Ideal screw entry point and projection angles for posterior lateral mass fixation of the atlas: an anatomical study

Serkan Simsek · Kazim Yigitkanli · Hakan Seçkin ·
Ayhan Comert · Halil I. Acar · Deniz Belen ·
İbrahim Tekdemir · Alaittin Elhan

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Abstract Although various posterior insertion angles for screw insertion have been proposed for C1 lateral mass, substantial conclusions have not been reached regarding ideal angles and average length of the screw yet. We aimed to re-consider the morphometry and the ideal trajections of the C1 screw. Morphometric analysis was performed on 40 Turkish dried atlas vertebrae obtained from the Department of Anatomy at the Medical School of Ankara University. The quantitative anatomy of the screw entry zone, trajectories, and the ideal lengths of the screws were calculated to evaluate the feasibility of posterior screw fixation of the lateral mass of the atlas. The entry point into the lateral mass of the atlas is the intersection of the posterior arch and the C1 lateral mass. The optimum medial angle is $13.5 \pm 1.9^\circ$ and maximal angle of medialization is $29.4 \pm 3.0^\circ$. The ideal cephalic angle is $15.2 \pm 2.6^\circ$, and the maximum cephalic angle is $29.6 \pm 2.6^\circ$. The optimum screw length was found to be 19.59 ± 2.20 mm. With more than 30° of medial trajections and cephalic trajections the screw penetrates into the spinal canal and atlanto-occipital joint, respectively. Strikingly, in 52% of our specimens, the height of the inferior articular process was under 3.5 mm, and in 70% was under 4 mm, which

increases the importance of the preparation of the screw entry site. For accommodation of screws of 3.5-mm in diameter, the starting point should be taken as the insertion of the posterior arch at the superior end of the inferior articular process with a cephalic trajection. This study may aid many surgeons in their attempts to place C1 lateral mass screws.

Keywords Atlas · C-1 · Entry zone · Lateral mass screw · Morphometry · Trajection

Introduction

The anatomy of the atlantoaxial region is complex, and instrumentation of the C1 and C2 vertebrae is technically demanding. Although numerous techniques have evolved to treat C1–C2 instability, studies have showed that C1–C2 posterior fusion with screw and rod fixation has superiority over other methods [8, 9, 11, 18]. Hence, atlantal lateral mass screw fixation technique is being widely used for various atlantoaxial problems such as traumatic, degenerative, and tumorous disorders [1, 2, 8–11, 15, 16, 18]. The method was clinically introduced by Goel and Laheri [8], and popularized later by Harms and Melcher [11], who adapted this technique to polyaxial screw and rod systems. Although the technique is frequently performed in upper cervical instabilities and quantitative information concerning the lateral mass of the atlas is well-known, no clear consensus has been reached on the ideal screw projection of the C1 lateral mass [13, 17, 19]. The purpose of this study is to evaluate meticulously the ideal key points for posterior C1 lateral mass screw fixation. Thereby, the entry point and the projection angles of the screw, and optimum screw lengths are re-considered.

S. Simsek · K. Yigitkanli (✉) · H. Seçkin · D. Belen
Ministry of Health, Ankara Diskapi Training and Research
Hospital, 2nd Neurosurgery Clinic, Şehit Osman Avcı Mah.,
46645 Ada, B28, KC Lale Evleri,
Eryaman, Ankara 06110, Turkey
e-mail: doktorkazim@mynet.com

A. Comert · H. I. Acar · I. Tekdemir · A. Elhan
Department of Anatomy of the Medical School,
Ankara University, Ankara, Turkey

Materials

Forty dry human adult Turkish C1 dried vertebrae were obtained from the Department of Anatomy of the Medical School, Ankara University. For vertebrae measurements, the calculations were obtained directly from the specimens. Moreover, all the angles were additionally calculated from digital photographs. The lengthwise dimensions were measured by using a digital caliper (YATO Electronics Co., Ltd, Tokyo, Japan, degree of accuracy: 0.01 mm) and the angles were measured by a protractor (degree of accuracy: 1°) from the digital photographs. For better evaluation of the geometry of the lateral mass and the dimensions of the entry zone, eight parameters were calculated: M1: Distance from the midline to middle of the superior facet, M2: Distance from the midline to medial wall of the vertebral artery (VA), M3: Distance from the midline to inner edge of the pedicles, M4: Width of the lateral mass, M5: Height of the lateral mass, M6: Height of the C1 lateral mass entry zone (Distance from the inferior midpoint of posterior arch to the edge of the inferior joint), M7: Height of the posterior arch of the C1, and M8: Width of the C1 entry zone (distance from the medial edge of the inferior articular process to the lateral edge at the suggested entry point of the screw).

The ideal starting point for posterior screw insertion is the insertion of the inferior posterior C-1 arch at the midpoint of the C-1 lateral mass. While the vertebral artery

travels laterally, the screw is projected medially. Inferiorly, the atlantoaxial joint is located; thus, the cephalic angle must be attained sagittally. The sagittal and axial angles of the ideal screw path were calculated as superior and medially. The ideal end-point was determined as the superior base of the superior border of the anterior tubercle that is 4–5 mm below the superior articular joint anterior end at the midpoint of lateral mass anteriorly on the vertical plane ($\alpha 2$). In addition, the sagittal angle of the tip of the anterior tubercle at the same axial angle was measured as a reference angle ($\alpha 1$) and antero-superior border of the superior articular joint of lateral mass, as cephalic maximum angle of the screw ($\alpha 3$). To calculate the ideal medial angle the midline of the anterior surface of the lateral mass was considered at the axial plane ($\beta 1$), to calculate the maximal medial angle, the reference point was considered the junction between the anteriomedial end of lateral mass and anterior arch of the atlas at the axial plane ($\beta 2$).

Results

Forty paired Turkish dried C1 vertebrae were studied; the mean, standard deviation, and range of each parameter measured for the left side and the right side as well as for bilateral sides were recorded and listed separately in Table 1. No significant differences were found between the left and right sides in this measurement ($P > 0.05$). The

Table 1 The results of measurement of the 40 cases of the atlas

Definition	Right		Left		Bilateral	
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
M1 Distance from the midline to middle of sup facet (mm)	18.55 $\pm$ 1.7	14.75–22.05	18.77 $\pm$ 1.5	14.87–21.66	18.66 $\pm$ 1.6	14.75–22.05
M2 Distance from the midline to medial wall of VA (mm)	22.52 $\pm$ 1.6	19.65–26.37	22.45 $\pm$ 1.8	19.42–27.71	22.49 $\pm$ 1.7	19.42–27.71
M3 Distance from the midline to inner edge of pedicles (mm)	14.05 $\pm$ 1.3	11.9–17.33	14.08 $\pm$ 1.4	11.47–17.75	14.06 $\pm$ 1.3	11.47–17.75
M4 Width of the lateral mass (mm)	11.91 $\pm$ 1.3	9.20–15.63	12.73 $\pm$ 1.1	9.70–15.03	12.32 $\pm$ 1.3	9.2–15.63
M5 Height of the lateral mass	28.83 $\pm$ 2.5	24.19–37.75	30.09 $\pm$ 2.6	26.3–37.05	29.46 $\pm$ 2.6	24.19–37.75
M6 Height of the C1 lateral mass entry zone (Distance from inferior midpoint of posterior arc to edge of the inferior joint) (mm)	3.37 $\pm$ 0.9	1.02–5.57	3.94 $\pm$ 0.7	2.00–5.45	3.66 $\pm$ 0.8	1.02–5.57
M7 Height of the posterior arch of the C1 (mm)	4.03 $\pm$ 0.7	2.97–5.93	4.37 $\pm$ 2.1	2.50–11.71	4.22 $\pm$ 2.7	2.5–11.71
M8 Width of the C1 entry zone (mm)	8.32 $\pm$ 2.0	5.96–13.04	8.56 $\pm$ 2.19	5.23–12.76	8.48 $\pm$ 2.28	5.23–13.04
$\alpha 1$ Sagittal angle of the tip of the anterior tubercle (°)					5.9 $\pm$ 2.62	2–14
$\alpha 2$ Ideal sagittal angle (°)					15.2 $\pm$ 2.6	10–22
$\alpha 3$ Maximal sagittal angle (°)					29.6 $\pm$ 2.6	20–34
$\beta 1$ Ideal medial angulation (°)	13.5 $\pm$ 1.9	10–18	13.4 $\pm$ 1.8	10–17	13.5 $\pm$ 1.9	10–17
B2 Maximal medial angulation (°)	29.4 $\pm$ 3.0	24–35	29.4 $\pm$ 3.0	25–35	29.4 $\pm$ 3.0	24–35

Fig. 1 The photograph of the C1 dry vertebra showing, M1: Distance from the midline to middle of the superior facet, M2: Distance from the midline to medial wall of the vertebral artery (VA), M3: Distance from the midline to inner edge of pedicles, M4: Width of the lateral mass, M5: Height of the lateral mass, M6: Height of the C1 lateral mass entry zone (Distance from inferior midpoint of posterior arch to edge of the inferior joint), M7: Height of the posterior arch of the C1, and M8: Width of the C1 entry zone (distance from the medial edge of the inferior articular process to the lateral edge at the suggested entry point of the screw

width of the screw entry zone was calculated as 8.48 ± 2.28 mm (5.23–13.04 mm). The distance from the insertion point of the screw to the edge of the inferior joint was under 3.5 mm in 26 (52%) of the specimens and under 4 mm in 35 (70%) of the specimens (Table 1; Fig. 1a, b).

The path and angulation of the screw placement relative to the sagittal plane (β) and the axial plane (α) were measured (Table 1; Fig. 2a, b). The mean ideal angle of medialization relative to the axial plane was approximately 14° ; the mean maximum angle of medialization was 30° . Because the bilateral angulations were overlapping on the lateral digital radiographs, the angulations of the screw placement relative to the sagittal plane had only one outcome instead of left and right. The mean maximum superior angulation for screw placement relative to the sagittal plane was 30° ; the ideal superior angulation was 13.5° and the superior angulation of the tip of the anterior tubercle was 6° (Table 1; Fig. 2a, b).

The ideal length of the screw inside the lateral mass was calculated according to the suggested trajectories as 19.59 ± 2.20 mm (15.45–24.34 mm) (Table 2).

Fig. 2 The photographs of the ideal angulations in degrees, according to the suggested entry point inside the lateral mass relative to the sagittal plane (α) and the axial plane (β). On the sagittal plane, α_0 : sagittal angle taken from the entry point parallel to the posterior arch of the C1, α_1 : sagittal angle of the tip of the anterior tubercle, α_2 : the ideal sagittal angle superior to the anterior tubercle, and α_3 : maximal sagittal angle at the superior edge of the lateral mass anteriorly (a). On the axial plane, β_1 : ideal angle of medialization and β_2 : maximal angle of medialization (intersection between the medial end of the lateral mass and the anterior arch) (b)

Discussion

Fixation of C1–C2 with lateral mass/pedicle-screw and rod placement provides immediate stability and has technical advantages compared with other atlantoaxial fixation procedures, including wire/cable and transarticular fixations [1, 2, 8–11, 15, 16, 18]. Particularly with the advent of polyaxial screws, intraoperative reduction of the C1–C2 deformity has become an available procedure in suitable cases [1, 2, 8–11, 15, 16, 18]. Moreover, in this technique C1 lateral mass screw placement can be used when precise anatomical knowledge is gained. These conclusions have increased the importance of the feasibility of posterior C1 lateral mass screw fixation in recent years.

Table 2 The results of ideal length of the C1 screw at the ideal trajectories

Definition	Right		Left		Bilateral	
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
L Ideal length of the screw	19.74 $\pm$ 2.09	16.00–24.30	19.43 $\pm$ 2.32	15.45–24.34	19.59 $\pm$ 2.20	15.45–24.34

In posterior lateral mass fixation technique, the geometry of lateral mass should be understood precisely. By examining the lateral mass anatomy, it can clearly be observed that there is reasonably protected space for insertion of appropriate screw into the lateral mass of the atlas [3, 5]. The dimension of this space, which is called the entry zone, is highly variable in the literature [3, 13, 17, 19]. The next query is to locate the ideal screw insertion point on the posterior aspect of the lateral mass. Goel et al. [8, 9] prefer to insert the screw at the center of the posterior surface of the inferior articular process, 1–2 mm above the articular surface. Harms and Melcher [11], defined the insertion point at the midpoint of the posterior surface of the inferior articular process at the junction of the posterior arch and the lateral mass. The present study confirmed the same spot with dry vertebrae measurements with close attention to the entry point and the dimensions of the entry zone.

The width of the entry zone of the screw under the posterior arch is 8.48 ± 2.28 mm with a range of 5.23–13.04 mm, but the height of the C1 entry zone is 3.66 ± 0.8 mm. In 52% of our specimens, the length (the height of the entry zone) of the inferior articular process was less than 3.5 mm, which makes it difficult to accommodate 3.5 mm screws. This result is not concordant with the findings of previous studies, which may be associated with racial differences. Only Wang and Samudrala [19] found that 41% of their specimens had a height less than 3.5 mm, and 65% had an entry height of less than 4 mm, which is similar to our study. In other studies, the height of the entry zone was bigger than 3.5 mm in all of the specimens [13, 17]. Rocha et al. [17] stated that partial removal of the inferior portion of the posterior arch was necessary to facilitate placement of a 4-mm screw in half of their C-1 specimens. We suggest that for accommodation of screws of 3.5-mm in diameter, the starting point should be taken as the insertion of the posterior arch at the superior end of the inferior articular process with a cephalic trajectory (Fig. 3). A 3.5 mm screw would have a radius of 1.75 mm. The trajectory is medial and superior. For that reason, the screw radius could probably be within the inferior articular surface of C1 and the base of the posterior arch and, still the screw can be placed safely and obtain adequate bone purchase. It is important to take care of the entry site of the screw, because the height between the vertebral artery groove and the suggested entry point is only 4.02 mm (range 2.5–13.1 mm).

Fig. 3 The photograph of the suggested entry point and cephalic trajectory of the screw

Several medial and lateral screw trajectories have been suggested in the literature. In a study by Rocha et al. [17] the maximum angle of medialization from the midline was calculated as $16.7 \pm 1.3^\circ$ (range: 14.6 – 20.7°). Hong et al. [13] reported the screw angulation to be 14.7° relative to the axial plane. We found the ideal medial angulation as $13.5 \pm 1.9^\circ$ and the maximal medial angulation as $29.4 \pm 3.0^\circ$. Wang and Samudrala [19], calculated the medial angulation between 25 and 45° , which is greater compared to the angles defined in our study. According to our results, with more than 30° of medial trajectories, the screw penetrates into the spinal canal.

The mean maximum superior angulation for screw placement was found to be $21.7 \pm 4.7^\circ$. Hong et al. [13] defined the sagittal angulation as 22.9° . In our study, the ideal sagittal angle was determined to be $15.2 \pm 2.6^\circ$, and the maximal cephalic angle, $29.6 \pm 2.6^\circ$, which suggests that higher trajectories of the screw penetrates to the atlantooccipital joint. In addition, the sagittal angle of the tip of anterior tubercle was calculated as $5.9 \pm 2.62^\circ$, which may be used as a reference point at fluoroscopy of the lateral projection.

Planning the bicortical placement of C1 screws is important to have better bone purchase [11]. The thickest and most dense cortical bone was found in the anterior cortex of the anterior ring, suggesting that the strongest screws would be placed bicortically [6]. Although the strength of the bicortical C1 lateral mass screws was significantly higher than that of the unicortical screws according to the study of Eck et al. [7], these authors recommended the use of unicortical C1 screws because of potential catastrophic complications and only in patients with severe osteoporosis or inflammatory diseases

(rheumatoid arthritis), to avoid poor screw purchase, bicortical placement was considered.

Neurovascular structures anterior to the C1 lateral mass is also at risk [4, 12, 14]. Internal carotid artery may be located within 1 mm of the ideal exit point of the C-1 lateral mass screw [3, 4]. Therefore, the depth of the screw inside the lateral mass is of importance. In our study, the ideal length of the screw inside the lateral mass was determined to be 19.59 ± 2.20 mm. Similarly, in the study by Hong et al. [13] the mean screw length in the lateral mass was found to be 22 mm. Wang and Samudrala [19], calculated the minimal screw depth as 14.4 ± 2.0 mm and maximal screw length as 22.5 ± 2.6 mm inside the lateral mass. These parameters are the screw depths inside the lateral mass. Actual screw length increases to place the rod to the polyaxial head of the screw, because of the overlying posterior arch of the C1. Rocha et al. [17] calculated the ideal screw length with the overlying C1 posterior arch as 26–34 mm (mean: 30.4 mm).

Based on the findings in our study and the brief review of the literature, it can be said that there are significant variations in the morphology and thus, in the ideal angulations of the C-1 lateral mass screw fixation. It would be of interest for future studies to compare morphometric data with CT-derived data to determine this accuracy.

For an ideal atlas screw placement, preoperative computed tomography scans of the C-1 anatomy and the ideal trajections should be precautiously calculated. Intraoperative fluoroscopy may be useful, and the tip of the anterior tubercle of the C-1 lateral mass is good a reference point for the ideal sagittal angulation of the screw. Spinal navigation is another option to make C1 screw placement safer. The transection between the superior end of anterior tubercle and the lateral mass should be taken at ideal sagittal cephalic angulation. The ideal cephalic direction of the screw should be about 15° anterosuperior on the sagittal plane and 14° inward on the vertical plane. With more than 30° of medial trajections, and cephalic trajections the screw penetrates into the spinal canal and atlantooccipital joint, respectively. Strikingly, in 52% of our specimens, the height of the inferior articular process was under 3.5 mm, which increases the importance of the preparation of the screw entry site. This study may aid many surgeons in their attempts to place C1 lateral mass screws.

Conflict of interest statement No financial disclosure.

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