The anatomic study of clival screw fixation for the craniovertebral region

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Received: 20 October 2011 / Revised: 25 December 2011 / Accepted: 3 January 2012 / Published online: 2 February 2012
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Abstract

Purpose To study the anatomic parameters related to clival screw and establish reference data concerning the craniovertebral fixation technique.

Methods Morphometric measurement of the clivus and the surrounding anatomic structures were obtained on 41 dry bone specimens. Then, 2-D CT reconstruction of the craniovertebral region of 30 patients (19 men and 11 women, ranging in age from 20–64 years with an average age of 38.8 years) were performed to measure the safety range for a 3.5-mm screw placement. Nine entry points were evaluated. Finally, one male fresh cadaver specimen (age 46 years) was dissected to observe the craniovertebral region.

Results The clivus faces the basilar artery, the V ~ XII cranial nerves, the pons, and ventral medulla oblongata at its intracranial surface. The longitudinal diameter of extracranial clivus was 25.87 ± 2.64 mm. The narrowest diameter of the clivus was 12.84 ± 1.08 mm, the distance between the left and right hypoglossal canal was 32.70 ± 2.09 mm at its widest part. The distance between the

left and right structures, the maximum value was 49.31 ± 4.16 mm at carotid canal, the minimum value was 16.54 ± 2.04 mm at the occipital condyle. The measurement of clival screws placement simulation via 2-D CT reconstruction images shows the maximum upper insertion angle of three components the optimal entry points, the candidate points, the limit entry points was 130.19° , 125.23° and 85.72° , and the total mean screw length was 7.57, 10.13 and 15.6 mm at the vertical entry angle, respectively.

Conclusions Clival screw placement is a viable option for craniovertebral fixation. There is a safe scope for the screw length and angle of the screw placement. And, these parameters obtained in the present study will be helpful for anyone contemplating the use of clival screw fixation.

Keywords Clivus · Craniovertebral fusion · Screw placement · Anatomical study

Introduction

The craniovertebral complex connects the cranium and the spine. Inflammation, injury, cancer, and deformity can result in destruction to this area with loss of stability. Instability carries the risk of high-level cervical spinal cord compression, potentially life-threatening chronic; therefore, surgical fixation and fusion are typically performed [1].

Historically, craniovertebral fixation methods can be divided into anterior, posterior and combined anteroposterior approaches. Most of the stability of posterior fusion using occipitocervical fixation, which is relatively mature [2–4]. Existing anterior fixation techniques contain Harms titanium, subarticular atlantoaxial locking plate (SAALP) fixation, and transoral atlantoaxial reduction plate [5–7],

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which are more suitable for the treatment of atlantoaxial fracture or dislocation. However, due to large bone defects after atlantoaxial tumor resection, these devices are not applicable. Then, some doctors have already used autogenous iliac crest graft alone, but it was difficult to establish real-time stability and have a higher risk of graft displacement, changing the positioning of the patient during operation may cause fatal injury. Also, some person shaped the head of the autogenous iliac bone into groove like for implantation, embedded in the anterior arch of the atlas, ending with anterior cervical plate (titanium plate) fixation with the lower cervical spine, so that stability was better than bone graft alone. Furthermore, Suchomel et al. [8] presented a case of a chordoma treated with a single-stage total C-2 intralesional spondylectomy, and the anterior defect was reconstructed using a 14-mm diameter Harms mesh cage filled with autologous and iliac crest bone graft and then screwed into the clivus and C-3 endplate caudally. Rawlins et al. [9] used a titanium plate to fix the bone graft into the clivus and the body of the 3rd cervical vertebra, as the anterior reconstruction. Goel et al. [10] reported a patient with congenital basilar invagination after odontoidectomy performed with plate and screw fixation of the clivus to the body of the 3rd cervical vertebra. It was considered that direct fixation to the clivus may be a more rigid alternative to previously described techniques [11–13].

Given these potential uses for clival screw fixation, we believed that the technique should be included in the armamentarium of craniovertebral fixation techniques, particularly for the treatment of atlanto-axial tumors. And yet, to the best of our knowledge, there are no literature that have document the entry point, trajectory, and optimal length of clival screws, and then in this paper the detailed and relative anatomical data for clival region was measured on 41 cases skull specimens and a radiologic evaluation using 1.0-mm interval computed tomography (CT) scan images was performed for screw placement to determine the safe scope of the screw length with feasible entry angle for the clival screw fixation. Finally, we observed the surrounding structures of clivus in a fresh cadaver specimen.

Materials and methods

Measurements in the dry bone specimens

Forty-one dry bone specimens containing the sphenoid and occipital bones were provided by the Department of Anatomy, Wenzhou Medical College, Wenzhou, People's Republic of China. The race, sex, and age of the specimens were unknown. The detailed and relative anatomical data for clival region were measured (Fig. 1). The distance from

the pharyngeal tubercle and central line of the basilar part of occipital bone to the foramen lacerum, foramen ovale, medial margin of outer entrance of carotid canal, medial margin of jugular fossa, anterior part of occipital condyle and the medial margin of outer entrance of hypoglossal canal were measured; the distance between the left and right foramen lacerum, foramen ovale, medial margin of outer entrance of carotid canal, medial margin of jugular fossa, anterior part of occipital condyle and medial margin of outer entrance of hypoglossal canal were also measured. Additionally, the longitudinal diameter of extracranial clivus, the distance from the pharyngeal tubercle to the anterior portion of the foramen magnum were measured. Finally, the narrowest diameter of the clivus just at the level of the apices of the extracranial clivus and the widest part between the left and right medial margin of outer entrance of hypoglossal canal were measured (Fig. 2). The above data were measured by a digital vernier caliper with an accuracy of ± 0.02 mm (Absolute Digimatic, Mitutoyo, Japan).

Computed tomographic scan reconstruction of the craniovertebral region

This study was approved by the Institutional Review Board of the hospital, and all craniovertebral region CT scans performed between May 2006 and April 2011 at our institution were included for analysis. Exclusion criteria included (1) CT scans of patients aged <20 years, (2) postoperative CT scans, (3) abnormal craniovertebral anatomy, such as congenital atlantooccipital assimilation, and (4) CT scans of patients with tumor, trauma, or infection.

Fig. 1 Midline sagittal section of the clivus and adjacent structures (1 clivus, 2 sphenoid sinus, 3 pituitary gland, 4 basilar artery, 5 pons, 6 medulla, 7 optic nerve, 8 clival dura, 9 cisterna pontis, 10 anterior arch of atlas, 11 dens, 12 pharyngeal recess, 13 hard palate)

Fig. 2 The black points and lines show the measurement schemes: 1 the pharyngeal tubercle, 2 foramen lacerum, 3 foramen ovale, 4 medial margin of outer entrance of carotid canal, 5 medial margin of Jugular fossa, 6 medial margin of outer entrance of hypoglossal canal, 7 anterior part of occipital condyle, 8 the anterior margin of the great occipital foramen, 9 D line: the central line. The red points represent the given nine entry points of clival screws: A1, A2, A3; B1, B2, B3; C1, C2, C3 on the extracranial clivus

Healthy patients were recruited as study subjects to minimize unpredictable influences from pathological conditions. Finally, 30 healthy patients of East Asian ancestry (19 men, 11 women) with an average age of 38.8 years (age range 20–64 years) fulfilling the selection criteria were included.

The craniocervical region scan was using Philips Brilliance 16 computed tomographic (CT) scan machine (Philips Medical Systems, Eindhoven, The Netherlands). Scan parameters included layer thickness of 1.0–1.5 mm, collimation of 0.75–1.5 mm, pitch of 0.7 mm, and reconstruction level of 1 mm. The original data were entered into the MXV work station and 2-dimensional (2-D) image reconstruction performed using multiplanar reconstruction (MPR) methods. And then, angles and lines were drawn and measured using Star PACS (INFINITT, Seoul, South Korea).

Entry points

In the reconstructed midsagittal images (Fig. 3), a tangent of C3 endplate was made starting from the point X, located at the anterior edge of C3 endplate to the terminal point Y, and the distance between X and Y was 13 mm (commonly used titanium mesh diameter). The point O was located at the bottom of clivus. A2 was located at the intersection of the tangent of extracranial clivus and the line that starting from X and parallel to the line YO, C2 just at the top portion of the middle line of extracranial clivus, and B2 was determined as the midpoint between B2 and C2. The

line A, B and C were the horizontal line that passes through the point A2, B2 and C2, respectively (Fig. 2).

The placement of screw is determined by the entry point and the insertion angle. Based on the anatomic relationships along with trajectories and the characteristics of internal fixation plate, nine entry points on the extracranial clivus were determined as shown in Fig. 2. Then, the nine entry points as right inferior-lateral (A1), inferior-middle (A2), left inferior-lateral (A3), right mediolateral (B1), middle (B2), left mediolateral (B3), right superior-lateral (C1), superior-middle (C2), and left superior-lateral (C3) were designated, respectively. The point of A1, A2 and A3 were located on the straight line A; B1, B2 and B3 were located on the straight line B; and C1, C2 and C3 were located on the straight line C. The distance between adjacent points on a line was 3.5 mm (the pitch diameter of Zephir plate). The middle point and two lateral points on a line as the entry points were determined for the purpose of the single or double screws fixation on the clivus. The points on line A was regarded as the optimal entry points, the points on line B as the candidate points, and the points on line C as the limit entry points.

Screw insertion angles

Once the entry points were determined, the next step was to determine the amount of upward angulation. Due to the limit of surgical approach to the clivus [14–17], the horizontal angle (HA), vertical angle (VA) and limit angle (LA) were measured as the screw insertion angles as show

Fig. 3 Midline sagittal illustration of the craniocervical region showing simulation clival screws entry point (A2, B2 and C2), trajectory, entry angle (HA, VA and LA) and the location of plate or cage (XY, OY and XA2). See text for description of the points, lines and angles

in Fig. 3. HA indicated the angle that parallel to the sagittal axis. VA was defined as the angle that is perpendicular to the extracranial clivus. Because the internal fixation device hindered the manipulation of screws insertion, LA was determined as the angle between the line A2C2 and the line XA2 that is parallel to the line YO. However, because the sphenoid sinus varies in shape and size [18] and the relative position of the pituitary fossa in the clival region, at the points on line C or B, LA corresponds with the angle between the line A2C2 and the tangent of the posterior margin of the sphenoid sinus or the pituitary fossa to avoid the screws being directly inserted into them. The vertical angle referred to the optical entry angle, exhibiting better mechanical stability, and the angle between the other two was determined as the safe angle scope for the clival screw fixation. The angle between the line XA2 and A2C2 was also obtained as the bending angle of the plate or net cage required to suit the inclination of the extracranial clivus. In each case, in order to get the values at the entry points of A1, B1, C1, A3, B3 and C3, we also reconstructed the left and right sagittal section images, and the distance between the left or right and the midsagittal section was 3.5 mm, just the space between adjacent points on the line A, B or C.

Screw length

With respect to the length of clival screws, the transverse section images of each entrance point with above three insertion angles were reconstructed. In the screw placement, two factors had to be considered, the first being the orientation of the lateral entry angle. On one hand, it crossed the clivus more perpendicularly and improving its mechanical stability. On the other hand, with the vertical angle, it was easier than other lateral entry angle to operate for the spinal surgeon. Another important factor to be considered in preserving the dura, the basilar artery, pons, ventral medulla oblongata and the V ~ XII cranial nerves that sited on the intracranial clivus. If a screw was placed too deeply, these structures would be damaged. Even if these structures not directly injured, if the lateral cortex of the clivus was violated, it might cause intracranial hemorrhage near the pons and ventral medulla oblongata, which could be fatal. Given those factors, the optimal screw should be inserted by a vertical angle on each transverse section and allowed the screw tip to reach but not perforate the contralateral cortical bone, and avoiding injury while achieving an adequate length of the screw purchase. Meantime, if the screws were inserted into the sphenoid sinus or the pituitary fossa especially at the entry points that located on line C or line B, the tangent of the posterior margin of the pituitary fossa or the sphenoid sinus at the entry point would be made, and then the corresponding entry angle and screw length were measured. At

the same time, the length of OA2, OC2, XA2 that the plate needed and OY that the net cage or the autogenous bone graft required during intra-operation were measured.

Observation in fresh cadaver specimen

One male fresh cadaver specimen of East Asian ancestry (age 46 years) was obtained from the Department of Anatomy, Wenzhou Medical College. The man had died of acute brain injury without concomitant craniovertebral injuries. The specimen was confirmed by X-ray to have a normal craniovertebral region. The head and neck were placed on the operating table, avoiding lateral flexion and rotation. The clival region was dissected using scalpels and rongeur, and then 0.5–1.0 mm thin sagittal slices were also made via stoelting tissue slicer for the observation.

Statistical analysis

Paired *t* test was performed to compare the distance from the left and right structure near clivus to the pharyngeal tubercle and the central line, respectively. Multiple McNemar tests with Bonferroni correction were used for comparison of screws length among the nine entry points. To compare the safe ranges of upward angulation, one-way repeated measures analysis of variance (ANOVA) test followed by post hoc Tukey test for individual comparisons were used. Statistically significant differences were defined at $P < 0.05$ for all analyses. The values were given as mean $\pm$ SD. Statistical analysis was carried out using SPSS (SPSS Inc, Chicago, IL, USA) package software.

Results

Measurements in the dry bone specimens

The distance from the pharyngeal tubercle and the central line to the foramen lacerum, the medial margin of outer entrance of carotid canal, the medial margin of jugular fossa, the anterior part of occipital condyle and the medial margin of outer entrance of hypoglossal canal were show in Tables 1 and 2. Compared with the left and right anatomical structure near clivus, there was no significant difference except the distance between the medial margin of jugular fossa and the central line, the foramen ovale and the central line ($P < 0.05$). The longitudinal diameter of extracranial clivus and the distance from the pharyngeal tubercle to the anterior portion of the foramen magnum were 25.87 ± 2.64 mm (19.08–31.24 mm) and 12.76 ± 1.56 mm (8.12–16.28 mm), respectively. The narrowest diameter of the clivus was 12.84 ± 1.08 mm (10.38–15.02 mm), and the distance between the left and right

hypoglossal canal was 32.70 ± 2.09 mm (28.12–37.20 mm) at its widest part. The distance between the left and right anatomical structure near clivus was shown in Table 3, the maximum distance was 49.31 ± 4.16 mm (41.42–57.54 mm) between the left and right carotid canal, minimum distance was 16.54 ± 2.04 mm (11.18–21.78 mm) between the left and right occipital condyle. Linking the both side of the medial margin of outer entrance of hypoglossal canal, the foramen lacerum and the apices of the extracranial clivus, we got an irregular trapezoid that determined as the relatively safe scope for the entry points (Fig. 2).

Computed tomographic scan reconstruction of the craniovertebral region

The measurement of clival screws placement via 2-D CT reconstruction images showed that there were 29 cases settled to the vertical angle at the point B1, B2 and B3, and 1 case did not. And yet, 13 cases met the vertical angle at C1 and C2, 12 cases met it at C3. Additionally, at the entry point C1, only one case reached the vertical angle, and one case reached it at C2 and C3. Putative screw lengths are presented in Table 4. From the line A to line C, the screw length was gradually increased. The minimum screw length

appeared on line A at VA was 7.42 ± 1.67 mm (4.84–11.52 mm) and the maximum value, on line B at LA, was 17.29 ± 4.54 mm (9.45–31.26 mm). At VA the optimal entry angle, the total mean screw length was 7.57, 10.13 and 15.6 mm at the optimal entry points, the candidate points and the limit entry points, respectively. The length of OA2, OC2, XA2 were 10.98 ± 1.42 mm (8.13–14.57 mm), 27.88 ± 2.85 mm (21.6–34.84 mm), 50.75 ± 3.67 mm (44.78–58.65 mm), respectively, and 0Y that the net cage or the autogenous bone graft required was 42.91 ± 2.93 mm (34.67–50.32 mm). The screw lengths results are displayed graphically in Fig. 4.

Compared with A2 at HA and VA, respectively, A1 and A3 all had significant decrease in screws length ($P < 0.05$). Multiple comparisons were carried out in HA, VA and LA at each entry point separately, and there was a significant difference at the points that located on the line A and line B ($P < 0.05$). Although length was higher in the LA than in the VA at the points of the line C, the difference was not statistically significant ($p = 0.82$).

Safe range of upper angulation

The bending angle of the plate or net cage required refer to the angle between the line XA2 and line A2C2 was

Table 1 The distance between the pharyngeal tubercle and the anatomical structure near clivus measured in bone specimens ($n = 41$) (mm)

Foramen lacerum	Carotid cannal	Jugular fossa	Hypoglossal canal	Occipital condyle	Foramen oval
Left					
15.03 ± 1.80 (11.46–18.52)	24.26 ± 2.05 (21.32–31.40)	25.12 ± 1.93 (21.24–29.96)	19.61 ± 1.44 (16.88–22.70)	15.65 ± 1.65 (12.52–19.06)	27.78 ± 1.97 (24.28–32.18)
Right					
14.68 ± 1.91 (10.68–18.52)	26.25 ± 2.26 (21.80–30.04)	25.01 ± 2.10 (20.18–29.00)	19.25 ± 1.22 (16.54–21.70)	15.60 ± 1.91 (11.34–20.12)	27.74 ± 1.42 (24.78–30.18)
Total					
14.85 ± 1.85 (10.68–18.52)	26.26 ± 2.14 (21.32–31.40)	25.06 ± 2.00 (20.18–29.96)	19.42 ± 1.34 (16.54–22.70)	15.63 ± 1.77 (11.34–20.12)	27.76 ± 1.71 (24.28–32.18)

Values are represented in mean $\pm$ SD

Table 2 The distance between the central line and the anatomical structure near clivus measured in bone specimens ($n = 41$) (mm)

Foramen lacerum	Carotid cannal	Jugular fossa	Hypoglossal canal	Occipital condyle	Foramen oval
Left					
10.60 ± 1.01 (8.58–12.34)	24.88 ± 2.27 (20.16–29.06)	22.81 ± 2.04 (18.58–26.84)	16.96 ± 1.35 (14.28–20.40)	9.68 ± 1.36 (7.06–12.92)	23.08 ± 1.57 (19.84–27.02)
Right					
10.08 ± 0.81 (8.00–12.04)	25.01 ± 2.17 (20.72–29.00)	23.20 ± 1.91 (19.18–27.64)	16.81 ± 1.20 (14.46–20.22)	9.48 ± 1.15 (7.56–12.18)	23.72 ± 1.91 (19.86–27.22)
Total					
10.34 ± 0.95 (8.00–12.34)	24.95 ± 2.21 (20.16–29.06)	23.01 ± 1.98 (18.58–27.64)	16.85 ± 1.25 (14.28–20.40)	9.58 ± 1.26 (7.06–12.92)	23.40 ± 1.77 (19.84–27.22)

Values are represented in mean $\pm$ SD

Table 3 The distance between the left and right side of anatomical structure near clivus measured in bone specimens ($n = 41$) (mm)

Foramen Lacerum	Carotid cannal	Jugular fossa	Hypoglossal canal	Occipital condyle	Foramen oval
18.93 ± 1.54 (15.30–23.44)	49.31 ± 4.16 (41.42–57.54)	44.17 ± 3.78 (35.62–51.08)	32.70 ± 2.09 (28.12–37.20)	16.54 ± 2.04 (11.18–21.78)	45.70 ± 3.36 (38.28–53.18)

Values are represented in mean ± SD

Table 4 Putative screw length ($n = 30$) (mm)

	HA	VA	LA
A1	8.13 ± 1.46 (5.69–12.31)	7.42 ± 1.67 (4.84–11.52)	13.49 ± 3.81 (6.55–21.05)
A2	8.37 ± 1.44 (5.69–11.95)	7.74 ± 1.72 (4.34–11.64)	13.60 ± 3.83 (6.26–20.76)
A3	8.16 ± 1.48 (5.69–11.95)	7.55 ± 1.72 (4.84–11.42)	13.44 ± 3.57 (6.55–20.85)
B1	11.60 ± 2.18 (8.28–17.34)	10.00 ± 2.16 (6.35–16.05) ^a	17.16 ± 4.94 (9.45–32.01)
B2	11.70 ± 2.19 (8.39–16.98)	10.12 ± 2.30 (6.32–15.99) ^a	17.23 ± 4.96 (9.71–31.66)
B3	11.78 ± 2.29 (9.42–8.28)	10.28 ± 2.46 (6.34–16.51) ^a	17.29 ± 4.54 (9.45–31.26)
C1	16.14 ± 2.50 (12.67–24.57)	15.71 ± 3.01 (10.10–19.33) ^b	16.67 ± 4.78 (10.93–28.26)
C2	16.06 ± 2.44 (12.78–22.76)	15.46 ± 3.11 (10.04–19.74) ^b	16.52 ± 4.44 (10.82–27.37)
C3	16.15 ± 2.47 (12.23–23.13)	15.63 ± 3.09 (10.08–21.54) ^c	16.69 ± 4.73 (11.02–27.75)

Values are represented in mean ± SD

^a 29 patients had this value

^b 13 patients had this value

^c 12 patients had this value

Fig. 4 Bar graph demonstrating the length of clival screws for the different entry point. **a** Significant difference compared with A2 group at HA ($P < 0.05$); **b** significant difference compared with A2 group at VA ($P < 0.05$); **c** significant difference compared with HA and VA on each point ($P < 0.05$). Error bars represent SD

130.19° ± 8.00° (114.41°–147.70°). It was the same as the LA at the entry points on line A; however, there were only 22 cases met it on line B and no case settled to it on

line C. LA that the maximum allowable upper angle at the point B1, B2 and B3, C1, C2 and C3 are show in Table 5. The total mean of the maximum upper insertion angle was approximately 125.23° and 85.72° at the entry points on line B and line C, respectively. C1 and C2 varied slightly, but there was no significant difference. Thus, there was a statistically significant intergroup difference between the B3 and B2 ($P < 0.05$) (Table 5).

Observation in fresh cadaver specimen

In Fig. 1, the clivus, pitched at a 45°, was composed of the basal part of the occipital bone and the corpus ossis sphenoidalis. It is commonly divided into the upper, middle, and lower clivus. The upper clivus runs from the dorsum sellae and posterior clinoid process to the plane of dorello's canal. The middle clivus extends from the petrous

Table 5 Limit entry angle at the point on the line C and line B ($n = 30$)

C1 ^a	C2 ^a	C3 ^a	B1 ^b	B2 ^b	B3 ^b
86.09 ± 23.05 (34.07–126.70)	86.64 ± 26.12 (37.18–151.05)	84.42 ± 22.22 (34.43–129.85)	125.71 ± 13.28 (77.49–147.70)	124.00 ± 14.47 (79.24–147.70)	125.99 ± 12.04 (89.13–147.70)

Values are represented in mean ± SD

^a No case settled to the bending angle

^b 22 cases settled to the bending angle

apex at dorello's canal to the pars nervosa of the jugular foramen, and the lower clivus is comprised between the pars nervosa of the jugular foramen and the foramen magnum. The intracranial surface of the upper two-thirds of the clivus faces the pons and the V–XII cranial nerves, the inferior one-thirds faces the basilar artery and ventral medulla oblongata, and is concave from side to side. The extracranial surface of the clivus gives rise to the pharyngeal tubercle at the junction of the middle and lower clivus. The upper clivus faces the roof of the nasopharynx that extends downward in the midline to the level of the pharyngeal tubercle. In the two sides of clival region, there were foramen lacerum, carotid canal, internal acoustic port, jugular foramen.

Discussion

The goals of clival screw are to provide immediate stability, improve fusion rates, diminish the need for postoperative external immobilization, and decrease rehabilitation time. Since Goel et al. [10] first reported a case of transoral plate and screw fixation of the clivus to the body of the cervical vertebra, several studies have been published using the clival screw fixation for the craniocervical region [8, 9]. However, the anatomy of the clivus and the geometry of the craniocervical junction present challenges for the placement of instrumentation, and also there are no literature that have document the entry point, trajectory, and optimal length of clival screws; our next logical step was to study the anatomic of clival screw fixation for the craniocervical region.

In our study, the values obtained from our specimens were useful to avoid damage to the internal carotid arteries and hypoglossal and abducens nerves during insertion of the screws to the clival bone. The longitudinal diameter of extracranial clivus derived from the bone specimens was 25.87 ± 2.64 mm (19.08–31.24 mm). Disparity from the 2-D CT measurements was noticeable, of which the average distance was calculated as 27.88 ± 2.85 mm (21.6–34.84 mm). And yet, the average distance between the point O and point A calculated on 2-D CT images was 10.98 ± 1.42 mm (8.13–14.57 mm), which was close to the position of pharyngeal tubercle that the distance from it to the anterior portion of the foramen magnum was 12.76 ± 1.56 mm (8.12–16.28 mm) measured on the bone specimens. The largest individual differences appeared between the left and right medial margin of outer entrance of carotid canal. Therefore, we should carefully operate and separate those structures to prevent the internal carotid injury. Pharyngeal tubercle as the important sign of the extracranial clivus due to the invariable position related to anterior margins of foramen magnum. Thus, on the threshold, we can take

it as the center, 15 mm as diameter, to safely dissect the soft tissue structures and expose the clivus.

The entry point and the insertion angle illustrate the screw placement. However, anatomic constraints limit the potential entry points and trajectories. In the clivus region, if the entry point is placed too laterally, for example, the internal carotid or the inferior petrosal sinus is placed at risk. A very upper entry point, on the other hand, may cause the screw to be inserted into the sphenoidal sinus and also may place the pituitary and even the hypothalamus at risk. Also, the vertebral artery and the hypoglossal nerve and even the medulla oblongata may be injured if the entry point is placed too inferior posterior. In addition, even if these structures are not directly injured, if the lateral cortex of the clivus is violated, it might cause intracranial hemorrhage near the pons and ventral medulla oblongata, which could be fatal. Therefore, on the extracranial clivus, nine entry points were determined. And a working knowledge of the anatomy of the clivus region is imperative, for its anatomical borders and related structures greatly affect the surgical procedure.

Other important anatomic considerations include the relationship of the sphenoid sinus and the clivus during the screws insertion. The sphenoid sinus varies in shape and size and is asymmetrically divided into two parts by an irregular septum, even in the same sphenoid the left and right pneumatization may completely differ, and then affect its relations to surrounding structures [18], especially the entry angle and the corresponding length of clival screws at the entry points. The sphenoid sinuses can be classified into three types: conchal type, pre-sphenoid type, post-sphenoid and occipital types in which the pneumatization extends backwards below the hypophyseal fossa and sometimes into the occipital bone [19]. In our CT image research, there were 3 conchal types, 15 pre-sphenoid types, 12 post-sphenoid and occipital types.

On our measurement of screws, due to the relationship of the sphenoid sinus and the clivus, 13 cases met the vertical angle at C1 and C2, 12 cases met it at C3, 22 cases met the bending angle on line B and no case settled to it on line C. We suggest that when applying clival screw fixation, the length of screw should range from 7.42 to 17.29 mm below the maximum upper insertion angle range from 84.42° to 130.19° for safety. With this placement, the screw will not injure the surrounding structure or enter the skull. The actual length and entry angle of screw should be determined by combining preoperative X-ray and CT images, and image guided placement should be used during surgery. Compared with A2 at HA and VA, A1 and A3 all has significant decrease in screws length, it may have been because the position of the point A2 was close to the pharyngeal tubercle, arising from the surface of extraocular clivus.

When it comes to the surgical approach, a wide range of anterior approaches have been proposed to reach different parts of clivus. Suchomel et al. [8] created a small right-sided submandibular channel through the floor of the mouth at vertical angle via an oral surgical route for anticipated clival screws. Rawins et al. [9] gained access to the anterior upper cervical spine and expose clivus through a mandibular osteotomy and soft palate split. However, all have been developed using two basic anterior midline routes, the transnasal and the transoral [20, 21]. Anterior approaches to the cervical vertebral junction and clivus were originally proposed for the treatment of vertebro-basilar aneurysms [22, 23] or neoplasms [24]. Anterior access route includes the transseptal–transsphenoidal, transmaxillary, transpalatal and transoral–transpalatal, transmandibular, transmaxillary–transnasal, and the facial translocation approaches [25–31]. And now the endoscopic approach to the clivus has become a well-established alternative to traditional surgery. It provides a thorough transnasal exposure of the area, which can be clearly visualized with angled endoscopes [18]. In our study, for the clival screws fixation at the horizontal angle (HA), we can choose the transmaxillary–transnasal, the transmaxillary, the transpalatal and transoral–transpalatal. At the vertical angle (VA), it can be achieved by the transmaxillary, the transpalatal and transoral–transpalatal approach. With respect to the limit angle (LA), at a relatively larger angle, the transcervical approaches can implement the screw placement, and yet, the transsubmandibular, transoral–transpalatal, and the transmaxillary may be selected to achieve the fixation procedure at a smaller angle. However, every surgical approach to clivus has potential complications. It mainly includes bleeding, infection, dysphagia, plate dehiscence, CSF leakage and meningitis [17, 32].

The risks associated with this technique are substantial, and thus we recommend this to be used only in unique cases after meticulous preoperative planning. Preoperative image studies include coronal, axial, and sagittal CT images may be of benefit not only in determining the feasibility of the technique before surgery, but also when used in conjunction with an image-guidance system in intraoperative, determination of entry and target points, screw trajectory, and optimal screw length.

Limitations of this study

In this study, gender, age, race, and original diagnoses were not considered. The variation of upward angulation and screw length shown in this study might, at least in part, originate from this diversity. Next, this study mainly focused on bony structures and gave less consideration to soft tissues such as anomalies of the vertebral artery. Furthermore, to insert the screw at the entry points on superior

portion of the extracranial clivus may be difficult in some cases because anatomic variations of the sphenoid sinus are common and the inferior wall is very thin in well-developed sphenoid sinuses. Finally, biomechanical testing protocol was required to evaluate clival screws fixation.

Conclusion

Clival screw placement is a viable option for craniovertebral fixation especially for the anterior reconstruction after the tumor resection in the atlanto-axials. The parameters obtained in the present study will be helpful for anyone contemplating the use of clival screw fixation. The results of the current study showed there is an optimal entrance angle and a safe scope for the screw length and angle of the screw placement that, if followed, should minimize adverse consequences. Also it is recommended that close study of the thin-cut CT images of the clivus region and surrounding structures prior to surgery to determine feasibility and plan clival screw placement.

Acknowledgments Supported by Zhejiang Top Key Discipline of Surgery, National Natural Science Foundation of China (30700843).

Conflict of interest None.

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