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A STUDY OF MORPHOMETRIC ANATOMY OF AXIS VERTEBRAE AND ITS CLINICAL IMPORTANCE

Jayshree Patel, Meenakshi bansal, *Dipal Arya and Mehta C.D.

Department of Anatomy, Government Medical College, Surat, India *Author for Correspondence

ABSTRACT

The axis (second cervical vertebra) is unique in possessing the dens or odontoid process and very specialized superior articular facets. The study was carried out to gather the metrical data of this atypical cervical vertebra. Forty dried intact human axis vertebrae were measured using digital vernier caliper accurate up to 0.01 mm. Various linear measurements of body, dens, pedicle, superior and inferior articular facets were studied .The mean width of the dense axis was 9.67mm and mean height was 11.84mm. The mean height of anterior corpus axis was 20.09mm.The mean maximum length and width of superior articular facet were15.37mm and 14.16mm respectively. All the measurement were observed to be more on the left side than on the right and all these differences were statistically insignificant. The data in this study should be useful to surgeons while working around the second cervical vertebra to avoid injury to the vital structures. The anatomy of the vertebrae exhibits complex, three-dimensional structures, showing extensive variability in morphology. Characteristics of the axis vertebrae must be noted before any spinal operation such as trans-pedicular screw fixation, trans-articular screw fixation, screw fixation of dens axis, inter-spinous wiring, and inter laminar clamp.

Keywords: Axis, Dens, Morphometry

INTRODUCTION

The second cervical vertebrae, namely the axis (C2), have different anatomical features from other cervical vertebrae. Various surgical techniques such as inter-laminar clamp, inter-spinous wiring, plate and screw fixation have been currently employed to correct the instability of the atlanto-axial complex caused by numerous traumatic and non-traumatic conditions. Recently, transarticular and transpedicular screws fixation have been widely used in stabilizing the cervical column (Apfelbaum, 1995; Dickman and Hurlbert, 1998; Gupta and Goel, 2000; Gottlieb, 1994; Madawi *et al.*, 1997; Mandel *et al.*, 2000). In spite of the benefits conferred by transpedicular screw fixation in the cervical column, controversy exists regarding its potential risks. Incorrect insertion of pedicle screws can cause damage to adjacent vital structures such as the spinal cord, nerve roots, cranial nerves and vertebral arteries. Clinically, iatrogenic injury to the vertebral artery during an approach to the atlanto-axial region is rare, but has a potential hazard (Ebraheim *et al.*, 1998; Gottlieb, 1994; Karaikovic *et al.*, 1997). This study aims to evaluate the various dimensions of the axis vertebrae quantitatively and analyze their relationship with the vertebral artery foramen, in addition to determining the safe sites for different surgical approaches.

MATERIALS AND METHODS

Forty human C2 vertebrae from the department of anatomy Government Medical College and SMIMER medical college, Surat were examined. All samples were inspected to ensure that the vertebrae were intact and free from osteophytes or metastatic tumour before measurements were made. All parameters were measured using a vernier caliper accurate to 0.01 mm for linear measurements. Different parameters for C2 as described in (Figures 1-3 and Table 1) were defined and measured.

Figure 1: Vernier caliper and Axis vertebrae



Figure 2: Description of axis measurements taken from the anterior - posterior aspect

The width of dens axis was measured as the widest diameter of dens axis on coronal plane (**A**). The height of dens axis was measured as the distance from the tip of dens axis to the horizontal line, which arbitrarily passed superior to superior articular facets of axis (**B**). The height of the anterior corpus axis was measured as the distance from the line, which arbitrarily passed superior to superior facets to the lowest point corpus of axis on midline (**C**). The distance of the superior articular facet was measured as the distance from the most lateral border of the superior articular facets of axis to the midline (**D**). The distance of transverse process was measured the distance from the most lateral border of the transverse processes of axis to the midline (**E**). The length of inferior articular facets was measured as the A-P dimension of the articular surface (**F**). The width of inferior articular facets was measured as the transverse dimension of articular surface (**G**). The superior articular facet frontal angle was measured as an opning

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supposed to be superior facets and the line, which arbitrarily passed superior to them on transverse plane (H). HL: Horizontal line, ML: Midline.



Superior articular facet length (M) Superior articular facet width (N)



Pedicle width (O) Height of Dens (B)



Transverse dia. of vertebral canal Height of anterior corpus axis (C) Figure 3: Axis measurements taken from the superior-inferior aspect

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The length of superior articular facet was measured as the A-P dimension of articular surface (M). The width of the superior articular facet was measured as the transverse dimension of articular surface (N). Pedicle width was measured as the distance from axis external surface to internal surface at the level of transverse foramen (O). The maximum A-P dimension of the vertebral canal measured along the midsagittal plane passing through the canal's widest point (I). The minimum A-P dimension of the vertebral canal measured along the midsagittal plane passing through the canal's midpoint (J). The maximum transverse dimension of the vertebral canal was measured along the frontal plane passing through the canal's midpoint (K). The minimum transverse dimension of the vertebral canal was measured along the frontal plane passing through the canal's narrowest point (L).

The data were evaluated by the descriptive statistics and sample test. Significance was accepted at probability values of less than 0.005.

RESULTS AND DISCUSSION

Forty dried a human Axis vertebrae were examined. All samples were inspected to ensure that the vertebrae were intact and free from osteophytes or metastatic tumors before measurements were made. The findings were shown in Table-1.The data obtained was analysed in the following manner:

Axis Measurements

Dimensions of dens axis: The widest diameter of dens axis on the coronal plane varied from 7.52 to 13.71 mm (mean 9.67 mm). The mean distance from the tip of dens axis to the horizontal line which arbitrarily passed superior to the superior articular facets of axis (height of dens on coronal plane) was 11.84 mm. The mean width of the articular surface of axis on the coronal plane was 7.69 mm and its mean height was 9.84mm. The long axis of dens axis generally formed an angle according to vertical axes of C2 body from the lateral view. The angle of dens axis was measured to be narrow between an axis that was supposed to pass longitudinally to dens axis and the vertical line on a sagital plane.

The height of corpus axis on the coronal plane was measured to be distant from the line which arbitrarily passed superior to the superior facets to the lowest point on the corpus of axis midline, and it ranged from 14.23 mm to 23 mm. The shape of the superior facet of C2 was varied. The superior articular facet was directed laterally to join with the inferior facet of atlas and was convex from a lateral view. It was oval-shaped in 72% of facets and circular in the remaining 28%. In 72% of superior facets that were oval-shaped, A-P dimension was more than the transverse dimension, while the transverse dimension was more than the antero -posterior dimension in 28% of superior facets that were circular shaped. No significant statistical difference was observed in the mean dimensions of the superior articular facets on both sides of the C2 vertebrae.

Description of parameter		Mean (mm)	Range (mm)
Width of the dens axis		9.67	7.52-13.71
Height of the dens axis		11.84	7.39-15.00
Height of the anterior corpus axis		20.09	14.23-23
Distance from lateral most edge of	R	19.30	10.11-23.5
Superior articular facet to midline	L	19.70	11.78-25
Distance from the tip of the	R	23.76	13.78-28
Transverse process to midline	L	23.97	11.97-29
Maximum length of the inferior	R	10.62	7.5-14.5
Articular facet	L	10.68	8-14
Maximum width of the inferior	R	9.23	6-13
Articular facet	L	8.92	6-15
Superior articulatr facet frontal	R	20.27	8.5-33.99
Angle	L	20.81	17-36.53
Maximum A-P dimension of Vertebral can	nal	14.37	8-20.86
Minimum A-P dimension of		12.60	7.33-19.41
	Description of parameterWidth of the dens axisHeight of the dens axisHeight of the anterior corpus axisDistance from lateral most edge ofSuperior articular facet to midlineDistance from the tip of theTransverse process to midlineMaximum length of the inferiorArticular facetMaximum width of the inferiorArticular facetSuperior articular facet frontalAngleMaximum A-P dimension of	Description of parameterWidth of the dens axis Height of the dens axis Distance from lateral most edge of Superior articular facet to midlineRDistance from the tip of the Transverse process to midlineLMaximum length of the inferior Articular facetRArticular facetLMaximum width of the inferior Articular facetRArticular facetLMaximum width of the inferior Articular facetLMaximum A-P dimension ofMinimum A-P dimension of	Description of parameterMean (mm)Width of the dens axis9.67Height of the dens axis11.84Height of the anterior corpus axis20.09Distance from lateral most edge ofR19.30Superior articular facet to midlineL19.70Distance from the tip of theR23.76Transverse process to midlineL23.97Maximum length of the inferiorR10.62Articular facetLArticular facetL8.92Superior articular facet frontalR9.23Articular facetL8.92Superior articular facet frontalR9.23Articular facetL8.92Superior articular facet frontalR9.23Articular facetL8.92Superior articular facet frontalR9.23Anticular facetL9.24Superior articular facet frontalR9.25Maximum A-P dimension of Vertebral canal14.37Minimum A-P dimension of12.60

 Table 1: Anatomical parameters of the Atlas

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	Vertebral canal			
Κ	Maximum transverse dimension of		17.10	10-24.83
	Vertebral canal			
L	Minimum transverse dimension of		15.65	9.09-22.93
	Vertebral canal			
М	Maximum length of the surface of the	R	15.37	8.68-23.52
	Superior articular facet	L	15.24	7.00-23.91
Ν	Maximum width of the surface of the	R	13.95	6.4-21.31
	Superior articular facet	L	14.16	7.1-21.85
0	Width of the pedicle from its internal	R	7.53	3.09-11.58
	Surface to its external surface at the level	L	7.73	3.09-11.57
	Of transverse foramen			

The mean distance from the outer most border of the superior articular facets of axis to the midline was 19.5mm. Distances from the outer most border of transverse processes of axis to the midline ranged from 13.78 to 29 mm (mean 23.72 mm). The mean width of the pedicle from its internal surface to the external surface at the level of the transverse foramen was 7.63mm (3-11.5 mm). No statistical difference was found between the two sides. The shape of the inferior facet of C2 was not very different from the superior facet. The inferior facet of axis as well as other vertebrae always projected from the junction of pedicle and lamina downwards. The facet was generally circular in shape. It was circular in 94% of facets and oval in 6%. In inferior facets that were oval-shaped, the transverse dimension was more than the A-P dimension. The mean A-P dimension was 10.65 mm (8-14.5 mm) and the mean transverse dimension was 29 mm (6-15 mm). No significant statistical difference was found between the two sides. The maximum A-P dimension of the vertebral canal was 14.37 mm on average, and the mean narrowest AP diameter was 12.60 mm. The maximum transverse diameter of the vertebral foramen was 17.10mm and the mean minimum transverse diameter of the vertebral canal was 15.65 mm. The mean width of the pedicle on the transverse plane (the distance from axis' external surface to the internal surface at the level of transverse foramen) was 7.63 mm. The width of the C2 pedicle was less than 5 mm in14.28% of specimens.

As surgical techniques and instrumentation for treatment of unstable cervical spine as a result of traumatic, congenital or neoplastic disorders continue to evolve, more knowledge about bones and surrounding anatomy is required. The relationship between the vertebral artery and C1-C2 vertebrae has a determining role in planning an operative approach. Various techniques such as interlaminar clamp and hook plating, lateral screw and plate fixation and interspinous wiring have been described for treating cervical instability. Transpedicular screw fixation is one of the most sophisticated procedures currently in use to treat atlas and axis instabilities. Recently, screw fixation has gained popularity for treating dens axis fractures. Use of transpedicular screws has been reported for treating spinal trauma, extensive laminectomies, and destruction of bony elements by neoplasm. Although pedicle screws have been found to provide superior fixation with the least likelihood of hardware loosening in comparison with other surgical techniques, controversy exists regarding its potential risks (14). Pedicle screws can cause injury to vertebral arteries under the superior facets of axis during insertion. The rate of recognized vertebral artery injury was identified as 2% in Gupta and Goel's report (Gupta and Goel, 2000), 4.1% in Wright and Lauryssen's study (Lauryssen, 1998), and 8% in Madawi et al., 's paper (Madawi et al., 1997). However, the actual incidence of vertebral artery injury may be higher than those reported because of the low survey response and the possibility of unrecognized vertebral artery injury. The actual risk of neurological deficit was only 0.2% per patient because the contralateral uninjured vertebral artery circulation was adequate and ischemia did not occur (Mandel et al., 2000). Gupta and Goel (2000) reported that they encountered bleeding probably through a vertebral artery laceration in 2 of 106 cases in whom atlantoaxial facet fusions were performed using plate and screw technique, and bleeding stopped after screw tightening in both these cases.

According to our study, the length and width of the inferior facet of C2 were 10.65mm and 9.07mm respectively. In other words, length of the inferior facet of C2 was more than its width. According to

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study of Sengul and Kadioglu, the length and width of the inferior facet of C2 were 11.6mm and 9.5mm respectively. Lu *et al.*, (1998) determined that the length of inferior facet of C2 was 20 mm in males and 19 mm in females; the width of the inferior facet of C2 was 20 mm in males and 18 mm in females. Gupta and Goel (2000) stressed that the thickness of the inferior facet under the lateral aspect of the posterior arch was 10.65 mm, providing adequate space for insertion of the screw with little danger of injury to the vertebral artery at the C1-C2 level. They advised that screws must be implanted from the middle of the posterior surface of the inferior facet and directed 15 degrees medial to the sagittal plane and 15degrees superior to the axial plane.

Treatment of odontoid fractures, in which the fracture occurs across the base of the odontoid process at its junction with the corpus of axis remains controversial. The most commonly used surgical treatment, either as initial therapy or when immobilization fails, is a posterior fusion between the arches of the atlas and the axis. Depending on the technique, this may require an additional period of external immobilization to increase the likelihood of success. This approach, while stabilizing the spine well, results in elimination of the normal rotation between the atlas and the axis, which accounts for more than one-half of the normal axial rotation of the cervical spine (Apfelbaum, 1995). On the contrary, anterior screw fixation allows direct fixation across the fracture site and achieves immediate stability, while restoring and preserving normal movements of the cervical spine. In this technique, one or two screws are inserted under careful biplane fluoroscopic control from the inferior edge of the axis through the body of axis and into the odontoid to its apex (Apfelbaum, 1995; Dickmman, 1998). The trajectory of the screw for anterior screw fixation of odontoid is parallel to the vertical axes of the odontoid. In presented study, we observed that the mean widest diameter of dens axis on the coronal plane was 9.67 mm. The distance from tip of dens axis to the anterior inferior edge of corpus axis was approximately 32 mm.Sengul and Kadioglu reported the mean widest diameter of dens axis on the coronal plane was 11 mm. The distance from tip of dens axis to the anterior inferior edge of corpus axis was approximately 36 mm.

The height of the C2 vertebral body in the anterior spine was measured as a mean value of 22.1mm by Lang and 20.4 mm by Lu et al., (1998). Karaikovic et al., (1997) measured isthmus height and width of C2 in 53 cadavers' axis vertebrae. They found that approximately 92% of their 53 specimens had widths measuring more than 4 mm, and the heights were less than 5 mm in 12% of cases. Ebraheim et al., (1998) reported the superior pedicle width to range from 4-11mm. In the study of Mandel et al., (2000), who measured the C2 isthmus width and height using both direct anatomic and computed tomographic measurements in 205 human cadavers' C2 vertebrae, only five specimens (2.4%) had one or both isthmus widths of less than 5mm. Gupta and Goel (2000) reported that the mean screwable thickness of C2 pedicle was 7.8 mm, and that the mean height of the pedicle was 8 mm. In the present study, the width of C2 pedicle ranged from 3.09 to 11.58 mm. Sengul and Kadioglu measured the width of C2 pedicle ranged from4to12.5mm; 7.5% of specimen had isthmus widths of less than 5 mm. Mandel et al., (2000) suggest that placing a 3.5 mm screw in a patient with C2 isthmus dimensions (smaller than 5 mm in either the height or width) is technically difficult. In the presence of a small C2 isthmus width and/or height, approximately 10% of patients may be at risk for a vertebral artery injury with placement of C1-C2 transarticular screws. A condition that increases the risk of vertebral artery injury in this region is due to the presence of two characteristics of the superior facet of C2 vertebra, which differs from the facets of all other. First is that the superior facet of C2 presents proximity to the corpus and the medial aspect of pedicle axis when compared to other facets, which are located in proximity to the junction of pedicle and lamina. The second and more crucial characteristic is that the vertebral artery foramen is present partially or completely in the under surface of superior facet of axis while in other cervical vertebrae, vertebral artery foramen is located entirely in relation to the transverse foramen. This unusual location of vertebral artery can deem the artery prone to injury if the screw is directed straight ahead anteriorly in a sagittal plane (Gupta and Goel, 2000). A relatively safe screw trajectory was found to be at 40 degrees medial to the sagittal plane and 20 degrees superior to the axial plane by Gupta and Goel (2000). Madawi et al., (1997) reported a screw trajectory through C2 vertebra meaning that a safe screw trajectory ranges between 0 degrees in the parasagittal and 14 degrees medial in the horizontal plane. According to study of

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Sengul and Kadioglu the mean transverse dimension of the vertebral canal of C2 was 24.7 mm; and the mean maximum A-P dimension of the vertebral canal was 20.8mm. We observed that the mean transverse dimension of the vertebral canal of C2 was 17.10 mm; and the mean maximum A-P dimension of the vertebral canal was 14.37mm.

In conclusion, based on the examination of forty axis vertebrae, a detailed set of anatomical data on dimensions and relations have been presented. This information may be helpful in avoiding and minimizing complications such as vertebral artery injury, spinal cord injury, and cranial nerve damage during a C1-C2 stabilizing operation.

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