Anterior pedicle screw fixation of C2: an anatomic analysis of axis morphology and simulated surgical fixation

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Abstract

Study design Human cadaveric study measuring the morphology of C2 vertebra, description of anterior placement of pedicle screw with post-fixation computed tomography (CT) analysis.

Objective To assess the potential feasibility and safety anterior placement of C2 pedicle screws.

Summary of background data Posterior pedicle screw fixation has become an established technique for upper cervical reconstruction. To our knowledge few reports in the previous literature have described the placement of or anatomy related to anteriorly approach C2 pedicle screws.

Methods The morphology of 60 human C2 vertebrae was measured directly to assess the size, position, and relative approach angle of the pedicles from an anterior perspective. In an additional 20 cadaveric cervical spines, bilateral 3.5 mm titanium C2 pedicle screws were placed and analyzed for pedicle morphology and placement accuracy with thin cut, 1 mm axial CT.

Results The mean C2 pedicle width measured directly and by CT scan was 7.8 and 6.6 mm, and the average length of the right and left pedicle was 26.4 and 25 mm, respectively. The mean transverse angle (α) was 17.6° and 21.4°, whereas declination angle (β) anterior to posterior was 13.8° and 10.6°, respectively.

Conclusions Quantitative data regarding C2 pedicle shape and location with respect to the anterior placement of pedicle screws have not been previously reported. This study indicates that anterior placement of 3.5 mm C2 pedicle screws through a transoral approach may be both feasible and safe and also provides an important anatomic analysis that may guide clinical application.

Keywords C2 · Anatomy · Pedicle screw · Transoral approach · CT scans

Introduction

Many instrumentation systems have successfully been used for treating atlantoaxial pathologies, instability, or dislocation in the cervical spine [1–3]. Wiring techniques have been improved by newer screw techniques, including the C2 transarticular, posterior pars, pedicle or translaminar techniques [4–6]. Although these screw techniques have been used successfully, they may carry a risk of construct failure, screw loosening, or vertebral artery injury due to poor bone quality or challenging posterior and posterolateral morphology and anatomic variations.

More recently, techniques have been developed utilizing C1 and C2 screws and rod systems, rather than plating, in attempts to increase the utility of the fixation method across various pathologies and complex anatomy. The application of posterior C2 pedicle screws has been proposed to

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Fig. 1 Direct and radiographic measurements of C2 pedicular anatomy and anterior screw placement trajectory. $L1$ distance from screw entry point to the sagittal midline, $L2$ distance from screw entry

point to internal edge of transverse foramen, $L3$ length of the screw projection. α Transverse angle, β declination angle

Fig. 2 C2 pedicle screw showing in coronal (a), axial (b), and sagittal (c) CT orientations. $L1$ distance from screw entry point to the sagittal midline, $L2$ distance from screw entry point to internal border

of transverse foramen, $L3$ length of the screw projection. α Transverse angle, β declination angle

overcome fixation limitations at this level, in part, because of high pullout strength [7]. However, these techniques require posterior approaches for application, which increases morbidity as well as the risk for neurologic damage and infection. The feasibility of anterior pedicle screws for the axis, which represents a useful option for pathologies that are intrinsically better approached anteriorly, is heretofore unreported. Therefore the purpose of this study was to undertake a quantitative evaluation of the relevant C2 anatomy, and to determine overall feasibility of anterior C2 pedicle screws and locate the potential safe entry point.

Materials and methods

Sixty paired adult Chinese cadaveric axis specimens were obtained from the Department of Anatomy, Southern Medical University, Guangzhou, People's Republic of China. In these 60 C2 vertebrae, direct measurements were taken using a high precision digital caliper (precision 0.01 mm, YATO, Tokyo, Japan) as part of a morphometric analysis of C2 pedicles and approach angles for anterior placement of pedicle screws. An additional 20 complete human cadaveric cervical spines were analyzed for placement accuracy and pedicle morphology following placement of anterior pedicle screws using computed tomography (CT). 3.5 mm pedicle screws (Medtronic Sofamor Danek, Memphis, TN) were placed through a

transoral approach and assessed using thin-cut (1 mm) axial CT (Siemens, Germany). The safe C2 pedicle screw entry (O) was 5 mm below the vertex point of margo medialis of superior articular surface of axis in transoral approach (Fig. 1a). The measurement parameters were all made bilaterally and follow: L1, distance from screw entrance point to sagittal midline (Fig. 1a); L2, distance from screw entrance point to the medial border of transverse foramen (Fig. 1a); L3, the length of screw projection (distance from the screw entry point to the nutrient foramen) (Fig. 1c); α , extraversion angle (Fig. 1b) and β , declination angle (Fig. 1c).

Data analysis

Statistical analysis was performed using the SPSS 15.0 software package. Frequency statistics were used to characterize direct and CT measurement results and students *t* tests were performed to evaluate any morphological differences between left and right pedicular anatomy. Statistical significance was evaluated at $p < 0.05$.

Results

Direct quantitative measurements in 60 C2 vertebrae evaluated showed a mean distance from anterior screw entry point to anterior midline (L1) of 7.8 mm (stdev 0.74 mm) and from the screw entry point to the internal

Table 1 Anatomic parameters of C2 anterior pedicles with respect to an anterior approach for pedicle screw placement: $n = 60$

Parameters	Left		Right		Bilateral	
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
L1	7.98 $\pm$ 0.79	6.00–9.42	7.62 $\pm$ 0.68	6.48–8.94	7.80 $\pm$ 0.74	6.00–9.42
L2	5.27 $\pm$ 1.39	3.34–7.66	6.82 $\pm$ 1.68	4.12–9.88	6.07 $\pm$ 1.72	3.34–9.88
L3	26.5 $\pm$ 1.38	24.12–30.24	26.20 $\pm$ 1.67	23.14–29.68	26.38 $\pm$ 1.53	23.14–30.24
α	17.79 $\pm$ 4.01	11.1–28.3	17.32 $\pm$ 3.89	9.3–26.0	17.55 $\pm$ 3.93	9.3–28.3
β	13.63 $\pm$ 3.60	6.5–21.5	13.94 $\pm$ 3.81	7.1–21.5	13.82 $\pm$ 3.67	6.5–21.5

Table 2 CT measurements of anterior pedicle screw of axis: mean $\pm$ SD (min–max), $n = 20$

Items	Left		Right		Bilateral	
	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range	Mean $\pm$ SD	Range
L1	6.66 $\pm$ 2.0	5.50–9.01	6.53 $\pm$ 2.0	5.30–9.02	6.62 $\pm$ 2.0	5.30–9.02
L3	24.02 $\pm$ 2.0	22.80–26.02	26.10 $\pm$ 2.0	24.10–28.5	25.10 $\pm$ 2.0	22.80–28.5
α	20.13 $\pm$ 1.87	18.3–23	22.58 $\pm$ 1.32	21.5–24.8	21.36 $\pm$ 2.00	18.3–24.8
β	10.70 $\pm$ 3.60	6.5–11.8	10.32 $\pm$ 4.7	6.2–14.1	10.6 $\pm$ 1.93	6.2–14.1

Fig. 3 Postoperative radiograph and CT scans of a 55-year-old man with irreducible atlantoaxial dislocation along with no complications. **a** Anterior–posterior radiograph, **b** lateral radiograph, **c** axial CT, **d** coronal CT

edge of the transverse foramen (L2) of 6.07 mm (stdev 1.72 mm). In six patients (10 %), the distance from the anterior pedicle screw entry point and the transverse foramen at C2 was less than 4 mm. Mean screw projection length (L3) was 26.38 mm (stdev 1.53 mm), transverse angle (α) was 17.55° (stdev 3.93°) and declination angle (β) was 13.82° (stdev 3.67°) (Fig. 2).

In a comparison of mean left and right parameters, no statistically significant differences were observed between any distance or angular measurements, $p > 0.05$, Tables 1, 2.

Discussion

In recent years, myriad fixation techniques for the upper cervical spine have been described. Efforts in this difficult patient population have centered on providing rigid internal immobilization while minimizing the risk of vertebrae artery injury [8, 9]. Recently, several studies have focused on increasing fusion rates of atlantoaxial articulate through additional fixation [10, 11].

The anatomical characteristics of C2 are different in practice from other cervical vertebrae, namely in the

localization of the pedicle and pars interarticularis [12, 13]. Borne et al. [14] explained that the true pedicle of C2 was the narrow portion joining the odontoid base to the superior articulating process while the isthmus is the portion located between the superior and inferior face. Conversely, Yarbrough and Hendey [15] reported the pedicle lies between superior–inferior articular processes. Naderi et al. [16] considered the pedicle and isthmus as a single pediculo-isthmus component. In our understanding and consistent with the current results, the pedicle of the C2 vertebra is the portion between the superior facet and anteromedial to the transverse foramen while the isthmus is the narrower portion between the facets [17].

This study aimed to measure the relevant anatomy and assess the feasibility of anterior pedicle screw of C2 quantitatively. We quantitatively measured 60 cadaveric C2 vertebrae and 20 dry specimens by CT scans, observing the parameters of pedicle screw entrance and calculating the obliquity of the pedicle.

No quantitative information about the anterior pedicle screw of axis was found in the previous literature, so current results were not able to be compared to historical results. Rather, these results represent, to our knowledge, the first reporting of detailed C2 pedicular anatomy and the anterior approach to transpedicular fixation.

Limitations of this study include the relatively small number of cadaveric specimens assessed by CT scans and a wide variation in the size of C2. In addition, as this was primarily an anatomic and cadaveric feasibility study, the risks of the approach and procedure, including neurologic or vascular impingement, need further study in vivo.

Concerning the screw entrance point and obliquity of axis according to the observation of specimen and measurements, the results show that the pedicle screw remained intra-osseous when using “O” (Fig. 1a) as the entry point. With respect to this, the distance from the screw entry point to atlantoaxial joint articular surface was 5 mm, L1 was 7 mm, α was 18° , and β was 14° . In general, there was approximately 6 mm space between the screw entry point and the medial border of the transverse foramen, providing a meaningful distance between the screw and its trajectory and vascular anatomy. Additionally, with the anterior transoral approach, direct visualization of these structures are possible, unlike in a posterior approach. Preoperative planning should include careful analysis of thin-cut axial and coronal/sagittal reconstruction CT scans from C0 to C3 in all patients being treated for atlantoaxial instability (Fig. 3) with transpedicular fixation, whether performed through an anterior transoral or posterior approach [18].

Conclusion

The dimensions of C2 pedicle are capable of accommodating 3.5 mm C2 pedicle screw from an anterior transoral approach. However, preoperative CT scans should be evaluated in all patients with atlantoaxial instability to determine the feasibility of this technique. The relative advantages and disadvantages of anterior and posterior C2 pedicle screw techniques require further study in the clinical setting.

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Conflict of interest There is no actual or potential conflict of interest in relation to this article.

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