ORIGINAL ARTICLE

Morphometric study of the Axis vertebra

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Summary

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. A hundred dried intact human axis vertebrae were measured using digital vernier caliper accurate up to 0.01 mm and a goniometer. Various linear and angular measurements of body, dens, lateral mass, pedicles, superior and inferior articular facets, lamina and spine were studied. The mean antero-posterior diameter of body of axis vertebra was 14.77 ± 1.73 mm. The external height of lateral mass on the right side was 8.77 ± 1.43 mm and 8.28 ± 1.26 mm on the left side. The height of dens was 14.86 ± 1.54 mm and the average transverse diameter was 9.28 mm. All the measurements, namely length, thickness and height of lamina were observed to be more on the right side than on the left, and all these differences were statistically significant. ($P < 0.0001$) The data in this study should be useful to surgeons while working around the second cervical vertebra to avoid injury to the vital structures.

Key words: Axis – Dens – Morphometry

Introduction

The axis (second cervical vertebra) is unique in possessing a dens or odontoid process and very specialized superior articular facets. It acts as an axle for rotation of the atlas and the head around the strong dens which projects cranially from the superior surface of the body (Standring, 2008). A good understanding of the exact dimensions and shape of this bone is necessary for the evaluation of many clinical problems (Doherty and Heggeness, 1995).

Several surgical techniques, such as interlaminar clamping, interspinous wiring, plate and screw fixation, have been employed to correct the instability of the atlanto-axial complex or occipito-cervical junction caused by numerous traumatic and non-traumatic conditions. In spite of the benefits conferred by transpedicular screw fixation in the cervical column, controversy exists regarding its potential risk. Incorrect insertion of a pedicle screw can cause damage to adjacent vital structures such as the spinal cord, nerve roots, cranial nerves and vertebral arteries (Senegul and Kodiglu, 2006). As new internal fixation methods evolve, a better understanding of the geometry and dimensions of the bone in ques-

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tion is clearly indicated (Doherty and Heggeness, 1995).

This study reports a detailed quantitative evaluation of several dimensions of one hundred human axis vertebrae.

Materials and Methods

One hundred dried human axis vertebrae of unknown sex collected from the Departments of Anatomy of five medical colleges were examined. Only intact vertebrae, free from any osteophytes or metastatic tumors, were included in the study. All the linear parameters were measured using a digital vernier caliper accurate to 0.01 mm. The caliper had a depth gauge, which was used to measure the height of *foramen transversarium* accurately. The angular measurements were made using a standard goniometer. All measurements were made by a single observer. All symmetrical structures were measured bilaterally. The following parameters were measured for each axis.

The body was measured for the antero posterior (A-P) diameter and transverse diameter of the body at the base of the vertebra. Anterior vertebral body height was measured at the anterior midline of the body from the inferior edge to the superior border, which was defined by a line drawn at the superior aspect of the superior articular processes (Fig. 1). Posterior vertebral body height was measured at the posterior midline of the body of the vertebra from the posterior inferior edge to the superior border. The end plate lip height was calculated as the difference between the anterior body height and the posterior body height (Doherty and Heggeness, 1995).

The height of the dens was measured from the superior border of the superior articular facets to the tip of the dens. The maximum and minimum transverse diameter and the antero-posterior diameter were measured. The vertical angle of the dens was determined as an angle between the inferior surface of the vertebral body and the vertical axis of the dens. The height and transverse diameter of the articular surface on the anterior surface of the dens was measured. The length, height and thickness of the lamina were measured. We also noted the height of the bifid spine and the distance between its two parts.

The total height of the vertebra was measured as the distance from the inferior edge of the body in the anterior midline to the tip of the odontoid process (Fig. 1).

The length of the pedicle from the anterior-most point of the pedicle (anterior-most point on the superior articular facet) to the posterior edge of the inferior articular facet on the inferior aspect of the vertebra was measured. Pedicle width was measured as the distance from the external surface of pedicle to its internal surface at the level of foramen transversarium. Pedicle height was measured from the superior surface of the pedicle to its inferior surface. The median angle of the pedicle was measured as the angle between the axis of the pedicle and the median sagittal line of the bone (Fig. 2).

The shape, the antero-posterior and transverse diameter of the superior and the inferior articular facets were measured. The superior facet angle relative to the axis of the facet and the sagittal plane was measured on both sides.

The antero-posterior diameter of the vertebral foramen was measured at the inlet and outlet of the foramen at the midline. Its maximum transverse diameter was also measured (Fig. 3).

The length, height and thickness of the lamina were measured. We also noted the height of the bifid spine and the distance between its two parts.

The measurements of the lateral mass included its external height from the mid-

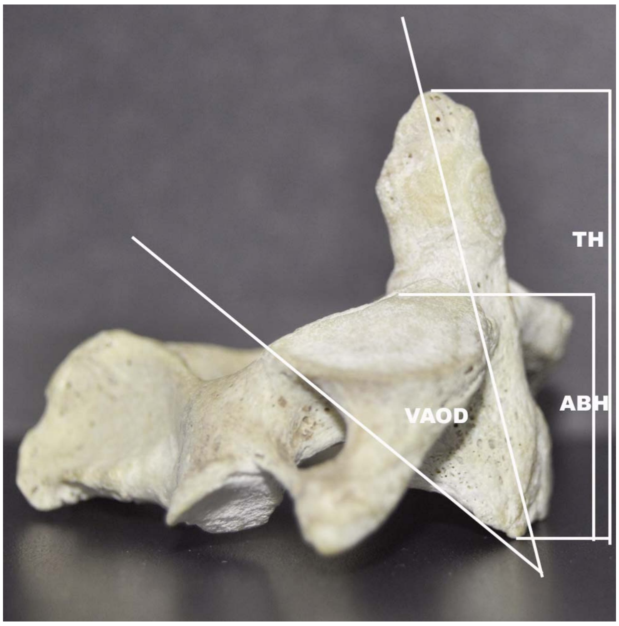

Fig. 1. Lateral view of the axis. TH – total height; ABH – anterior body height; VAOD – vertical angle of dens.

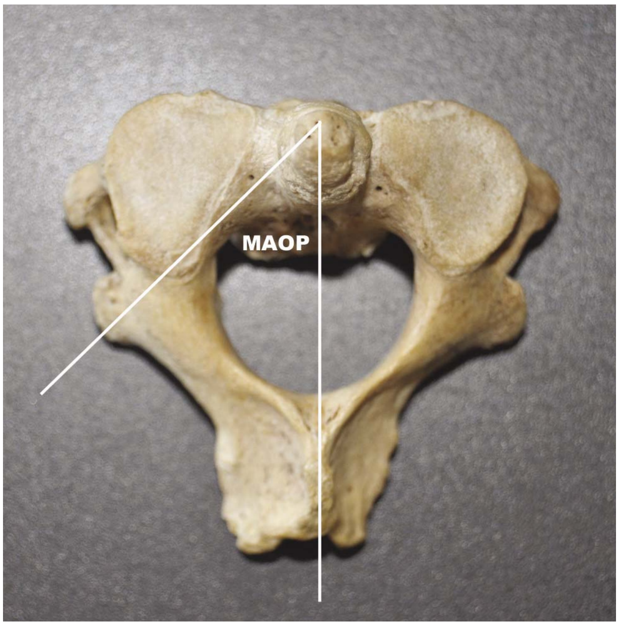

Fig. 2. Superior view of the axis. MAOP – median angle of pedicle.

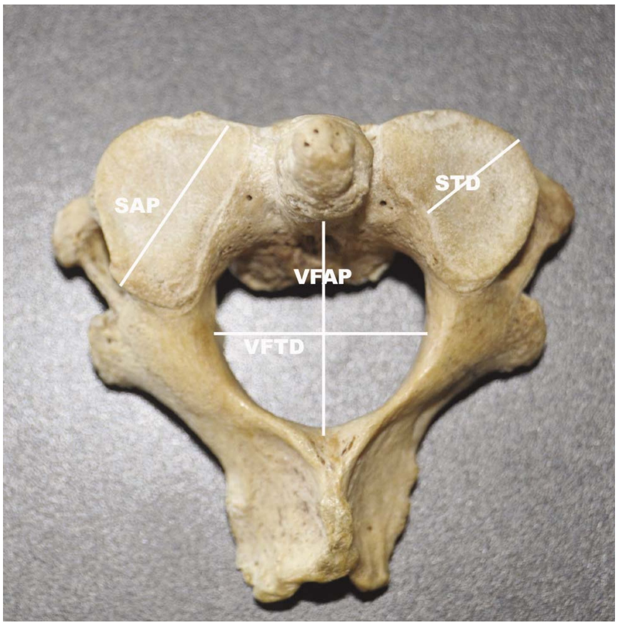

Fig. 3.- Superior view of the axis. VFAP – Vertebral foramen antero-posterior diameter; VFTD – vertebral foramen transverse diameter; SAP – superior articular facet antero-posterior diameter; STD – superior articular facet transverse diameter.

point of the superior articular facet to the lower-most point on its inferior surface. The height of the foramen transversarium was measured at the maximal vertical diameter and its width at the maximal horizontal diameter (Madawi et al., 1997).

The data were analyzed statistically and the Z test was applied, using SPSS software.

Results

The findings are shown in tables 1, 2 and 3. The width of the pedicle was less on the right side and greater on the left, and this difference was statistically significant. However, the difference in the length of the pedicles was not significant.

The superior articular facets were large, flat or slightly convex and were directed laterally. It was observed that 63% of these were oval in shape and 37% were circular. The shape of the inferior articular facets was not different from the superior articular facets and 88% of the inferior articular facets were circular in shape while the remaining 22% were oval. There was no difference in the diameters of the superior and inferior articular facets on the two sides.

The external height of the lateral mass was greater on the right side -i.e. 8.77 ± 1.43 mm- than on the left side - i.e., 8.28 ± 1.26 mm. This difference was statistically significant ($P<0.05$).

All the dimensions of the lamina of the axis showed a significant bilateral difference, being more pronounced on the right side.

Discussion

Metrical details of the axis vertebra are important for several surgical procedures. Table 4 gives a comparison between the different parameters of the axis in the present study and those reported in previous studies by other authors. The variations seen in the different parameters are perhaps due to the difference in the ethnicities to which these vertebrae belonged in various studies.

If transpedicular screw placement were desirable in order to stabilize a fracture line through the axis pedicle, detailed knowledge of the pedicle would be essential (Xu et al., 1995). Table 5 compares our measurements of the pedicle with those of other authors. Gupta and Goel (2000) reported that the mean screwable thickness of the pedicle of the axis was 7.8 mm. In the present study, pedicle width ranged from 3.91 to 14.43 mm. Senegul and Kodiglu (2006) found that 7.5% of the specimens had an isthmus width less than 5 mm, while in the present study 4% of the specimens showed a width of less than 5 mm.

Table 1. Measurements of unpaired parameters of axis.

Nº	Parameter	Range(mm)	Mean ± SD (n=100) (mm)
1	**Body**		
	A-P diameter	9.94 – 20.24	14.77 ± 1.73
	Transverse diameter	11.83 – 23.5	15.99 ± 2.12
	Anterior body height	16.28 – 26.3	20.49 ± 2.25
	Posterior body height	11.13 – 23.17	16.07 ± 2.11
	End plate lip height	3.12 – 5.29	4.42 ± 1.93
2	**Vertebral foramen**		
	Transverse diameter	11.9 – 26.36	21.59 ± 1.77
	A-P diameter at inlet	14.66 – 22.85	18.47 ± 1.68
	A–P diameter at outlet	12.64 – 19.29	15.11 ± 1.37
3	**Dens**		
	Height	11.61 – 18.66	14.86 ± 1.54
	A-P diameter	7.25 – 12.48	9.92 ± 0.94
	Maximum width	4.44 – 11.7	9.28 ± 1.07
	Minimum width	5.84 – 10.68	8.76 ± 0.88
	Vertical angle of dens	30 – 65°	53.6 ± 6.55°
	Total height	25.68 – 42.1	34.17 ± 3.21
Articular facet	Vertical diameter	6.01 – 17.23	9.39 ± 1.95
	Transverse diameter	4.1 – 12.52	7.47 ± 1.29

The superior articular facets of the axis vertebra differ from the facets of all other cervical vertebrae in two important ways, which make this region especially prone to vertebral artery injury during screw fixation. First, these facets in the axis are present in the proximity of the body when compared with vertebrae where they are located close to the lamina. Second, the *foramen transversarium* of the axis is partially or completely present on the inferior surface of the superior articular facet, while in other cervical vertebrae this foramen is very closely related to the transverse process (Cacciola et al., 2004). In the present study, 63% of the superior articular facets were oval and 37% were circular. In the oval facets, the A-P diameter was longer than the transverse diameter in all except one. Cacciola et al. (2004) observed that in 54% of the superior articular facets the A-P diameter was longer than the transverse

Table 2. Measurements of paired parameters of pedicle and articular facets.

Nº	Parameter	Range(mm)	Mean ± SD (n=100) (mm)			
			Rt.*	Lt.†	Rt.	Lt.
1	Pedicle	Length	20.69 – 39.88	10.31 – 37.36	28.71 ± 3.25	28.29 ± 3.72
		Width	3.91 – 10.49	4.29 – 14.43	7.19 ± 1.31	7.73 ± 1.65
		Height	5.07 – 11.9	3.62 - 16	8.20 ± 1.48	8.32 ± 7.67
		Median angle	40 – 75º	40 – 75º	8.20 ± 1.48	8.32 ± 7.67
2	Superior articular facet	A-P diameter	13.24 – 19.24	11.93 – 20.85	16.64 ± 1.54	16.66 ± 1.76
		Trans. diameter	10.76 – 18.1	11.24 – 17.7	14.44 ± 1.65	14.64 ± 1.42
		Superior angle of SAF	60 – 90º	60 – 90º	79.55 ± 5.73º	79.60 ± 5.67º
3	Inferior articular facet	A –P diameter	6.41 – 14.55	5.82 – 14.47	9.87 ± 1.72	9.61 ± 1.79
		Trans. Diameter	7.02 – 14.14	6.59 – 14.19	9.93 ± 1.49	9.92 ± 1.58
4	Lateral mass	External height	5.42 – 12.21	5.97 – 11.82	8.77 ± 1.43	8.28 ± 1.26
5	Foramen transversarium	Height	1.93 – 9.97	2.8 – 9.61	6.39 ± 1.22	6.23 ± 1.14
		Width	3.11 – 8.67	3.36 – 7.68	5.49 ± 1.05	5.37 ± 0.88
6	Lamina	Length	11.13 – 21.59	7.9 – 20.22	16.38 ± 1.97	13.30 ± 3.19
		Height	7.13 – 18.5	3.14 – 13.86	13.09 ± 2.99	7.38 ± 3.16
		Thickness	2.83 – 13.25	2.53 – 7.86	8.02 ± 2.90	5.20 ± 1.16

* - Right, † - Left, Trans. – Transverse, SAF – Superior articular facet

Table 3. Measurements of some parameters of the axis.

Nº	Parameter	Range (mm) Rt.	Lt.	Mean ± SD (n=100) (mm) Rt.	Lt.
1	Dist. between SAF and midline	15.87 – 28.31	17.4 – 29.25	20.92 ± 2.23	21.75 ± 2.23
2	Dist. between tip of TP and midline	20.11 – 32.04	21.01 – 33	26.68 ± 2.54	26.66 ± 2.86
3	Height of spine	8.12 – 20.84	4.42 – 19.28	13.14 ± 2.74	12.61 ± 2.45
4	Distance between limbs of the bifid spine	0.51 – 18.23	10.05 ± 2.90		

* - Right, † - Left, SAF – superior articular facet, TP – transverse process

diameter and in 27% the transverse diameter was greater than A-P, whereas only 19% were circular. The mean antero-posterior diameter of the superior articular facet in the present study was 16.64 mm. Xu et al. (1995) reported lengths of 18.2 mm in males and 17.1 mm in females, while Senegul and Kodiglu (2006) reported 17.5 ± 1.5 mm; they also observed the width of the superior facet to be 14 ± 1.5 mm, and Xu et al. (1995) reported it as 17.6 mm and 16.9 mm in males and females respectively. We found it to be 14.5 mm. Hence, our figures match with those of Senegul and Kodiglu (2006). The angle between the long axis of the superior facet and the sagittal plane in our study was 79.5°, while Xu et al. (1995) reported it as 66.3° in males and 68.4° in females.

The shape of the inferior articular facet was circular in most (88%) of the vertebrae and oval in 12%, while Senegul and Kodiglu (2006) reported that these facets were circular in 96% and ovoid in 4%. They also observed that, in ovoid facets the transverse diameter was longer than the antero-posterior diameter. In our study, in nine facets the transverse diameter was longer than the antero-posterior diameter, but in three the A-P diameter was longer than the transverse diameter. In the present study, the mean antero-posterior diameter of the inferior articular facet was 9.74 mm and the width was 9.9 mm. Senegul and Kodiglu (2006) observed that the mean A-P dimension was 11.6 mm and the mean transverse dimension was 9.5 mm. Lu et al. (1998) determined the length of the inferior articular facet as 20 mm in males and 19 mm in females, while the width was 20 mm in males and 18 mm in females.

In the present study, the various dimensions of the dens, such as length, the antero-posterior diameter, and minimum and maximum width were comparable to those reported in previous studies (Table 4). Nucci et al. (1995) found that the crucial transverse outer diameter for the emplacement of two 3.5 mm cortical screws with tapping in the dens was 9 mm. They observed that in 95% of cases the diameter was more than 9 mm. In the present study only 58% had a diameter of the dens greater than 9 mm. The vertical angle of the dens in the present study was 53.6°, whereas

Table 4. Comparison of some Axis parameters in different studies.

Parameters		Xu et al. (1995)	Doherty & Heggeness (1995)	Senegul & Kodiglu (2006)	Lang (1995)	Lu et al. (1998)	Present study
Body	A-P diameter	16.1	16.2				14.77
	Trans diameter	19	18.7				15.99
	Ant. Body height*	21.1	23.3	22.1	22.1	20.4	20.49
	Post. body height†	16.5					16.07
	Lip height		4.1				4.42
Dens	Height	15.5		14.5			14.86
	A-P diameter	10.3	11.2				9.92
	Max. width	10	10.8	11.2			9.28
Vertebral foramen	Trans. diameter	21.9	23.6	24.7			21.59
	A-P inlet	18	16.5	20.8			18.47
	A-P outlet	15.3					15.11

* - Ant. – Anterior, † Post. - Posterior

Table 5. Comparison of parameters of pedicle of Axis in different studies.

Parameter	Present study	Xu et al. (1995)	Madawi et al. (1997)
Length	28.5	25.6	28.7
Width	7.46	8.6	7.8
Height	8.26	7.7	7.9

Xu et al. (1995) measured it as 64.1°. The total height of the axis vertebra was 34.17 mm in our study and Doherty and Heggeness (1995) reported it as 39.9 ± 3mm. In the present study the articular facet on the anterior surface of the dens had a mean vertical diameter of 9.39 mm and a mean width of 7.47 mm. Doherty and Heggeness (1995) reported the vertical diameter of the articular facet of dens as 15.5 mm.

Madawi et al. (1997) studied the different dimensions of the lateral mass of the axis. They observed the external height of lateral mass to be 8.6 mm, whereas in the present study it was 8.77 ± 1.43 mm on the right side and 8.28 ± 1.26 mm on the left side. The bilateral difference was statistically significant.($P<0.05$) The mean transverse diameter of *foramen transversaria* was 5.43 mm in the present study while Madawi et al. (1997) measured it as 5.6 mm. The mean height of the *foramen transversaria* in the present study was 6.31 mm whereas according to Madawi et al. (1997) it was 5.7 mm. Hence these findings match each other.

The length, thickness and the height of the lamina were higher on the right side as compared to the left and this difference was statistically significant.

Here, the mean distance of the outer border of the superior articular facet from the midline on the right side was 20.92 ± 2.23 mm and on the left side it was 21.75 ± 2.23 mm. Senegul and Kodiglu (2006) observed it as 21.3 ± 2.8 mm on the right side and 21.9 ± 2.3 mm on the left side. The bilateral difference in the present study was not statistically significant.

The mean distance from the tip of the transverse process to the midline in the present study was 26.68 ± 2.54 mm on the right side and 26.66 ± 2.86 mm on the left side while Senegul and Kodiglu (2006) measured it as 27.3 ± 2.8 mm on the right side and 27.2 ± 2.8 mm on the left side.

The spinous process of the axis is large with a bifid tip and a broad base, which is concave inferiorly. We observed the height and the distance between the two limbs of the bifid spine. The height was 13.14 mm on the right and 12.61 mm on the left side. Marked variation was observed in the distance between the limbs of the bifid spine, ranging from 0.51 mm to 18.23 mm, with a mean value of 10.05 mm.

The dimensions reported in the present study should be useful for the surgeons while working around the axis vertebra to avoid injury to vital structures. It can also be also useful to devise new methods of fixation of the fractured odontoid process or axis pedicles.

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