angle

Table 2 Parameters of clivus by gender

Variables	Male		Female		p value*
	Mean ± SD	Range	Mean ± SD	Range	
B length (mm)	− 0.4 ± 12.5	− 27.2–23.7	4.5 ± 10.0	− 10.9–32.1	0.059
SB angle (°)	120.4 ± 4.7	109.7–127.4	122.0 ± 4.8	110.6–131.5	0.124
Clival length (mm)	28.8 ± 2.4	23.0–33.2	26.9 ± 2.9	22.3–36.1	0.001
D1 (mm)	99.4 ± 5.7	82.2–111.4	95.7 ± 5.9	84.9–109.5	0.006
D2 (mm)	97.3 ± 6.6	76.8–109.0	94.7 ± 7.0	82.7–114.7	0.093
D3 (mm)	98.0 ± 5.9	78.6–107.2	95.5 ± 6.2	84.7–111.6	0.018
D4 (mm)	96.2 ± 6.7	75.0–108.4	93.2 ± 7.3	80.2–110.0	0.058
α (°)	74.5 ± 7.8	59.5–92.5	76.8 ± 5.9	66.0–92.6	0.136
β (°)	91.2 ± 7.4	72.2–105.0	93.4 ± 6.5	80.2–107.5	0.169
γ (°)	82.6 ± 7.4	61.6–97.6	85.5 ± 6.2	72.7–96.7	0.059
W1 (mm)	14.2 ± 2.7	9.8–21.1	12.8 ± 2.9	8.8–22.5	0.007
W2 (mm)	44.1 ± 5.0	37.1–56.6	43.6 ± 6.1	34.3–55.5	0.84
W3 (mm)	32.1 ± 7.0	12.9–45.9	30.7 ± 5.8	14.9–39.9	0.271

Clival Length, length of the extracranial clivus; D1, D2 and D3, distance between the vertex of lower incisor and the top portion of extracranial clivus, the bottom portion of extracranial clivus, and the pharyngeal tubercle, respectively. D4, perpendicular distance from the vertex of lower incisor to the tangent of extracranial clivus. B Length, distance between the vertical point of D4 and the bottom portion of extracranial clivus. SB angle, anterior skull base angle. α, β and γ, angle between the tangent of extracranial clivus and D1, D2 and D3, respectively. W1, W2 and W3, diameter of extracranial clivus at the level of top portion, bottom portion and pharyngeal tubercle, respectively

*Male versus Female, statistically significant differences were set at a $p < 0.05$

Table 3 Parameters of cervical vertebra by gender

Variables (mm)	Male		Female		p value*
	Mean ± SD	Range	Mean ± SD	Range	
H0	14.8 ± 2.0	10.6–20.5	14.1 ± 1.9	9.9–18.7	0.129
H1	22.5 ± 3.0	16.6–30.2	19.6 ± 2.7	12.7–26.3	0.000
H2	37.0 ± 3.4	29.8–42.8	32.5 ± 3.0	26.7–43.0	0.000
H3	64.9 ± 4.4	56.8–73.9	56.9 ± 3.4	49.1–66.1	0.000
L1	79.0 ± 6.1	60.5–89.9	79.1 ± 7.1	68.2–100.7	0.624
L2	74.2 ± 7.2	53.3–87.8	72.7 ± 6.8	60.0–94.4	0.131
L3	63.5 ± 6.8	50.0–78.8	59.4 ± 6.4	47.7–79.3	0.007
TF1					
L	23.0 ± 1.3	20.5–25.9	21.0 ± 1.6	17.6–24.1	0.000
R	23.2 ± 1.6	20.0–28.5	20.7 ± 1.6	14.9–23.9	0.000
TF2					
L	14.8 ± 1.7	11.2–18.1	12.8 ± 1.7	9.0–16.6	0.000
R	13.7 ± 1.7	10.7–17.6	11.9 ± 1.7	8.3–16.0	0.000
TF3					
L	13.2 ± 1.1	10.3–15.1	12.2 ± 1.2	10.6–17.8	0.000
R	12.1 ± 1.2	8.3–14.2	11.0 ± 1.1	9.3–15.2	0.000

H0, H1, H2 and H3, distance between the pharyngeal tubercle and the foramen magnum, the middle point of anterior margin of C1 anterior tubercle, C2 vertebra and C3 vertebra, respectively. L1, L2 and L3, distance between the vertex of lower incisor and the middle point of anterior margin of C1 anterior tubercle, C2 vertebra and C3 vertebra, respectively. TF1, TF2 and TF3, distances from the medial margin of transverse foramen to the midsagittal line of vertebra in C1, C2 and C3, respectively. L, left. R, right

*Male versus Female, statistically significant differences were set at a $p < 0.05$

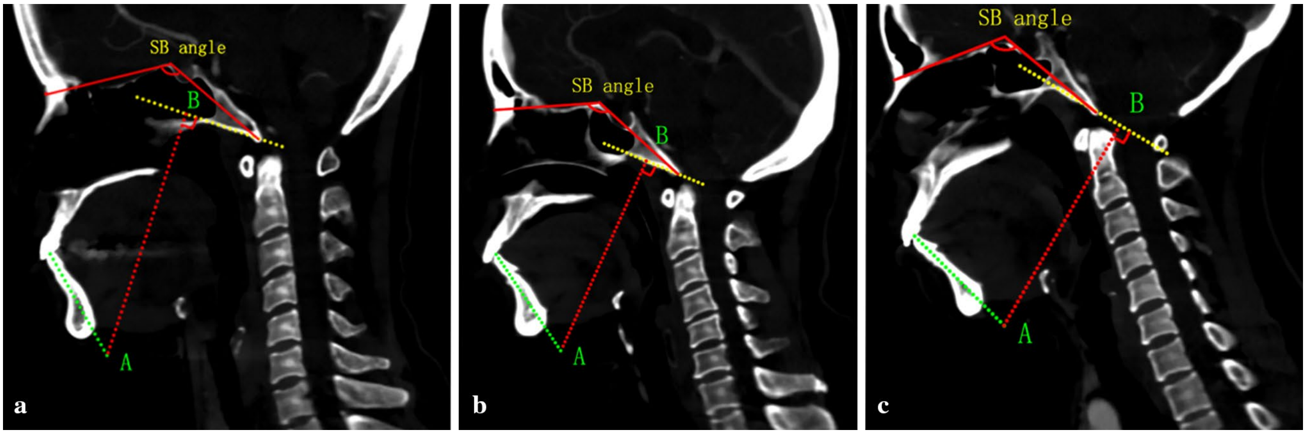


Fig. 3 Typical midsagittal image of each type of B length and SB angle. **a**, **b**, **c** Demonstrates typical midsagittal image of Type 1, Type 2 and Type 3, respectively. Green dotted line represents maximum mouth opening. Yellow dotted line represents the tangent of extracranial clivus. Point A represents the vertex of lower incisor. Red dotted line represents the perpendicular distance from Point A to the tangent of extracranial clivus, and Point B is defined as the vertical point. SB angle represents the anterior skull base angle

Results

Patient demographics

A total of 80 adult patients (60.4 ± 11.6 years old) within 40 males and 40 females were included for present study. Different types of the B Length and SB angle were exhibited in Table 1. The results of the parameters of extracranial clivus and cervical vertebra were showed by gender in Tables 2 and 3. The relevant *p* values of comparison between males and females were listed behind each variable.

Different types of B length and SB angle

The B Length ranged from −27.2 to 32.1 mm and the mean ± SD was 2.1 ± 11.5 mm. There was no significant statistical difference in B Length between genders ($p = 0.059$). Only one in eighty cases (1.2%) of the normal adults belonged to Type 1 whose B Length was 32.12 mm. Most of normal adults (61.3%) were Type 2 with a mean B Length of 8.7 ± 6.8 mm, while Type 3's was −9.7 ± 5.7 mm occupying for 37.5%.

The mean SB angle was 121.2° ± 4.8°, and no statistical difference was found between genders ($p = 0.124$). However, the Type 1 had a significantly greater SB angle than both Type 2 and 3 (128.9° vs. 122.7° ± 4.1°, $p = 0.000$; 128.9° vs. 118.5° ± 4.6°, $p = 0.000$, respectively). Meanwhile, the SB angle was greater in Type 2 than that in Type 3 (122.7° ± 4.1° vs. 118.5° ± 4.6°, $p = 0.000$) (Fig. 3).

Parameters of extracranial clivus

The clival length was 27.9 ± 2.8 mm, while the male's was significantly longer than the female's (28.8 ± 2.4 mm vs. 26.9 ± 2.9 mm, $p = 0.001$). The D1, D2, D3 and D4 were 97.5 ± 6.1 mm, 96.0 ± 6.9 mm, 96.8 ± 6.1 mm and 94.7 ± 7.1 mm, respectively. Among the above four variables, only the D1 and D3 in male were significantly longer than those in female (99.4 ± 5.7 mm vs. 95.7 ± 5.9 mm, $p = 0.006$; 98.0 ± 5.9 mm vs. 95.5 ± 6.2 mm, $p = 0.018$, respectively). The α, β and γ were 75.7° ± 7.0°, 92.3° ± 7.0° and 84.0° ± 6.9°, respectively. These three angles had no significantly difference between genders. The W1, W2 and W3 were 13.5 ± 2.9 mm, 43.8 ± 5.6 mm and 31.4 ± 6.4 mm, respectively, and only W1 was significantly longer in male than that in female (14.2 ± 2.7 mm vs. 12.8 ± 2.9 mm, $p = 0.007$).

Parameters of cervical vertebra

The H0, H1, H2 and H3 were 14.4 ± 2.0 mm, 21.0 ± 3.2 mm, 34.8 ± 3.9 mm and 60.9 ± 5.6 mm, respectively. H1, H2 and H3 were longer in male than those in female (22.5 ± 3.0 mm vs. 19.6 ± 2.7 mm, $p = 0.000$; 37.0 ± 3.4 mm vs. 32.5 ± 3.0 mm, $p = 0.000$; 64.9 ± 4.4 mm vs. 56.9 ± 3.4 mm, $p = 0.000$, respectively). The L1, L2 and L3 were 79.1 ± 6.6 mm, 73.4 ± 7.0 mm and 61.5 ± 6.8 mm, respectively, and only L3 was significantly longer in male than that in female (63.5 ± 6.8 mm vs. 59.4 ± 6.4 mm, $p = 0.007$). The TF1L, TF1R, TF2L, TF2R, TF3L and TF3R were all significantly longer in male than that in female (23.0 ± 1.3 mm vs. 21.0 ± 1.6 mm, 23.2 ± 1.6 mm vs. 20.7 ± 1.6 mm, 14.8 ± 1.7 mm vs. 12.8 ± 1.7 mm, 13.7 ± 1.7 mm vs. 11.9 ± 1.7 mm, 13.2 ± 1.1 mm vs. 12.2 ± 1.2 mm, 12.1 ± 1.2 mm vs. 11.0 ± 1.1 mm, respectively; all the *p* values were the same: $p = 0.000$).

Discussion

This was a retrospective analysis of patients requiring thin layer CT scanning of the head and cervical spine in our hospital. All the patients had the examination with resting position. It was unpractical to require the patients to keep in the maximum mouth-opening status during the whole CT scanning. Moreover, it was reported that the maximum mouth opening of adult Chinese was 52.02 mm [13]. So we drew a line of 52 mm from the vertex of lower incisor along the axis of mandible on the common CT scanning midsagittal images, representing for the maximum mouth opening of Chinese normal adults. Patients would gain a greater maximum mouth opening once in anesthesia than in conscious so that the results of this study were reliable.

Parameters to assess operating space by transoral approach

This study is an extension of our previous works. The present study assessed the operating space for patients undergoing CVJ surgical with the clivus screw and plate fixation by transoral–transpharyngeal approach or transoral–transpalatopharyngeal approach. The surgical could be conducted in patients who needed reconstruction for the CVJ instability, which resulted from (1) trauma-induced atlantoaxial dislocation; (2) clival or upper cervical tumor; (3) rheumatoid; (4) deformity such as basilar invagination; (5) iatrogenic causes such as the occipital resection for decompression that left no opportunity for reconstruction from the posterior approach. In the status of maximum mouth opening during the surgery, distances from the vertex of lower incisor to the top and bottom portion of the extracranial clivus and the pharyngeal tubercle were 97.5, 96.0 and 96.8 mm, respectively. The angles between the tangent of the extracranial clivus and the lines draw between the vertex of lower incisor and the above three structures of clivus were 75.7°, 92.3° and 84.0°, respectively. The distances from the vertex of lower incisor to the middle point of anterior margin of C1 anterior tubercle, C2 vertebra and C3 vertebra were 79.1, 73.4 and 61.5 mm, respectively. These data could serve as references for the CVJ surgical operation through transoral approach. Since the operation field was deep and narrow, common device might not be capable in the placement of clivus screw and plate so that special designed instruments were required for this surgical.

The distances from pharyngeal tubercle to the foramen magnum and C1-3 vertebra, and diameters of extracranial clivus at different levels might server as references for clivus plate design. What's more, distances from transverse foramen to the midsagittal line indicated that the safety field for screw fixation was 22.0 mm (L) and 22.0 mm (R), 13.8 mm (L) and 12.8 mm (R), 12.7 mm (L) and 11.6 mm (R) for C1-3, respectively. The vertebral artery would be injured if the screw was purchased beyond the safety field. The clival length, D1, D3, H1, H2, H3, L3, W1, and distances of left and right transverse foramen to the midsagittal line of vertebra were longer in male than those in female. These variables could reflect bone structure size, which is normally larger in male than that in female. The clival length was 27.9 mm, similar to our previous measurement on dry bones (25.8 mm) [7, 9]. The diameter of the extracranial clivus increased from the level of the top portion to pharyngeal tubercle and then to the bottom portion, which differed, however, from a previous data of the widest and narrowest diameter of the extracranial clivus (32.6 mm and 18.9 mm, respectively) [9]. Interestingly, the top portion considered as the narrowest diameter was similar to the data from another study (12.84 mm) [7]. The deviation might be resulted from different measurement methods and different tools such as dry bone specimen or CT images.

It was reported that the exposure field through transoral approach started from the middle clivus to upper C3 vertebral body [15]. However, it was observed in the present study that the line between vertex of lower incisor and the top portion of extracranial clivus did not go through the hard palate on the CT midsagittal image in all these cases, indicating that most of the normal adults could undergo the clival surgery without splitting the hard palate.

Conventional management of CVJ lesions and our previous works

CVJ lesions such as congenital deformity, tumor or spinal tuberculosis may threaten the patients' life, which require resection and reconstruction of the clivus and upper cervical vertebra [1]. There are several traditional approaches to access the anterior craniovertebral region. The transoral–transpharyngeal and transoral–transpalatopharyngeal were considered as standard transoral approach, in which the clivus, C1 and C2 vertebra, and laterally 2 cm to either side of the midline could be exposed [11]. However, patients with limited mouth-opening ability or restricted neck extension would have a limited exposure to undergo CVJ surgical by these approaches [9]. To extend a greater rostral and caudal exposure of the CVJ, the transmaxillary approach [16] and transmandibular approach [17] were performed to split the maxilla or mandible as combination with transoral approach. Although the above techniques would cause additional complications such as oral incompetence, limited tongue mobility and sensation, they would still be acceptable in face of the severity of the neurosurgical condition caused by CVJ pathology [11]. However, with assistance of advanced instruments, it would be increasingly rare to apply these craniofacial osteotomies. The endonasal endoscopic approach, as a representation of endoscopic approach, provided a novel and effective route to access the CVJ, showing advantages such as lower rates of postoperative dysphagia and respiratory complications [18]. Nonetheless, it was proposed that endoscopic approaches should be considered as complementary rather than an alternative to the traditional microsurgical transoral–transpharyngeal approach [19]. Except these anterior approaches, the posterolateral approach could also provide exposure of the lower third of the clivus, the foramen magnum, and the upper cervical spine [20].

Briefly, compared with other approaches, the transoral–transpalatopharyngeal approach was the most convenient one because it had less iatrogenic injury and fewer postoperative complications [9, 21], regardless that transoral approaches had a limited operating space to gain the target area without palate splitting or the mandibular osteotomy.

There are many ways to reconstruct the CVJ. Commonly a modified Harms mesh was applied to reconstruct the clivus and the upper cervical spine [5]. However, the Harms mesh cage was found that it had a displacement after application in a case of spondylectomy [22]. The present author thus conducted anatomy and CT-based studies to prove the viability and safety of clival screw placement [7, 8], designed a novel clivus plate fixation and evaluated its feasibility to be an alternative in vitro cadaveric biomechanical of the device in previous study [9, 10]. Besides, we characterized clivus of C1A (atlas assimilation) patients with an unnormal-like rectangular shape, and confirmed a screw placement at the inferior clivus [22]. To step further, the present study evaluated the feasibility of the clivus plate placement by transoral approach and established some guidelines as supplement to our previous works on CT images.

The screw entry point with optimal angle on the extracranial clivus by transoral approach

Normally the macroaxis of a screw should be perpendicular to the extracranial clivus to gain a better mechanical stability, which was referred as optimal entry angle [7]. If not, the clivus fixation might not provide biomechanical stability perfectly because the tail tip of screw would not cling to the screw hole of clivus plate. What's more, the uneven surface of the clivus plate might result in a retropharyngeal fascia tension, constant stimulation on fascia, poor blood supply and ischemic necrosis of mucosa, and being vulnerable to affections. Additionally, if the screw was not purchased vertically, it would be uncertain for a surgeon that how far the screw should go. It would possibly cause screw penetration and intracranial hematoma once an incorrect estimation was made. Thus, it is vital to purchase a screw with optimal entry angle so as to avoid serious fixation device loosing and pharyngeal or intracranial complications. The ideal screw entry point of extracranial clivus should be thick enough to avoid anatomic structures damage caused by screw penetration.

Therefore, the perpendicular line from vertex of lower incisor to the tangent of extracranial clivus represented the optimal entry angle and Point B was the critical point. Screw trajectory was formed by the vertex of lower incisor and the screw entry point. The screw trajectory would not be vertical to extracranial clivus when screw entry point lied below Point B on the extracranial clivus. On the contrary, we could always find an optimal entry angle when screw entry point was above Point B on the extracranial clivus.

In the present study, the results showed that only 1.2% of the normal adults belonged to Type 1, which indicated that these people had no optimal angle to purchase a screw vertically into the extracranial clivus. Among three types, the SB angle of Type 1 (128.9°) is the closest one to the critical value (140°) to diagnose a platybasia, a congenital deformity of the basis cranii characterized with anterior skull base angle exceeding 140° [14]. The skull base was abnormally flattened as the anterior SB angle increased [23]. Thus, mandibular splitting was requisite for clivus screw and plate placement with optimal screw angle in platybasia patients and in normal people belonged to Type 1. There were 37.5% of the normal adults who had a completely optimal angle through transoral approach because the screw could be purchased vertically at any point of the extracranial clivus at the status of maximum mouth opening. There were 61.3% of the normal adults whose Point B was on the extracranial clivus, and the mean B Length was 8.7 mm, which indicated that the optimal angle does exist, and the lowest ideal screw entry point was 8.7 mm away from the bottom portion of the clivus. Thus, about two-third of the patients with CVJ lesion could not finish the placement of clivus screw and plate with optimal screw angle at the inferior clivus unless mandible splitting was performed to gather a greater caudal operating space.

This study evaluated the feasibility of clivus screw and plate placement on CVJ through transoral approach. Many factors affect the result. People who had a smaller anterior skull base angle, a greater maximus mouth opening, and a greater extracranial clivus upper cervical angle are likely to accomplish the operation with optimal screw angle. However, there are individual and ethic variations so that a CT-analysis is suggested before surgical.

The limitations of this study must be acknowledged. First of all, although the transoral approach is applied for pathologies such as those with C1/2 tumor, irreducible C1/2 subluxation, or the CVJ deformity, it is unclear whether the maximal mouth opening (MMO) of these patients could get to parameters of general population, which is no literature mentioned on MMO for such patients at present. Therefore, in this study, we measured the parameters by the MMO of normal adults referred from a published literature [13]. Secondly, various factors affect MMO, such as ethnic, age, gender and disease. Different studies on different race show different MM0, for examples, 48.8 ± 0.4 mm from 164 American students (age 21–42 years old) of Tufts University School of Dental Medicine [24], 52.02 ± 5.09 mm from 452 Chinese students (age 20–35 years old) of Medical Examination Center of the Third Hospital of Hebei Medical University [13], 49.10 ± 6.30 mm from 1442 Taiwanese (age 20–80 years old) from the Dental Department of Shin Kong Wu Ho-Su Memorial Hospital [25]. Patients of our hospital are basically from Chinese Mainland; therefore, to reduce the ethnic selective bias, we selected data of Chinese mainland. It was reported that the age had an effect on MMO. With age growing, the MMO decreased [26]. However, there is no reported MMO of elder Chinese from mainland so that we used 52 mm of young Chinese MMO to represent the elder's in this study, which, to be honest, could have increase the limitation to this study. What's more, it was reported that the MMO of male was greater than the female's in almost all literature [24]. Thirdly, the sample involved in this study was quite small that the conclusion might not be the same if we enlarge the sample. Lastly, we only measured the variables in Chinese people so there might be an ethnic limitation and the conclusion could not be applied directly on other ethnics.

Conclusion

The clivus screw and plate placement could be accomplished with optimal screw angle at a region upper than 8.7 mm from the bottom of extracranial clivus by transoral approach in most of patients. Mandibular splitting would be needed in those who have a greater anterior skull angle such as platybasia patients. Most of the normal adults could undergo the clivus and cervical surgery without splitting the hard palate. Moreover, CT-analysis was suggested to evaluate the individual clivus morphology before surgical.

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Compliance with ethical standards

Conflict of interest The authors have no personal, financial, or institutional interest and ethical/legal conflicts involved in this article. The Manuscript submitted does not contain information about medical device(s)/drug(s).

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