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RESEARCH

Determination of reference values of the craniovertebral junction in healthy individuals using computed tomography

Sağlıklı bireylerde kraniyovertebral bileşkenin referans değerlerinin bilgisayarlı tomografi ile belirlenmesi

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Abstract

Purpose: This study aims to investigate the clinical and anatomical characteristics of the craniovertebral junction in healthy individuals to establish reference data for surgical planning and evaluation.
Materials and Methods: The Computed Tomography (CT) images including, dens transverse length (D_{TL}), dens anteroposterior length (D_{APL}), dens height (D_H), dens tip (D_T), atlantooccipital joint angle (AOJ_A), distance between basion to opistion (BO_D), axis height (A_H), atlantooccipital interval (AOI), Welcher basal angle (WB_A), clivus canal angle (CC_A), Klaus height index (KHI), anterior atlanto-dental interval (AADI), and posterior atlanto dental interval (PADI) of 180 healthy individuals between 18-60 years were retrospectively evaluated.
Results: Measurement results were found as follows: D_{TL} 10.35±0.83 mm, D_{APL} 11.45±0.95 mm, D_H 15.70±1.44 mm, D_T 1.58±0.49 mm, AOJ_A 118.24±7.11°, BO_D 33.58±2.79 mm, A_H 34.78±2.82 mm, AOI 1.47±0.29 mm, WB_A, 130.41±5.89°, CC_A 160.56±9.94°, KHI 41.45±3.03, AADI 1.19±0.48 mm, and PADI, 19.47±1.84 mm, in healthy subjects, respectively. Additionally, some parameters, including D_{TL}, D_{APL}, D_H, BO_D, A_H, AADI, and PADI, were significantly higher in males than in females. D_{TL}, D_H, D_T, A_H, and AOI parameters showed a significant difference between ages.
Conclusion: Detailed anatomical and radiological knowledge of the craniovertebral junction is crucial in various clinical disciplines, including anatomy, radiology, anesthesiology, neurosurgery, and otolaryngology, due to its complex structure and critical anatomical relationships.
Key words:. Atlantoaxial dislocation, craniovertebral junction, dens axis

Öz

Amaç: Bu çalışma, sağlıklı bireylerde kraniovertebral bileşkenin klinik ve anatomik özelliklerini inceleyerek, cerrahi planlama ve değerlendirmelere yönelik referans veriler oluşturmayı amaçlamaktadır.
Gereç ve Yöntem: Dens transvers uzunluğu (D_{TU}), dens anteroposterior uzunluğu (D_{APU}), dens yüksekliği (D_Y), dens ucu (D_U), atlantooksipital eklem açısı (AOE_A), basion ile opistion arasındaki uzaklık (BO_U), axis yüksekliği (A_Y), atlantooksipital aralık (AOA), Welcher bazal açısı (WB_A), klivus kanal açısı (KK_A), Klaus yükseklik indeksi (KYI), anterior atlanto-dental aralık (AADA) ve posterior atlanto dental aralık (PADA) içeren bilgisayarlı tomografi (BT) görüntüleri, 18-60 yaşları arasındaki 180 sağlıklı bireyde retrospektif olarak değerlendirilmiştir.
Bulgular: Ölçüm sonuçları aşağıdaki gibi bulunmuştur: D_{TU} 10.35±0.83 mm, D_{APU} 11,45±0,95 mm, DY 15,70±1,44 mm, D_U 1,58±0,49 mm, AOE_A 118,24°±7,11°, BO_U 33,58±2,79 mm, A_Y 34,78±2,82 mm, AOA 1,47±0,29 mm, WB_A, 130,41°±5,89°, KK_A 160,56°±9,94°, KYI 41,45±3,03, AADA 1,19±0,48 mm ve PADA 19,47±1,84 mm, sağlıklı bireylerde sırasıyla, Ayrıca, D_{TU}, D_{APU}, D_Y, BO_U, A_H, AADI ve PADI gibi bazı parametreler erkeklerde kadınlara göre anlamlı derecede yüksekti, D_{TU}, D_Y, D_U, A_Y ve AOA parametreleri yaşlar arasında anlamlı farklılık gösterdi,
Sonuç: Kraniyovertebral bileşkenin ayrıntılı anatomik ve radyolojik bilgisi, kompleks yapısı ve kritik komşulukları nedeniyle anatomi, radyoloji, anestezi, beyin cerrahisi ve kulak burun boğaz gibi birçok klinik disiplinde önem taşır.

Anahtar kelimeler: Atlantoaksiyel dislokasyon, kraniyovertebral bileşke, dens axis

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INTRODUCTION

The craniovertebral junction (CVJ), a complex transitional zone, encompasses the posterior skull base, the atlas (C1), the axis (C2), and the supporting ligaments that connect the skull to the upper cervical spine. It is responsible for stability and movement[1-4], and represents the integrity of the cranium and spine. Anatomical and radiological evaluation is critical for understanding and managing various pathologies affecting this region [3-7]. The CVJ is more mobile than other spinal segments and contains vital nerves and vessels. Each dimension of CVJ affects the different mechanical features. For instance, ligaments contribute to stability, whereas the joints play a role in preventing neural injury[2,4,8-10].

The atlantooccipital and atlantoaxial joints allow head and neck movements, especially flexion, extension, and rotation [11]. Instability of the craniovertebral junction (CVJ) may result from congenital, acquired, or traumatic conditions and may compromise neural structures. This can lead to pressure on the brainstem, causing issues like arrhythmia, blood pressure changes, vertebrobasilar insufficiency, ischaemic attacks, neurological deficits, or even sudden death. Thus, understanding the CVJ's anatomy and pathologies is crucial. Also, injuries to the CVJ can result in significant morbidity and mortality[1,3,4,9,12-14]. Identifying normal craniometric measurements is crucial for diagnosing and treating CVJ pathologies [1]. The type and extent of pathology, along with anatomical considerations, determine the appropriate surgical approach. Surgical approaches such as the transoral-transpharyngeal route afford safe and direct access to the craniovertebral junction (CVJ) and brainstem, while minimizing the risk of injury to vital structures, including the internal carotid artery, cranial nerves, and endocrine glands. This approach is particularly advantageous in managing pathologies such as congenital anomalies, rheumatoid arthritis, and atlantoaxial dislocation[3,6,11,15-17].

The first two vertebral joints are vulnerable to injury resulting from exaggerated motion in any of the normal intrinsic directions of movement: vertical, anteroposterior, and rotatory [15]. Also, it is difficult to define the reference points in the CVJ due to overlapping structures, Cone beam computed tomography (CBCT) has many advantages of showing bone anatomy and pathology very clearly, lower radiation exposure, and lower cost compared to other imaging modalities, and therefore can be considered as an ideal neuroimaging method for evaluating this region. CT is one of the primary emergency neuroimaging modalities, preferred for the accurate assessment of classical anatomical lines and angles, and should be performed in all patients with head injuries[1,2,6,9,12,13,18,19]. Normal reference values provide valuable criteria for identifying cranio-cervical instability as well as for the preoperative and postoperative follow-up of craniovertebral junction (CVJ) pathologies[19-21]. Various craniometric measurements were performed using direct radiography, computed tomography (CT), multi-detector computed tomography (MDCT), and magnetic resonance imaging (MRI) [1]. Among these methods, CT offers several advantages due to its ability to clearly visualize bony landmarks. It is an essential method for evaluating the bony anatomy and pathology of the craniovertebral junction (CVJ), being practical, rapid, highly sensitive, and cost-effective. These characteristics collectively make CT a suitable screening tool[1,2,7,9,19].

The craniovertebral junction (CVJ) holds paramount clinical and anatomical significance as a complex transitional interface between the skull and cervical spine. Given its intricate structure and critical function, understanding the potential risk for CVJ injury is essential. Accordingly, to enhance the comprehension of the morphological characteristics of the craniovertebral junction in a healthy population, this study aims to systematically analyze the linear and angular measurements, as well as the anatomical relationships of the CVJ, thereby establishing normative reference values for healthy adults.

This study found that CT imaging provides accurate and reliable reference values for morphometric and angular measurements of the craniovertebral junction (CVJ) in healthy adults, that age and gender may influence these measurements, and such variables should be taken into account in the diagnosis and treatment of CVJ pathologies, as well as in surgical planning.

MATERIALS AND METHODS

Sample

Subjects who were admitted to the hospital for various clinical indications and underwent computed tomography (CT) were included in the study. The criteria for inclusion and exclusion in the study are detailed below: Participants were selected retrospectively from hospital records among individuals who underwent cranial/cervical CT imaging for non-pathological reasons (e.g., minor trauma or headache evaluation) and were confirmed to have no structural abnormalities in the craniovertebral junction (CVJ) region.

Subjects with known congenital, inflammatory, neoplastic, or traumatic conditions affecting the CVJ were excluded to ensure a homogenous and healthy sample. CT images were excluded if they exhibited missing or inconsistent data, imaging artifa cts that interfered with the identification of anatomical reference points or measurements, the presence of tumors affecting the craniovertebral junction (CVJ) anatomy, or developmental/inflammatory disorders According to the power analysis, assuming an effect size of d = 0.5, a statistical power of 80%, and a confidence level of 95% (α = 0.05), the minimum required sample size for the study was determined to be 128 subjects.

Procedure

This retrospective observational study was approved by the Cukurova University Clinical Research Ethics Committee (Decision No: January 03, 2025/151-9).

Image analysis

All CT scans were acquired using a 64×2-slice multidetector CT system (Siemens Somatom Definition AS, Siemens Healthcare) with the following standard protocol: 16 × 0.75-mm collimation with 1-mm-thick sections. Axial images were reconstructed at 1 mm, and we routinely obtained reformations in both sagittal and coronal planes. Multiplanar reformations were reformatted to 3-mm thickness every 3 mm through the cervical spine. This retrospective observational study was carried out by the Department of Radiology at Bozyaka Training and Research Hospital, University of Health Sciences in İzmir. CT Image analyses were performed by two observers [observer 1, a radiologist (MÖ), observer 2, an anatomist (SÖ)]. Additionally, the data were obtained from official hospital records, and all file security procedures were conducted in accordance with the protocols established by the relevant institution.

Measurements

The descriptions of parameters including 13 parameters including dens transverse length (D_{TL}), dens anteroposterior length (D_{APL}), dens height (D_H), dens tip (D_T), atlantooccipital joint angle (AOJ_A), distance between basion to opistion (BO_D), axis height (A_H), atlantooccipital interval (AOI), Welcher basal angle (WB_A), clivus canal angle (CC_A), Klaus height index (KHI), anterior atlanto-dental interval (AADI), and posterior atlanto dental interval (PADI) were shown in Table 1[1,2,7,9,16,17,22-34] and literature studies were shown in Table 2[1,4,5,7,9,18,22,28,30,32--35]. In addition, the data were first divided into two groups based on gender (females and males). Each gender group was then further categorized into five age groups: Group I (18–19 years), Group II (20–29 years), Group III (30–39 years), Group IV (40–49 years), and Group V (50 years and older). All measurements were expressed in millimeters and degree.

Statistical analysis

Statistical analyses were performed using SPSS version 20.0 (IBM Corp., Armonk, NY, USA). The Kolmogorov-Smirnov test was applied to assess the normality of data distribution. For variables showing a normal distribution, one-way analysis of variance (ANOVA) was used to evaluate differences across age groups, as it is appropriate for comparing means among three or more independent groups. If statistically significant differences were observed, post hoc tests (Tukey's HSD or Games-Howell, based on variance homogeneity) were used to determine which age groups differed to compare differences between genders, an Independent Samples t-test was performed, with a p-value < 0.05 considered statistically significant. Descriptive statistics, including the mean, minimum, maximum, and standard deviation, were calculated to summarize the distribution of the measured variables.

RESULTS

This study included 180 healthy subjects aged between 18 and 60 years, comprising 85 males and 95 females. The mean ages of females and males were 33.33±11.35 years and 33.11±10.92 years, respectively. Tables 3 and 4 present the mean values, standard deviations, and ranges of various length and angle measurements about the craniovertebral region. Measurement results were found as follows: D_{TL} 10.35±0.83 mm, D_{APL} 11.45±0.95 mm, D_H 15.70±1.44 mm, D_T 1.58±0.49 mm, AOJ_A 118.24±7.11°, BO_D 33.58±2.79 mm, A_H 34.78±2.82 mm, AOI 1.47±0.29 mm, WB_A, 130.41±5.89°, CC_A 160.56±9.94°, KHI 41.45±3.03, AADI 1.19±0.48

mm, and PADI 19.47±1.84 mm, in healthy subjects, respectively. Six parameters, including D_{TL}, D_{APL}, D_H, BO_D, A_H, and CC_A, showed statistically significant differences between genders ($p < 0.05$). Among these, the values of D_{TL}, D_{APL}, D_H, D_T, BO_D, A_H, AOI, and KHI were found to be higher in males than in females (Table 3).

A statistically significant difference was observed between age groups for the five parameters D_{TL}, D_H, D_T, A_H, and AOI, indicating variations in these measurements across different age ranges (Table 4). According to the post-hoc analysis performed to show in which age range the significance emerged in the statistical analysis, for D_{TL}, a significant difference was observed between decades 1 and 4 (p = 0.034), decades 1 and 5 (p = 0.016), decades 3 and 4 (p = 0.004), and decades 3 and 5 (p = 0.014), respectively. In D_{APL} measurements, statistically significant differences were observed between the first decade and the second (p = 0.010), third (p = 0.014), fourth (p = 0.030), and fifth decades (p = 0.049). For D_H, a significant difference was noted between decades 1 and 2 (p < 0.001), decades 1 and 3 (p = 0.001), decades 1 and 4 (p = 0.025), and decades 2 and 4 (p = 0.049). In dens tip, a significant difference was found between decades 2 and 3 (p = 0.010), decades 3 and 4 (p < 0.001), and decades 4 and 5 (p = 0.028). Regarding A_H, significant age-related differences were observed between the following decades: 1 and 2 (p < 0.001), 1 and 3 (p = 0.041), 2 and 3 (p = 0.036), 2 and 4 (p = 0.011), and 2 and 5 (p = 0.008). For AOI measurements, statistically significant differences were found between the first decade and the second (p = 0.001), third (p < 0.0001), fourth (p < 0.004), and fifth decades (p = 0.023). These results indicate that AOI values tend to change significantly with increasing age, particularly when comparing the youngest age group to older decades.

Table 1. Craniovertebral junction measurements and definitions

Measurements	**Definitions**
Dens transverse length (D_{TL})	Transverse diameter of the dens at the level of the widest point.
Dens anteroposterior length (D_{APL})	Antero-posterior diameter of the dens at the level of the widest point.
Dens height (D_H)	The distance from the superior most point of the dens to the superior line of the superior articular facet.
Tip of the dens (D_T)	Its most apical end has been referred to as the tip
Axis height (A_H):	Vertically in the posterior midline of the vertebral body from the inferior to the superior margin (total height).
Atlanto occipital joint axis angle (AOJ_A)	The angle is formed at the intersection of tangents drawn parallel to the alanto-occipital joints.
Diameter between basion and opisthion (BO_D)	The distance between the basion and the opisthion was accepted.
Atlantoocipital interval (AOI)	A line perpendicular to the articular surfaces of the occipital condyle and the lateral mass of atlas
Welcher Basal angle (WB_A)	The angle between the line extending from the nasion to the tuberculum sellae and the line between basion to the tuberculum sellae
Clivus canal angle (CC_A)	The angle between the line extending from the top of the dorsum sellae to the basion and the line between the inferodorsal portions of axis to the most superodorsal part of the odontoid process
Klaus height index (KHI)	The vertical range between the tip of the dens and the line drawn from the tuberculum sellae to the internal occipital tuberance.
Anterior atlantodental interval (AADI)	The distance from the posterior margin of the anterior arch of the atlas (CI) to the anterior margin of the odontoid process.
Posterior atlantodental interval (PADI)	Anterior aspect of the posterior arch of the atlas to the posterior margin of the odontoid process.

Table 2. Summary of CVJ morphometric measurements reported in the literature

Measurements	A_H (mm)	D_H (mm)	D_{APL} (mm)	D_{TL} (mm)	D_T (mm)	AOI (mm)	WBA (°)	CCA (°)	KHI	AADI (mm)	PADI (mm)
Khanal et al.[34]	35.60 (M) 33.66 (F)	NM	NM	NM	NM	1.44 (M) 1.30 (F)	NM	NM	NM	1.51 (M) 1.46 (F)	18.45 (M) 16.62 (F)
Yousuf et al.[32] (HS)	38.1 (T)	15.8 (T)	10.7 (HS)	10.3 (T)	NM	NM	NM	NM	NM	NM	NM
Kulharni et al. [22]	NM	NM	11.83 (M) 11.10 (F)	10.11 (M) 9.49 (F)	NM	NM	NM	NM	NM	NM	NM
Ekuma et al [30]	NM	NM	NM	NM	NM	1.188 (M) 1.174 (F)	NM	NM	NM	NM	NM
Rokka et al [4]	NM	3.56 (M) 3.37 (F)	NM	NM	NM	1.44 (M) 1.30 (F)	NM	NM	NM	1.51 (M) 1.46 (F)	18.45 (M) 16.62 (F)
Rojas et al [7] (HS)	NM	NM	NM	NM	NM	1.00 (T)	NM	NM	NM	1.3 (T)	NM
Nalbant et al [9]	36.44 (M) 33.03 (F)	NM	12.99 (M) 11.46 (F)	NM	NM	NM	128.7 (M) 129.67 (F)	NM	NM	1.72 (M) 1.43 (F)	20.82 (M) 17.84 (F)
Koenigsberg et al [26]	NM	NM	NM	NM	NM	NM	129° (T)	NM	NM	NM	NM
Yadav et al. [33]	NM	NM	NM	NM	NM	NM	126.17 (M) 125.68 (F)	160.24 (M) 162.11 (F)	45.54 (M) 43.63 (F)	NM	NM
Tanrısever et al.[1]	NM	NM	NM	NM	NM	NM	130.4 (M) 131.25 (F)	157.46 (M) 157.79 (F)	NM	1.27 (M) 1.29 (F)	20.20 (M) 18.82 (F)
Yoon et al.[28]	NM	NM	NM	NM	NM	NM	NM	NM	NM	1.4 (T)	18.0 (T)
Batista et al.[5]	NM	NM	NM	NM	NM	NM	113.7	153.6	NM	1.1 (T)	NM
Dash et al.[35]	NM	NM	NM	NM	NM	NM	121.54 (M) 121.83 (F)	NM	NM	1.12 (M) 1.11 (F)	NM
This paper	36.40 (M) 33.33 (F)	16.32 (M) 15.15 (F)	11.69 (M) 11.23 (F)	10.54 (M) 10.18 (F)	1.60 (M) 1.57 (F)	1.49 (M) 1.45 (F)	130.04 (M) 130.74 (F)	158.11 (M) 162.76 (F)	41.77 (M) 41.17 (F)	1.22 (M) 1.17 (F)	20.10 (M) 18.90 (F)

Dens transverse length (D_{TL}), Dens anteroposterior length (D_{APL}), Dens height (D_H), Tip of the dens (D_T), Axis height (A_H): Atlanto occipital joint axis angle (AOJ_A), Diameter between basion and opisthion (BO_D), Atlantoocipital interval (AOI), Welcher Basal angle (WB_A), Clivus canal angle (CC_A), Klaus height index (KHI), Anterior atlantodental interval (AADI), Posterior atlantodental interval (PADI), Non-measured (NM), Male (M), Female (F), Female and male subjects (T)

Table 3. The gender related changes of the craniovertebral junction in healthy subjects

Measurements (mm for length and distance; for angle measurements)	**Gender**	**Healthy Subjects (n=180)**			
		Mean±SD	**Minimum**	**Maximum**	**P value**
Dens transverse length (D_{TL})	Males (n=85)	10.54±0.86	8.50	12.50	**0.003**
	Females (n=95)	10.18±0.77	8.00	11.50	
	Total (n=180)	10.35±0.83	8.00	12.50	
Dens anteroposterior length (D_{APL})	Males (n=85)	11.69±0.93	9.50	14.00	**0.001**
	Females (n=95)	11.23±0.91	9.00	13.00	
	Total (n=180)	11.45±0.95	9.00	14.00	
Dens height (D_H)	Males (n=85)	16.32±1.35	13.50	19.00	**<0.001**
	Females (n=95)	15.15±1.28	13.00	19.00	
	Total (n=180)	15.70±1.44	13.00	19.00	
Dens tip (D_T)	Males (n=85)	1.60±0.42	1.00	2.00	0.670
	Females (n=95)	1.57±0.50	1.00	2.00	
	Total (n=180)	1.58±0.49	1.00	2.00	
Atlantoccipital joint angle (AOJ_A)	Males (n=85)	117.29±8.16	92.00	130.00	0.092
	Females (n=95)	119.08±5.93	104.00	135.00	
	Total (n=180)	118.24±7.11	92.00	135.00	
Distance between Basion and opisthion (BO_D)	Males (n=85)	34.57±2.85	27.00	40.00	**<0.001**
	Females (n=95)	32.71±2.43	28.00	39.00	
	Total (n=180)	33.58±2.79	27.00	40.00	
Axis height (A_H)	Males (n=85)	36.40±2.61	29.00	41.00	**<0.001**
	Females (n=95)	33.33±2.15	29.00	39.00	
	Total (n=180)	34.78±2.82	29.00	41.00	
Atlantooccipital interval (AOI)	Males (n=85)	1.49±0.30	1.00	2.10	0.290
	Females (n=95)	1.45±0.29	1.00	2.10	
	Total (n=180)	1.47±0.29	1.00	2.10	
Welcher basal angle (WB_A)	Males (n=85)	130.04±5.56	116.00	143.00	0.420
	Females (n=95)	130.74±6.18	116.00	150.00	
	Total (n=180)	130.41±5.89	117.0	150.0	
Clivus canal angle (CC_A)	Males (n=85)	158.11±10.40	139.00	179.00	0.002
	Females (n=95)	162.76±9.02	142.00	179.00	
	Total (n=180)	160.56±9.94	139.00	179.00	
Klaus height index (KHI)	Males (n=85)	41.77±2.94	37.00	51.00	0.188
	Females (n=95)	41.17±3.10	33.00	50.00	
	Total (n=180)	41.45±3.03	33.00	51.0	
Anterior atlantodental interval (AADI)	Males (n=85)	1.22±0.43	0,58	3.95	0.032
	Females (n=95)	1.17±0.52	0.50	3.75	
	Total (n=180)	1.19±0.48	0.50	3.95	
Posterior atlantodental interval (PADI)	Males (n=85)	20.10±2.24	13.60	29.00	0.004
	Females (n=95)	18.9±1.48	13.00	28.50	
	Total (n=180)	19.47±1.84	13.00	31.00	

Dens transverse length (D_{TL}), Dens anteroposterior length (D_{APL}), Dens height (D_H), Tip of the dens (D_T), Axis height (A_H): Atlanto occipital joint axis angle (AOJA), Diameter between basion and opisthion (BOD), Atlantoocipital interval (AOI), Welcher Basal angle (WBA), Clivus canal angle (CC_A), Klaus height index (KHI), Anterior atlantodental interval (AADI), Posterior atlantodental interval (PADI)

Table 4. The age-related changes of the craniovertebral junction in healthy subjects

Measurements (mm for length and distance; ° for angle measurements)	**Decade**	**Healthy subjects (n=180)**	
		Mean±SD	P value
Dens transverse length (D_{TL})	1 (n=25)	10.12±0.78	**0.028**
	2 (n=46)	10.33±0.85	
	3 (n=49)	10.17±0.91	
	4 (n=46)	10.55±0.69	
	5 (n=14)	10.79±0.78	
	Total (n=180)	10.35±0.83	
Dens anteroposterior length (D_{APL})	1 (n=25)	10.96±1.10	0.091
	2 (n=46)	11.57±1.02	
	3 (n=49)	11.53±0.97	
	4 (n=46)	11.47±0.75	
	5 (n=14)	11.57±0.53	
	Total (n=180)	11.45±0.95	
Dens height (D_H)	1 (n=25)	14.80±1.00	**0.001**
	2 (n=46)	16.15±1.59	
	3 (n=49)	15.97±1.31	
	4 (n=46)	15.58±1.33	
	5 (n=14)	17.36±1.65	
	Total (n=180)	15.70±1.44	
Dens tip (D_T)	1 (n=25)	1.60±0.50	**0.002**
	2 (n=46)	1.52±0.51	
	3 (n=49)	1.78±0.42	
	4 (n=46)	1.39±0.42	
	5 (n=14)	1.71±0.47	
	Total (n=180)	1.58±0.49	
Atlantoccipital joint angle (AOJ_A)	1 (n=25)	119.44±5.54	0.161
	2 (n=46)	118.89±7.30	
	3 (n=49)	119.04±5.69	
	4 (n=46)	117.22±7.21	
	5 (n=14)	114.50±11.38	
	Total (n=180)	118.24±7.11	
Distance between Basion and opisthion (BO_D)	1 (n=25)	33.08±2.52	0.061
	2 (n=46)	34.02±2.08	
	3 (n=49)	33.65±3.25	
	4 (n=46)	33.91±2.72	
	5 (n=14)	31.71±3.20	
	Total (n=180)	33.58±2.79	
Axis (C2) height (A_H)	1 (n=25)	33.44±3.24	**0.002**
	2 (n=46)	36.00±2.72	
	3 (n=49)	34.82±2.72	
	4 (n=46)	34.54±2.47	
	5 (n=14)	34.78±2.12	
	Total (n=180)	34.78±2.82	
Atlantooccipital interval (AOI)	1 (n=25)	1.70±0.30	**<0.001**
	2 (n=46)	1.47±0.31	
	3 (n=49)	1.40±0.32	
	4 (n=46)	1.41±0.21	
	5 (n=14)	1.49±0.18	
	Total (n=180)	1.47±0.29	
Welcher basal angle (WB_A)	1 (n=25)	129.92±8.16	0.808
	2 (n=46)	131.00±4.85	
	3 (n=49)	129.67±5.97	
	4 (n=46)	130.74±6.19	
	5 (n=14)	130.86±2.14	
	Total (n=180)	130.41±5.89	
Clivus canal angle (CC_A)	1 (n=25)	164.20±9.44	**0.204**
	2 (n=46)	158.44±10.07	
	3 (n=49)	161.33±9.25	
	4 (n=46)	160.17±10.70	

	5 (n=14)	159.64±9.38	
	Total (n=180)	160.56±9.94	
Klaus height index (KHI)	1 (n=25)	42.00±3.37	0.796
	2 (n=46)	41.50±2.63	
	3 (n=49)	41.55±3.37	
	4 (n=46)	41.09±3.15	
	5 (n=14)	41.14±2.03	
	Total (n=180)	41.45±3.03	
Anterior atlantodental interval (AADI)	1 (n=25)	1.18±0.48	0.286
	2 (n=46)	1.23±0.49	
	3 (n=49)	1.191±0.50	
	4 (n=46)	1.17±0.53	
	5 (n=14)	1.14±0.50	
	Total (n=180)	1.19±0.48	
Posterior atlantodental interval (PADI)	1 (n=25)	19.34±1.84	
	2 (n=46)	19.32±2.1	
	3 (n=49)	19.80±1.95	0.420
	4 (n=46)	19.28±1.57	
	5 (n=14)	19.66±1.44	
	Total (n=180)	19.47±1.84	

Dens transverse length (D_{TL}), Dens anteroposterior length (D_{APL}), Dens height (D_H), Tip of the dens (D_T), Axis height (A_H): Atlanto occipital joint axis angle (AOJA), Diameter between basion and opisthion (BO_D), Atlantooccipital interval (AOI), Welcher Basal angle (WB_A), Clivus canal angle (CC_A), Klaus height index (KHI), Anterior atlantodental interval (AADI), Posterior atlantodental interval (PADI)

DISCUSSION

Morphometric measurements of the craniovertebral junction serve as an essential tool for characterizing anatomical variations and pathological conditions in this region, thereby providing valuable insights that inform clinical decision-making and surgical planning. Therefore, we have evaluated 13 CT parameters including dens transverse length (D_{TL}), dens anteroposterior length (D_{APL}), dens height (D_H), dens tip (D_T), atlantooccipital joint angle (AOJ_A), distance between basion to opistion (BO_D), axis height (A_H), atlantooccipital interval (AOI), Welcher basal angle (WB_A), clivus canal angle (CC_A), klaus height index (KHI), anterior atlanto-dental interval (AADI), and posterior atlanto dental interval (PADI). Additionally, seven parameters, including D_{TL}, D_{APL}, D_H, BO_D, A_H, AADI, and PADI, were significantly higher in males than in females. Five measurements, D_{TL}, D_H, D_T, A_H, and AOI, demonstrated statistically significant differences across age groups. CVJ surgery represents a critical and complex component of spinal surgery. [1,31,36]. CVJ is the bony transition between the skull and cervical vertebrae. The occipital condyles (OC), atlas (C1), and axis (C2) form a biomechanically complex joint that involves ligaments, the spinal cord, cranial nerves, as well as vascular and lymphatic structures, all of which contribute to its functional complexity. The craniovertebral junction (CVJ) is highly mobile and contains vital structures including nerves and blood vessels.[1,6,8,9,12]. Various conditions can affect the craniovertebral junction (CVJ), including congenital, hereditary, and acquired anomalies, as well as traumatic, neoplastic, and infectious diseases. These can cause instability. These pathologies may affect the dens of the axis (DA), which moves toward the foramen magnum and presses on the brainstem. This pressure may lead to arrhythmia, blood pressure changes, respiratory depression, and death because of damaging vital structures[12-14]. The signs and symptoms of the CVJ pathologies are variable. Typically, they start silently, manifest themselves very late, progress slowly, and rarely recur. In addition, understanding the normal anatomical and radiological measurements of the craniovertebral junction (CVJ) is crucial for accurate diagnosis and for guiding treatment decisions in various neurological or structural disorders affecting this area. Furthermore, the craniovertebral junction (CVJ) is the most challenging area to evaluate radiologically within the entire cervical spine, and its accurate and detailed assessment is crucial in cases of injuries or pathologies affecting this region [1,2,6,7,9,30]. However, there is no clear consensus in the literature regarding the normal reference values reported in most studies[1].

The axis has a special anatomical and biomechanical feature. The dens axis fractures account for approximately a third of the cervical vertebrae fractures [23]. The cervical spine is exposed to much stress. The surgeries in this area are very risky because of possible damage to the aorta or adjacent vital structures. Therefore, precise knowledge of axis morphology is essential for preclinical research, accurate diagnosis of spinal cord disorders, effective surgical planning, and the appropriate selection and insertion of surgical tools. In particular, the dimensions of the odontoid process, such as its height and diameter, as well as those of the DA, play a critical role in odontoid screw fixation and anterior-posterior stabilization. The diameter and length of the odontoid process are particularly important for deciding whether one or two screws should be used in the event of a fracture. The dens is held in place by strong ligamentous attachments to the atlas and the skull. The joint formed by the occiput, atlas, and axis is critical and is known as the occipitocervical junction. [23,32,37]. The axis (C2) is of great importance due to its anatomical location and morphological characteristics. Incorrect placement of pedicle screws can damage adjacent vital structures, including the spinal cord, nerve roots, vertebral arteries, and cranial nerves, potentially leading to serious neurological or vascular complications [36,38]. For proper placement of two screws in the coronal plane, the transverse length of the OP becomes more important than the anteroposterior length. A minimum transverse length of 9.0 mm is required for safe insertion of two 3.5 mm cortical screws into the dens [32]. Additionally, the parameters D_{TL}, D_H, D_T, and A_H showed significant differences depending on age, while D_{TL}, D_{APL}, D_H, and A_H varied significantly between males and females. Our values were closer to those reported in the Nepalese population [34], generally higher, but different from those observed in the Indian population [22,32].

The atlantooccipital joint axis angle (AOJ_A) is defined as the distance at the intersection of tangents drawn parallel to the AOJ. These tangents intersect at the center of the odontoid process when the condyles are symmetric. The normal values of AOJ_A are accepted as between 124° and 127°. An increase in the angle may be a reason for occipital condylar hypoplasia [2]. In this study, the measured values were 117.29° for males and 119.08° for females, respectively. This value was also found to be higher in females compared to males, yet lower than the reference values commonly cited in the literature [2].

CC_A and WB_A are performed in the Mid-sagittal plane. Welcher basal angle (WB_A) was first described by Welcher in 1866. In the literature, terms such as Welcker basal angle, basal sphenoid angle, and basal angle are also used interchangeably to refer to the Welcker basal angle [1]. The WB_A is formed by the overlapping of the nasion, tuberculum line, and basion line, and the normal reference value of WB_A is accepted as 132°. An increase in this angle (140° or more) may be associated with a higher incidence of platybasia [2,19]. Platybasia and basilar invagination may develop in certain conditions, such as congenital craniofacial anomalies (e.g., osteogenesis imperfecta) and acquired disorders (e.g., trauma, senile atrophy). These have brainstem signs and symptoms and upper cervical cord compression [26]. WB_A data were between 113.7 degrees and 130.83 degrees in literature studies [1,5,9,26,33]. According to Koeningsberg, the same angle showed a significant difference between adults and children [26]. In this study, the WB_A value was higher in females than in males; however, it can be concluded that gender did not significantly affect the measurements. Additionally, our values were higher than those reported for Indian, Brazilian, and US populations, while being comparable to findings from other Turkish studies

The clivus and axis are the two reference points often favored to define the structure of the CVJ. Angular measurements relative to these structures are influenced by various factors, including bony orientation and the surrounding ligaments. Notably, the CC_A referred to responses to surgical intervention [34,39]. An extreme decrease in angle following occipitocervical fusion may be a reason for the development of dysphagia, dyspnea, and aspiration risk. Additionally, this affects many vital structures, such as the ventral brainstem and spinal cord motor fiber tracts, cardiopulmonary regulatory centers, etc [34,39,40-42]. The CVJ contains numerous foramina that are essential for the passage of blood vessels and cerebrospinal fluid between the spinal canal and the cranium. Congenital anomalies (such as Chiari malformation), physical disorders, poor posture, improper movements, and neurodegenerative diseases can lead to structural changes in the skull base. These alterations may result in compression of the brainstem, cerebellum, cervical spinal cord, and lower cranial and upper cervical nerves [39,43]. Another source reported the reference range for the Clivus Canal Angle as between 150° and 180°, noting that a decrease below 150° may increase the risk of ventral cord compression [2]. The measured values fell within the recommended reference range, with higher angles observed in females compared to males. Moreover, the findings are largely consistent with those reported in other populations [9,18,33]. A comprehensive review of the literature indicates that the cranial cervical angle (CC_A) ranges from 153.6° to 162.1°. In the present study, the mean CC_A values were 158.1° in females and 162.7° in males. These values were observed to be higher than those previously reported for the Brazilian population. The atlanto-occipital interval (AOI), a clinically reliable diagnostic parameter, has been demonstrated to be the most precise and reproducible method for evaluating the craniovertebral junction (CVJ) in cases of atlanto-occipital dissociation [2,7,30,34]. The AOI in healthy adults is expected to be less than 1.4 mm [40]. Ekuma et al.'s study demonstrated that the AOI parameter decreased inversely with age in both males and females. No significant difference in AOI was observed between genders [30]. In addition, Rojas et al. reported that this parameter may vary with age, suggesting that age-related differences could arise from multiple factors, including environmental influences, genetic variability, and age-associated joint degeneration [7]. In this paper, this value was lower in females than in males; however, no significant difference was found between genders. While the AOI parameter is reported to be between 1.00 and 1.18 in the literature, our values are higher than both the literature and the reference value. We think that the variability in the atlanto-occipital interval (AOI) may be attributed to factors such as age, sex, ethnicity, geographic region, and differences in imaging or measurement techniques.

The Klaus height index (KHI) is the vertical distance between the tip of the dens and the line drawn from the tuberculum sellae to the internal occipital tuberance. If this dimension is<30mm, the indicated tendency to basilar impression is basilar impression [2]. Yadav et al. conducted a CT study on 120 Indian subjects with craniovertebral junction malformations and found significant differences in the KHI parameter across gender and age groups [33].

The anterior atlantodental interval (AADI) is considered the most accurate measurement for evaluating atlantoaxial displacement. The posterior atlantodental interval (PADI), which contains nerve roots, the spinal cord, and important arteries, serves as an indicator for potential neurological damage. A reduction in the PADI can lead to vascular compromise of the anterior spinal artery, vertebral artery, and basilar artery, even without direct compression of the spinal cord [28]. Numerous studies have been conducted concerning the AADI and PADI. In a study by Rojas et al., the AADI was reported to be less than 2 mm in 95% of subjects [7]. If 2 mm is regarded as the maximum standard value, this discrepancy might reduce the sensitivity of CT evaluations across multiple clinical conditions [7]. In another study performed by Nalbant et al, AADI and PADI were measured as statistically significantly lower in females than in males. Both measures showed a significant difference between genders [9]. In addition, Yoon et al. reported that a posterior atlantodental interval of less than 14 mm may indicate a neurological deficit. Moreover, the fact that this value is lower in females than in males may account for the increased tendency toward neurological deficits among females [28]. In this study, the AADI value was determined to be less than 2 mm. Furthermore, although the PADI value was lower in females compared to males, it remained within the accepted reference range.

This study has several limitations that should be acknowledged. Due to its retrospective design, certain important parameters such as body weight and height were not available, which may influence the interpretation of the findings. Additionally, the data were collected from a single center, which may limit the generalizability of the results to broader populations. To overcome these limitations, future studies should be conducted prospectively and involve multiple centers. Additionally, it is important to include comprehensive anthropometric data such as participants' height and weight. These approaches will improve the accuracy of the findings and enhance the generalizability of the results to a broader population.

Consequently, thorough knowledge of the normal reference ranges in this region is crucial not only for understanding basic anatomical structures but also for surgical planning, delineating the limits of the operative field, reducing complication risks, and guiding various surgical approaches for pathologies or anomalies Therefore, we believe that craniovertebral junction morphology will be a guide for many experts such as anatomists, radiologists, neurosurgeons, ENT surgeons, anesthesiologists, and orthopedists. Knowing the reference measurements of healthy individuals and understanding sex and racial differences play a crucial role in clinical and pathological processes.

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