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ORIGINAL ARTICLE

Anatomy of the dens and its implications for fracture treatment: an anatomical and radiological study

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Abstract

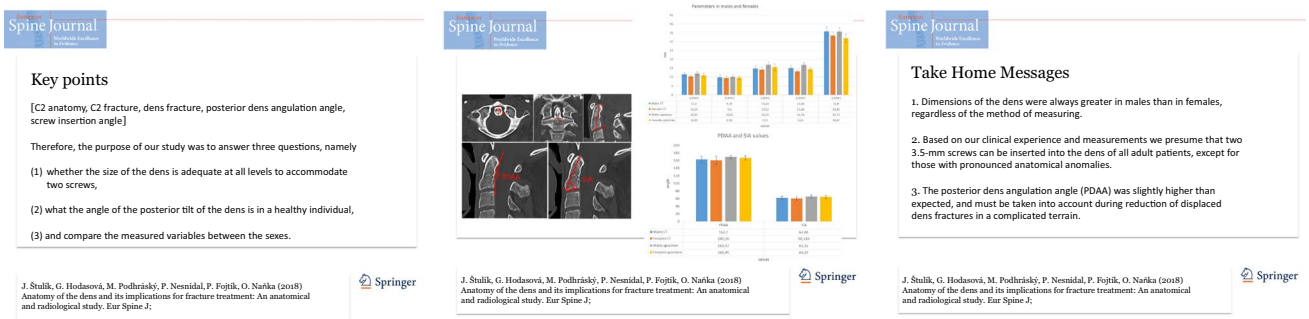
Purpose The most common injuries to the upper cervical spine are fractures of the dens axis. Therefore, the purpose of our study was to answer three questions, namely (1) whether the size of the dens is adequate at all levels to accommodate two screws, (2) what the angle of the posterior tilt of the dens is in a healthy individual and (3) compare the measured variables between the sexes.

Methods The cohort comprised 50 males and 50 females CT examination of the craniocervical junction. We measured the five diameters of the dens and posterior dens angulation angle (PDAA) and screw insertion angle (SIA). The same dimensions were measured in a control group, consisting of 40 non-pathological second cervical vertebrae specimens.

Results On CT scans, the mean PDAA was 162.7 degrees in males and 160.26 degrees in females; the mean SIA was 62.0 degrees in males and 60.2 degrees in females. On specimens, the mean PDAA was 169.47 degrees in males and 166.95 degrees in females; the mean SIA was 65.42 degrees in males and 64.47 degrees in females. All obtained values were higher in males; regardless of their measuring on either CT scans or specimens, differences between males and females were statistically significant ($p < 0.05$) in *a*, *c*, *d* and *e* values.

Conclusions The values of our measurements correlate with the dimensions identified previously in other studies. Based on our clinical experience and measurements, we presume that two 3.5-mm screws can be inserted into the dens of all adult patients, except for those with pronounced anatomical anomalies. Posterior dens angulation angle is slightly larger than we expected. The dens is significantly larger in males almost in all measurement.

Graphical abstract These slides can be retrieved under Electronic Supplementary Material.



Keywords C2 anatomy · C2 fracture · Dens fracture · Posterior dens angulation angle · Screw insertion angle

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Extended author information available on the last page of the article

Introduction

The atlantoaxial complex has a key role in the biomechanics of the cervical spine and the craniocervical junction. Anatomy of both the atlas and the axis is highly variable, in fact unique, in each individual. Nevertheless, getting a picture of their probable anatomy in a particular patient prior to an injury or disease is crucial for the surgeon. Handbooks of anthropology present a number of defined dimensions that may be identified in the second cervical vertebra [1], and multiple methodologies have been developed, of gender determination based on dimensions of the axis [2]. These works, however, do not capture all the characteristic features required for assessment of the dens size by a spinal surgeon.

The most common injuries to the upper cervical spine are fractures of the dens that account for 50–60% of C2 injuries and 5–15% of all injuries to the cervical spine [3].

Therefore, the purpose of our study was to answer three questions, namely (1) whether the size of the dens is adequate at all levels to accommodate two screws, (2) what is the angle of the posterior tilt of the dens in a healthy individual and (3) compare the measured variables between the sexes. The use of one or two screws was largely debated in the past with no consensus achieved between advocates of either concept. Our philosophy supports management of dens fractures always by two screws, particularly in elderly patients with a poor bone quality. Marked posttraumatic angulation deformities potentiated by a comminuted zone eliminate inter-patient anatomical variations, and the surgeon must rely only on hypothetical assumptions, both in case of direct osteosynthesis of the dens and posterior stabilization. Based on our clinical experience, we presume that two 3.5-mm screws can be inserted into the dens of all adult patients both males and females, except for those with pronounced anatomical anomalies. Our empirical estimate of a mean posterior angulation of the dens was 165-170 degrees. The aim of our theoretical study is to prove the above-mentioned premises and confirm their practical applicability.

Material and method

The database of the Motol University Hospital was used to identify 100 patients with a healthy cervical spine who underwent in the period of 2014–2015 CT examination of the craniocervical junction. The cohort comprised 50 males with the mean age of 38.7 years (range 20–56) and 50 females with the mean age of 39.8 years (range 21–57). The original Canon medical software of the Toshiba Aquilion Prime TSX-303A CT scanner was used to measure the diameter of the dens at the level of the inferior edge of the anterior arch of the atlas in the sagittal (a) and coronal (b) planes; the dimension of the dens base in the coronal plane (c); the dimension of the C2 vertebral body in the sagittal plane (d); the distance between the center of the base of the C2 vertebral body and the apex of the dens (e); the angle included by the line of the posterior inferior edge of C2 and the posterior superior edge of the dens (PDAA—posterior dens angulation angle); and the angle included by the line of the C2 base and the line connecting the anterior inferior edge of C2 and apex of dens (SIA—screw insertion angle). All measurements relate to external dimensions (Fig. 1).

The same dimensions, as described above, were measured in a control group, i.e., an early twentieth-century sample, consisting of 40 non-pathological second cervical vertebrae from the documented skeletal Pachner collection (21 men ranging in age from 37 to 83 years, average age 56 years, and 19 from women ranging in age from 18 to 91 years, average age 44 years) from Institute of Anatomy. Demographic data were acquired from autopsy records. All the dimensions on specimens were measured by a digital sliding scale and a protractor.

The values measured were then used to calculate means and standard deviation. Statistical analysis was based on the Wilcoxon signed-rank test with the significance level set at 0.05. We used computer software Excel (Microsoft Office) to perform statistical analysis.

Results

Dimensions and angles in C2 measured on CT scans

The mean diameter of the dens was 11.4 mm in males and 10.2 mm in females measured at the level of the inferior edge of the anterior arch of the atlas in the sagittal plane (a); and 9.8 mm in males and 9.3 mm in females measured at the level of the inferior edge of the anterior arch of the atlas in the coronal plane (b); the mean dimension of the dens base was 14.6 mm in males and 14.1 mm in females in the coronal plane (c); the base of the C2 vertebral body measured on average 15.0 mm in males and 13.0 mm in females in the sagittal plane (d); the mean distance between the center of the C2 base and the apex of the dens was 35.9 mm in males and 33.4 mm in females (e); the mean PDAA was 162.7 degrees in males and 160.26 degrees in females; the mean SIA was 62.0 degrees in males and 60.2 degrees in females (Table 1, Fig. 2, all values are given in Online resource 1). Differences between males and females were statistically significant ($p < 0.05$) in *a*, *d*, *e* and SIA values.

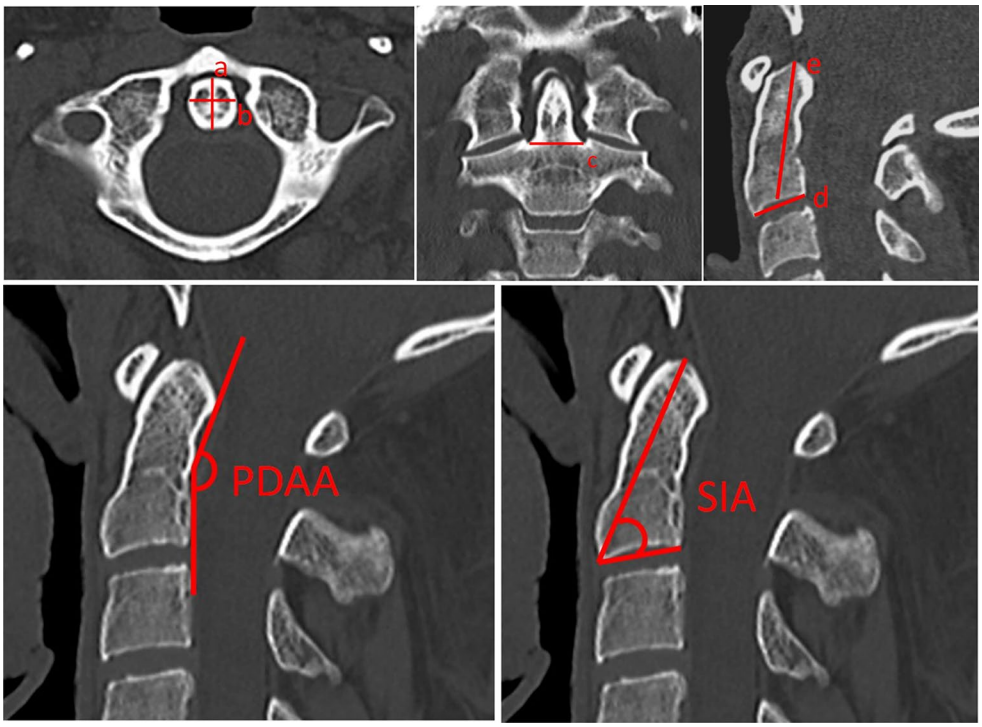

Fig. 1 Measured diameters of the dens at the level of the inferior edge of the anterior arch of the atlas in the sagittal (**a**) and coronal (**b**) planes; the dimension of the dens base in the coronal plane (**c**); the dimension of the C2 vertebral body in the sagittal plane (**d**); the distance between the center of the base of the C2 vertebral body and the apex of the dens (**e**); the angle included by the line of the posterior inferior edge of C2 and the posterior superior edge of the dens (PDAA—posterior dens angulation angle); and the angle included by the line of the C2 base and the line connecting the anterior inferior edge of C2 and apex of dens (SIA—screw insertion angle)

Table 1 Dimensions and angles in C2 measured on CT scans and statistical evaluation

n = 50	Age	*a* (mm)	*b* (mm)	*c* (mm)	*d* (mm)	e (mm)	PDAA (°)	SIA (°)
Dimensions and angles in C2 measured on CT scans in males								
Average	38.3	11.4	9.76	14.64	14.98	35.9	162.7	62.06
SD		1.02	1.49	1.55	1.27	2.53	8.56	4.13
Dimensions and angles in C2 measured on CT scans in females								
Average	39.3	10.24	9.3	14.12	13.08	33.42	160.26	60.184
SD		0.76	1.13	1.62	1.14	2.19	11.12	4.41
T test—*p* value		0.00000001*	0.0889	0.1087	0*	0.0000012*	0.23	0.033*

N number, *SD* standard deviation, *a* diameter of the dens at the level of the inferior edge of the anterior arch of the atlas in the sagittal plane, *b* diameter of the dens at the level of the inferior edge of the anterior arch of the atlas in the coronal plane, *c* the dimension of the dens base in the coronal plane, *d* the dimension of the C2 vertebral body in the sagittal plane, *e* the distance between the center of the base of the C2 vertebral body and the apex of the dens, *PDAA* posterior dens angulation angle, *SIA* screw insertion angle. Asterisks indicate statistic significance

Dimensions and angles in C2 measured on specimens

The mean diameter of the dens was 11.91 mm in males and 10.95 mm in females measured at the level of the inferior edge of the anterior arch of the atlas in the sagittal plane (a); and 10.05 mm in males and 9.58 mm in females measured at the level of the inferior edge of the anterior arch of the atlas in the coronal plane (b); the mean dimension of the dens base was 16.91 mm in males and 15.5 mm in females in the coronal plane (c); the base of the C2 vertebral body measured on average 16.76 mm in males and 14.4 mm in females in the sagittal plane (d); the mean distance between the center of the C2 base and the apex of the dens was 35.73 mm in males and 31.87 mm in females (e); the mean PDAA was 169.47 degrees in males

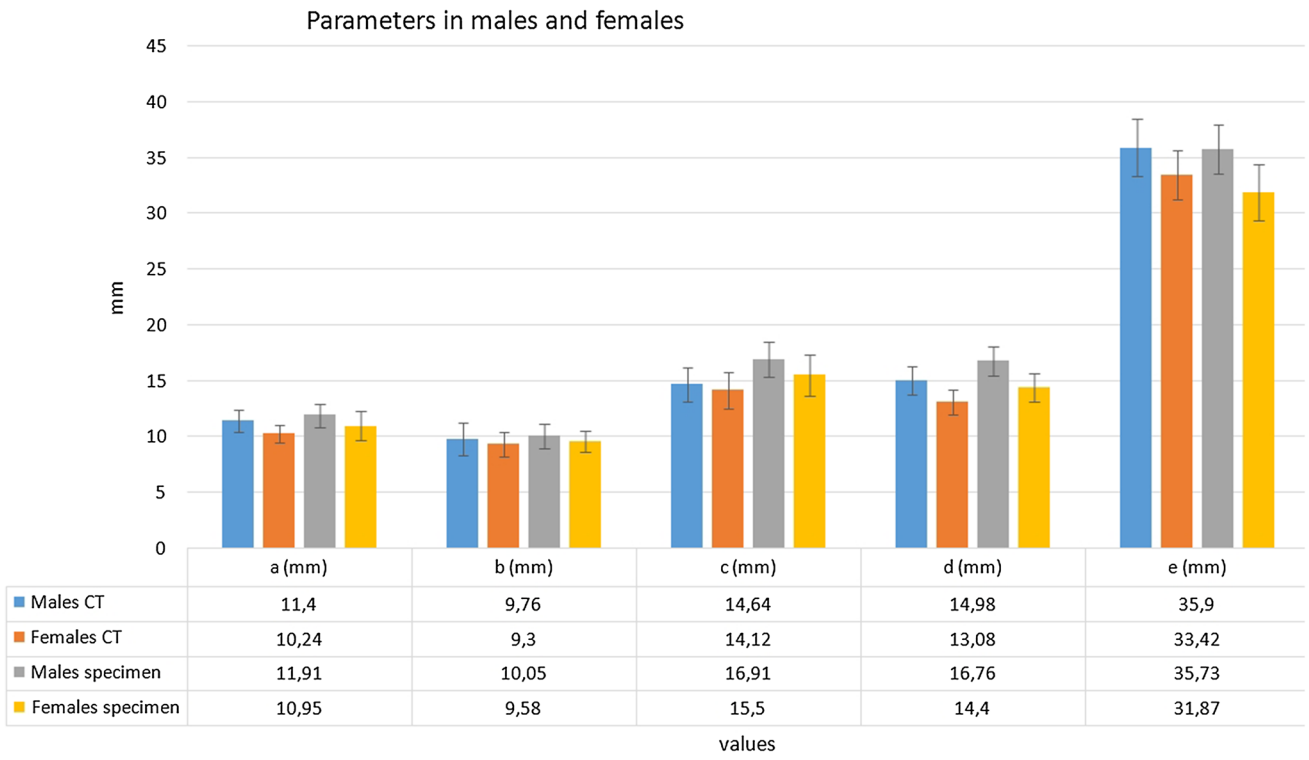

Fig. 2 Dimensions and angles in C2 measured on CT scans and specimens

and 166.95 degrees in females; the mean SIA was 65,42 degrees in males and 64.47 degrees in females (Table 2, Fig. 3, all values are given in Online resource 2). Differences between males and females were statistically significant ($p < 0.05$) in *a*, *c*, *d* and *e* values.

All obtained values were higher in males, regardless of their measuring either on CT scans or specimens.

Discussion

All the values that we have obtained both on CT scans and specimens are higher in males than in females, which fully corresponds to the findings of Helmuth and Rempe [2] who reported similar results in their study obtained by direct measuring of 14 different dimensions of the axis in specimens. Another study dealing with the morphology of the

Table 2 Dimensions and angles in C2 measured on specimens and statistical evaluation

	Age	*a* (mm)	*b* (mm)	*c* (mm)	*d* (mm)	*e* (mm)	PDAA (°)	SIA (°)
Dimensions and angles in C2 measured on specimens in males								
n = 21								
Average	56.2	11.91	10.05	16.91	16.76	35.73	169.47	65.42
SD		1.06	1.09	1.58	1.31	2.18	4.75	4.28
Dimensions and angles in C2 measured on specimens in females								
n = 19								
Average	46.8	10.95	9.58	15.5	14.4	31.87	166.95	64.47
SD		1.32	0.97	1.83	1.27	2.51	5.27	4.08
T test—*p* value		0.0179*	0.1726	0.0152*	0.0000015*	0.00002266*	0.128552	0.487

N number, *SD* standard deviation, *a* diameter of the dens at the level of the inferior edge of the anterior arch of the atlas in the sagittal plane, *b* diameter of the dens at the level of the inferior edge of the anterior arch of the atlas in the coronal plane, *c* the dimension of the dens base in the coronal plane, *d* the dimension of the C2 vertebral body in the sagittal plane, *e* the distance between the center of the base of the C2 vertebral body and the apex of the dens, *PDAA* posterior dens angulation angle, *SIA* screw insertion angle. Asterisks indicate statistic significance

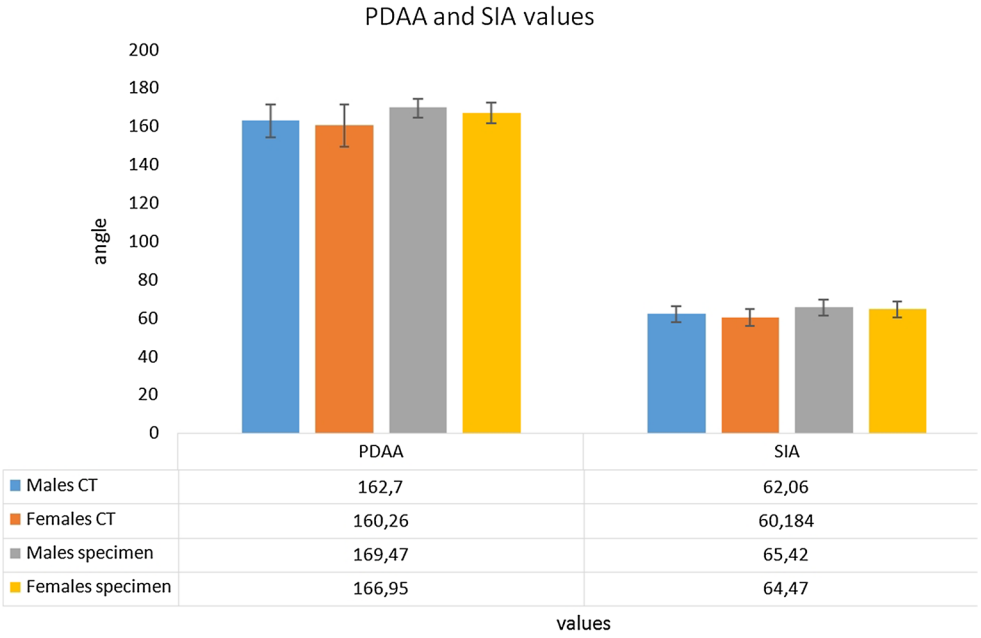

Fig. 3 Angles in C2 measured on CT scans and specimens

dens [4] presents dimensions that correspond to our values. Similar values and results are reported also by Xu et al. [5].

Direct osteosynthesis of the dens from the anterior approach is an effective and safe treatment for dens fractures, particularly in young patients. This method offers the advantage of preserving motion of the atlantoaxial complex without the necessity of bone graft harvesting and a rigid external fixation [6]. Its high efficacy in terms of bone union rates is comparable with the C1–C2 posterior fixation and fusion. According to Jenkins et al. [7] and Sasso et al. [8], there was no significant difference in the successful union rates achieved with either the one- or two-screw fixation techniques. The school of Professor Magerl, the father of direct osteosynthesis of the dens, prefers insertion of two screws and points out the anti-rotational effect of the second, shorter, screw [9–11]. Nucci et al. [12] defined the smallest external transverse diameter of the dens that would allow the introduction of two 3.5-mm screws. Kandziora et al. [13], Schaffler et al. [4] and Tun et al. [6] report transverse outer diameter of the dens in the range of 10.9–11.6 mm. Our measurements of the transverse dimension of the dens of 9.8 mm in males and 9.3 mm in females considerably differ from the above studies. In our view, the difference has been caused by a different method of measuring. We have measured the narrowest part at the inferior edge of the anterior arch of the atlas, rather than at the base which is several millimeters more caudal. The lowest value obtained was in four cases (4%) 7 mm (one female and three males), with the anteroposterior dimension at the same level being 10 mm in the female and 11 mm in males. These facts show that two 3.5-mm screws are theoretically applicable in 100% of cases both males and females. In their recent study, Gehweiler et al. [14] assessed the bone mass distribution and bone loss in C2, as well as dimensions and shape of the dens, and their implications for placement of two 3.5-mm screws. The bone mass distribution remained unchanged in the presence of bone loss, and virtual screw positioning of two 3.5-mm dens screws with a 1-mm safety zone on each side was possible in 97.5% of cases.

Schaffler et al. [4] did not identify a correlation of the body height or weight with dens dimensions; on the other hand, they found a significantly larger dens (by 5–10%) in males than in females. Tun et al. [6] state in their theoretical study that with the use of a single screw it is crucial to choose its proper size so that it fits exactly the medullary cavity of the dens, and its thread is fixed in the cortex. In our view, although it provides the best fracture stability, it considerably reduces the contact bone surface and compromises biology of bone repair. From this viewpoint, two 3.5-mm screws are again more beneficial.

Length of the screws for anterior fixation approximately corresponds to the value measured between the anterior inferior edge of the C2 body and the apex of the dens. However, due to considerable inter-patient anatomical variations, mainly in the anterior inferior edge of the C2 body, the value may significantly differ from the C2 height measured from the center of the C2 base to the apex of the dens in the sagittal or coronal section. This is caused by the inferior edge of the C2 body overlapping anteriorly, cranial concavity of the inferior endplate of the C2 body and the posterior dens angulation angle. Singla et al. [15] described a dens sagittal angle, i.e., the angle between a line passing longitudinally through the dens and the vertical line in the sagittal plane, the mean value of which was 13.2 degrees. Heller et al.

[16] report the height of the C2 body and dens of 37.8 mm and Doherthy et al. [17] 39.9 mm. Tun et al. [6] call SIA the body angle and report its mean value of 62.4 degrees and screw length of 38.0 mm. In the present study, the SIA values are lower in females, while in males they correlate with the study published by Tun. Screw length in females (38.7 mm) correlates with the above-given values; however, our measurements in males show considerably longer screws (42.2 mm). Screw length is significantly shorter in females than in males. From our results, we can say that there is more difference in the length then in diameter of the dens between males and females. To our knowledge, no study of posterior dens angulation angle (PDAA) has been published, yet. Our empirical estimate of posterior angulation of the dens, or its posterior edge of C2, of 165–170 degrees has been confirmed by the study which has revealed the angulation being even greater in both genders, 162.7 degrees in males and 160.3 degrees in females (169.5 and 166.9 degrees, respectively, when measured on specimens). Particularly, in cases of osteoporotic fractures in elderly patients, it is often difficult to recognize potential defects of the dens cortex and subluxation of atlantoaxial joints by image intensifier during surgery. The knowledge of the PDAA may help to reduce the atlantoaxial complex into proper position. It is also difficult in the cases with larger comminuted zone. According to our experiences, it is very helpful during posterior stabilization of the atlantoaxial complex where the anterior surgery is contraindicated.

Conclusion

Dimensions of the dens were always greater in males than in females, regardless of the method of measuring. The values of our measurements correlate with the dimensions identified previously in other studies. Insertion of two 3.5-mm screws into the dens was theoretically feasible in all cases. The posterior dens angulation angle (PDAA) was slightly higher than expected and must be taken into account during reduction of displaced dens fractures in a complicated terrain. All the values regarding the size and angulation of the dens are higher in males than in females.

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Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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