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Radiological Evaluation of Odontoid Process Volume by Using Digital Three-Dimensional (3D) Modeling for Sex and Age Estimation: A Retrospective Cone Beam Computed Tomography Study

Evaluación Radiológica del Volumen del Proceso Odontoideo Mediante el Uso de Modelos Tridimensionales (3D) Digitales para la Estimación del Sexo y la Edad: Un Estudio Retrospectivo de Tomografía Computarizada de Haz Cónico

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SUMMARY: Odontoid process is a very important anatomical structure for the craniovertebral junction. The first purpose of this study is to demonstrate that age and sex-dependent differences in odontoid process volume in a Turkish population can be defined, visualized, and measured using cone-beam computed tomography (CBCT). The second aim is to evaluate the sex and age dimorphism degree of the odontoid process. And the third aim is to develop volume-based discrimination formulas. CBCT images of 150 people (75 females, 75 males, age range 12-73 years, mean age 27.34 years) were retrospectively analyzed. The odontoid process volumes were measured using InVivo Dental software. It was found that males had a statistically higher odontoid process volume than females (p = 0.001). Statistically, a decrease in odontoid process volume was detected with age (p <0.0001). The mean odontoid process volume split point was <1745 mm3 for females and > 2733 mm3 for males. According to discriminant function analysis, 73.3 % females and 42.7 % males in total were correctly classified. According to the group centroid scores, values ??less than -0,601 indicate individuals over the age of 45, while values greater than 0.143 indicate individuals in the 12-18 age group. In total, 94.7 % of 12-18 age group and 8 % of 45 years and older individuals were correctly classified. According to the results obtained from this study, sex and age discriminant scores were moderate. However, the results of the present study show that odontoid process volume has strong potential to predict the under-18 age and older.

KEY WORDS: Odontoid process; Volume; 3D modeling; Age and sex determination.

INTRODUCTION

Determining the age and sex of individuals within a population is essential for constructing life tables, assessing age- and sex-related disease changes, and population reconstruction. This is increasingly important due to the rising numbers of undocumented immigrants, sports fraud, and crimes involving minors (Aggrawal, 2009). Skeletal maturation provides insights into craniofacial growth, and various skeletal measurements and indices allow researchers to define individual morphologies and examine differences between populations, identify racial characteristics, estimate stature, determine age and sex, and make inter-sex comparisons. Morphometric bone measurements have been extensively studied in areas such as chronological age, dental development, sexual maturation, and body height (O'Reilly & Yanniello, 1988; Krishan *et al*., 2016; Chatterjee *et al*., 2019).

Although determining sex is straightforward when a complete skeleton is available, not all bones are always found, making sexual dimorphism within and between populations relevant. While skeletal methods are used for age and sex estimation, factors such as environmental conditions and systemic disorders also impact bone maturation. The axis (C2) vertebra, often better preserved

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than pelvic bones, has unique anatomy, including the odontoid process, which enables head rotation by interacting with the atlas (C1) (Pickering & Carlson, 2004; Torimitsu *et al*., 2015).

Beyond supporting head rotation, the odontoid process resists shifting and flexion via the transverse ligament, underscoring the need for precise morphometric understanding of this region, especially for surgical interventions (Gil *et al*., 2015; Torimitsu *et al*., 2015; Tsuji *et al*., 2015; He *et al*., 2016; Korres *et al*., 2016; Srivastava *et al*., 2016; Zhou *et al*., 2016; Magat & Ozcan, 2019). Morphometric traits in the craniocervical region vary significantly by age and sex, with males generally displaying higher measurements. While limited studies exist on the morphometric analysis of the odontoid process, they predominantly involve cadaveric or CT images (Akobo *et al*., 2015).

CT is valuable for assessing the odontoid process by demonstrating bone changes (Akobo *et al*., 2015). Cone-beam computed tomography (CBCT) offers three-dimensional imaging at lower radiation doses, increasingly adopted in maxillofacial imaging for its high-contrast, low-artifact images and real-time analysis potential (Moffat *et al*., 1977). This study is the first to evaluate odontoid process volume based on age and sex using CBCT in a Turkish population. Given that vertebral body shape varies with growth and sex, this study assesses age- and sex-based differences in the odontoid process using CBCT, aiming to identify, visualize, and quantify these differences. Secondary aims include evaluating sex and age dimorphism and developing volume-based discrimination formulas.

MATERIAL AND METHOD

This retrospective study was approved by the Necmettin Erbakan University Faculty of Dentistry Ethics Committee for Non-Pharmaceutical and Medical Device Research (no. 2019.06). The tomography images of 150 people (75 women, 75 men, age range 12-73 years, mean age 27.34 years) who applied to Necmettin Erbakan University Faculty of Dentistry and received CBCT for various reasons between 2014-2024 were retrospectively analyzed. Individuals younger than 12 years of age, incomplete records, radiographs of poor diagnostic quality, craniofacial disorders involving the head and neck region, degenerative disease, infection, tumor, traumatic or congenital anomalies or syndromes were excluded from the study.

The research group was split into subgroups based on age and sex for the purpose of analysis. There were four age brackets: 12–18, 19–30, 31–44, and 45 and up. Table I shows the breakdown of the participants by age and sex.
The date of CBCT was subtracted from the date of birth to get the chronological age. The following parameters were used to obtain CBCT images: operating at 90 kVp and 5 mA, voxel 0.25 mm, 140 m x 100 mm field of view, 360° data acquisition, and no extra filtering. The imaging system was developed and manufactured by J Morita MFG Corp. of Kyoto, Japan. In the middle of the CBCT images was the target area. Following the instructions on the equipment, we normalized the median line and positioned each patient parallel to the floor.

A 15.6-inch healthcare monitor (Nio Color 3MP, Barco, Belgium) with a resolution of 1600 × 900 and a refresh rate of 60 Hz was used for all reconstructions and measurements. In order to better see landmarks, the examiner could also use orientation and enhancement aids like brightness, contrast, and magnification.

Figure 1 shows the procedure of exporting axial images from CBCT into DICOM file format with a 512×512 matrix for the purpose of evaluating the odontoid process anatomy. These files were then imported into the software

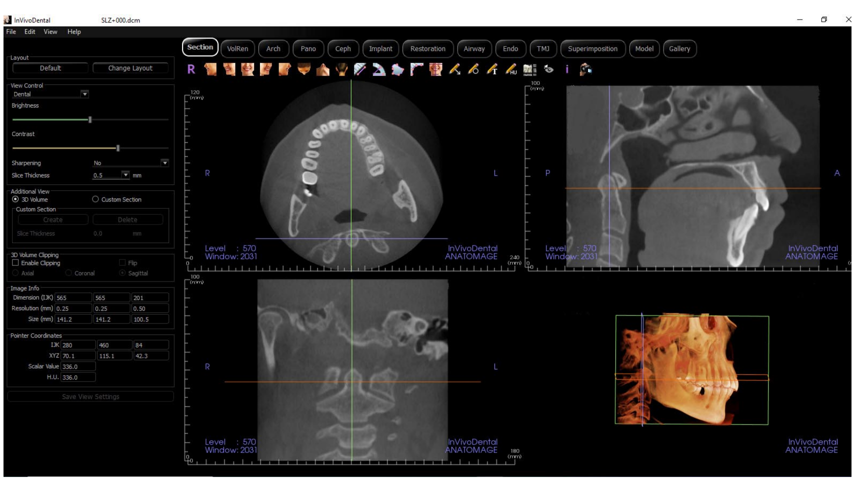

Fig. 1. Axial, sagittal, coronal and three-dimensional view of DICOM file format imported to InVivoDental software.

InVivoDental (Version 5, Anatomage, San Jose, CA, USA). In order to analyze the odontoid process's anatomy, 3D pictures were manually segmented (Fig. 2) The boundaries of the odontoid process were carefully determined during the segmentation process. The superior boundary was marked at the highest point where the odontoid process articulates with the atlas (C1), serving as the starting point for segmentation. The inferior boundary was defined at the junction where the odontoid process connects with the body of the C2 (axis) vertebra, separated precisely from the axis body. The anterior surface was clearly delineated to represent the front portion related to the atlas. The posterior boundary was defined parallel to the surface connected to the spinal canal, indicating the rear part of the odontoid process. Finally, the lateral boundaries on both the right and left sides of the odontoid process were carefully marked to avoid interference with surrounding bony structures. With these boundaries established, the volume of the odontoid process was accurately measured, and a three-dimensional model was created. Figure 3 shows the results of the automated measurement of odontoid process volumes following segmentation.

Fig. 2. Three-dimensional view of the odontoid process after manual segmentation.

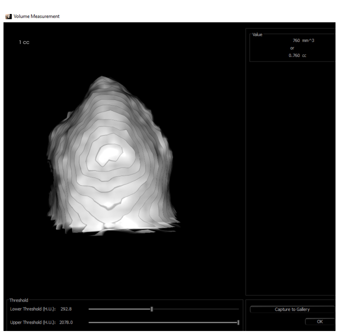

Fig. 3. Measuring the automatic volume of the sample obtained after manual segmentation by software.

We also calculated the sexual dimorphism index (SDI = (Male mean - Female mean) / Male mean)*100) of the odontoid process volume as stated by Gama *et al*. (2015). An index greater than 10 % indicates that the parameters are strongly sexually dimorphic (Gama *et al*., 2015).

All evaluations on CBCT images were performed by a radiologist (GM) with 14 years of experience in evaluating CBCT images. For intra-observer and inter-observer (SO with 30 years of experience) reliabilities, measurements were re-examined four weeks later by the same radiologists on 30 randomly selected samples under blinded conditions.

All statistical analyzes were performed using SPSS 22.0 for Windows (SPSS Inc., Chicago, IL, USA). One-sample Kolmogorov Smirnov test was used to evaluate the suitability of the data for normal distribution. The Mann-Whitney U test was used to evaluate whether there were significant differences between men and women in non-normally distributed volume data. The Kruskal-Wallis H test was used to evaluate whether the volume of the odontoid process differed statistically by age groups. Discriminant function analysis was used to determine age and sex dimorphism. In addition, cross-validation method was used to test the models derived from discriminant analysis and to increase the reliability of classification. Differences were considered significant at the $p<0.05$ level.

RESULTS

The intra-observer and inter-observer correlation coefficients for volume measurement was 0.934 and 0.901, respectively. This value was nearly excellent. In the sample studied (n=150), the distribution of males and females was equal (75 males, 75 females). Age distribution by sex (27.97 ± 11.52 and 31.72 ± 17.63 years, respectively) did not show a statistically significant difference ($p>0.05$).

The mean odontoid process volume of individuals in the entire sample was 1745.27 ± 709.92 mm^3 (779.00 – 4505 mm^3). The mean values, standard deviations, lowest and highest values of the examined odontoid process volume by sex and age groups are presented in Table I. It was determined that males had a statistically higher volume of the odontoid process than females ($p=0.001$). The distribution of mean odontoid process volumes by age groups is shown in **Table I.** Statistically, the volume of the odontoid process decreased with age ($p<0.0001$).

The data distribution was suitable for discriminant function analysis ($p < 0.01$) (Table I). Split points for odontoid process volume were determined for sex and age classification, with <1745 mm^3 for females and >2733 mm^3 for males (Table II). The model fit was good (Wilks' lambda = 0.935, p = 0.002), and the discriminant function score was calculated as -2.533 + 0.001 (Odontoid process volume), where values below zero indicate females and above zero indicate males. The classification accuracy was 73.3 % for females and 42.7 % for males, with an overall correct classification rate of 58 % by direct and cross-validation methods (Table III). The odontoid process volume's Sexual Dimorphism Index (SDI) was 18.7, with overall sensitivity and specificity at 56.1 % and 61.5 %, respectively, and an accuracy of 50 %.

Discriminant function analysis for age discrimination based on odontoid process volume showed a good model fit (Wilks' lambda = 0.807, p < 0.01) (Table IV). The mean volume thresholds were as follows: >1837.29 mm^3 for ages 12-18, 1524.43-1837.29 mm^3 for ages 19-30, 1357.99-1524.43 mm^3 for ages 31-44, and <1357.99 mm^3 for ages 45+. The discriminant function score formula was -2.709 + 0.002 (Odontoid process volume). Age groups aligned with centroid values: >0.143 for 12-18, -0.342 to 0.143 for 19-30, -0.601 to -0.342 for 31-44, and <-0.601 for 45+. The model correctly classified 94.7 % of 12-18-year-olds and 8 % of individuals over 45, with an overall classification accuracy of 49.3 % (Table V).

Table I. Descriptive statistical data of odontoid process volume by age and sex (mm^3).

		N	Minimum	Maximum	Mean	Standard Deviation	P value
Sex	Female	75	830.00	3832.00	1565.56	602.93	0.001*
	Male	75	779.00	4505.00	1924.99	765.37	
Age Groups	12-18 age	76	852.00	4505.00	2037.07	741.22	0.000*
	19-30 age	23	830.00	3751.00	1637.52	871.30	
	31-44 age	26	779.00	1973.00	1411.35	257.81	
	45 years and older	25	874.00	1821.00	1304.64	207.60	

*p<0,01

Table II. Function coefficients and split point value for female and male.

Function and variables	**Function coefficients**	**Standardized coefficients**	**Group centroid**	**Group centroid split point***
Odontoid process volume	0.001	1	M: 0.261	F < 0 < M
Constant	-2.533		F: -0.261	

* Group centroid split point: It is obtained by dividing the sum of the group centroid values calculated for males and females by two. M: Male F: Female Discriminant function score = -2.533 + 0.001 x (Odontoid process volume).

Table III. Sex classification accuracy of original and crossover data as a result of discriminant analysis.

		Sex	Predicted Group Membership		Total
			Female	Male	7
Original	Number (n)	Female	55	20	75
		Male	43	32	75
	Percent (%)	Female	73.3	26.7	100
		Male	57.3	42.7	100
Cross-validation	Number (n)	Female	55	20	75
		Male	43	32	75
	Percent (%)	Female	73.3	26.7	100
		Male	57.3	42.7	100

* As a result of the original and cross-validation, 58% of the sample was correctly classified.

Table IV. Function coefficients and split point value for age groups.

Function and variables	**Function coefficients**	**Standardized coefficients**	**Group centroid**	**Group centroid split point***
Odontoid process volume	0.002	1	1: 0.453	4 < 1357.99 mm^3 < 3 < 1524.43 mm^3<2 < 1837.29 mm^3 <1
Constant	-2.709		2: -0.167	
			3: -0.518	
			4: -0684	

*1: 12-18 Age, 2: 19-30 Age, 3: 31-44 Age, 4: 45 years and older Age Discriminant function score = -2,709 + 0,002 x (Odontoid process volume).

Table V. Classification accuracy of original and crossover data as a result of discriminant analysis.

		Yas Gruplari	Predicted Group Membership				Total
			12-18 Age	19-30 Age	31-44 Age	45 years and older	
Original	Number	12-18 Age	72	0	0	4	76
		19-30 Age	17	0	0	6	23
		31-44 Age	24	0	0	2	26
		45 years and older	23	0	0	2	25
	Percent	12-18 Age	94.7	0	0	5.3	100
		19-30 Age	73.9	0	0	26.1	100
		31-44 Age	92.3	0	0	7.7	100
		45 years and older	92	0	0	8	100
Cross-validation	Number	12-18 Age	72	0	0	4	76
		19-30 Age	17	0	0	6	23
		31-44 Age	24	0	0	2	26
		45 years and older	23	0	0	2	25
	Percent	12-18 Age	94.7	0	0	5,3	100
		19-30 Age	73.9	0	0	26.1	100
		31-44 Age	92.3	0	0	7.7	100
		45 years and older	92	0	0	8	100

* As a result of the original and cross-validation, 49.3% of the sample was correctly classified.

DISCUSSION

In this study, odontoid process volume was measured to assess age and sex estimation. Literature indicates significant sexual dimorphism in cervical vertebral foramen sizes, especially between males and females (Taitz, 1996; Tatarek, 2005; Kibii *et al*., 2010). Vertebral body measurements, such as length, width, and articulated faces, have often been used for sex prediction (Marlow & Pastor, 2011; Amores *et al*., 2014; Gama *et al*., 2015). Our results show that odontoid process volume can support age and sex estimation. Sex and age determination are crucial in forensic evaluations, and osteometric measurements have proven reliable for identifying anatomically distorted remains (Biwasaka *et al*., 2012).

Metric methods are considered more reliable than morphological ones, being reproducible and based on precise bone measurements (Akhlaghi *et al*., 2014; Monum *et al*., 2017). Virtual 3D modeling further enhances forensic analysis by preserving fragile materials and enabling advanced morphometric studies (Rodriguez Paz *et al*., 2019; Villa *et al*., 2019). Therefore, in this study, we evaluated the volume of the odontoid process using 3D image analysis software.

Certain behaviors are displayed during the maturation of odontoid processes. When determining whether a pregnancy is viable, changes in morphology and allometric growth can play a significant role. According to the findings, axis densities fluctuate at a rate of about 71/2-8 months. The shape of axial dens may attract a lot of attention in forensic investigations since a fetus reaches viability at day 210 of intrauterine life, which is 71/2 months (Kósa & Castellana, 2005). In a study conducted by Altan *et al*. (2012), it was stated that cervical vertebra sizes follow a somatic growth pattern and show a continuous increase in both boys and girls until the average age of 15-16. This is relevant since a study that looked at how well developed the cervical vertebrae were was shown to be related to centroid size, which implies that the cervical vertebrae's indirect size (Rhee *et al*., 2015).

For centroid size, Chatzigianni & Halazonetis (2009) found sexual dimorphism in cervical vertebrae size, with males having larger centroid sizes, especially post-growth. Hellsing (1991) and Stemper *et al*. (2008) reported that males have larger cervical vertebrae than females, while Rhee *et al*. (2015) found no sex differences in CBCT images. In a study on our population (Ekizoglu *et al*., 2021), all vertebral measurements, including heights and diameters, were higher in males, with C2-C7 height showing over 10 % of SDI. Wescott (2000) and Marlow & Pastor (2011), noted that height and transverse diameter are the most sexually dimorphic parameters in C2, with recent studies highlighting these differences during adolescence (Yoganandan *et al*., 2017; Miller *et al*., 2019, 2021). Our findings align with this, showing males had a higher odontoid process volume (SDI 18.7 %) than females, with a split point at 1745 mm^3 for females and 2733 mm^3 for males. Values below zero indicate females, above zero indicate males. Given that previous studies evaluated all cervical vertebrae rather than the odontoid process alone, more research is needed to compare and validate these findings.

Although the SDI was 18.7 % in this study, the overall accuracy was 50 %. Ekizoglu *et al*. (2021), evaluating the maximum cervical body vertebral height, foramen transverse diameter, and foramen anterior-posterior diameter measurements together, they found the reliability rate in the C2 vertebra to be 87.60 %. On the other hand, they emphasized that the accuracy in C1 vertebrae was less than 80 % (75 %). It is stated that a single vertebra does not accurately predict sex at or above the 80 % accuracy threshold (Rozendaal *et al*., 2020). Studies have shown that the accuracy of estimating sex increases with the increase in the number of measured parameters used in a discriminant function (Wescott, 2000; Bethard & Seet, 2013). This finding is compatible with our study. In our study, we evaluated only the volume of the odontoid process. Therefore, the value we obtained was below 80 %. Christensen & Crowder (2009) stated that although some methods achieve accuracy rates of less than 80 %, these methods can be used alone if the available skeletal material does not allow the use of other methods (such as fragmented remains). We think that in addition to metric measurements, volume should be added to studies involving the vertebrae.

By age six, the vertebral foramen reaches about 90 % of its adult size, transitioning in shape from circular to triangular (Clark, 1985). Most growth occurs in the transverse diameter, achieving adult size by age 10, while vertebral length continues to develop into early adolescence and reaches full size by age 20 (Albert *et al*., 2010). These findings suggest that odontoid process volume can also serve as an indicator for age estimation.

It was found that the mean volume of the odontoid process and body volume increased from 11.5 to 55.96 mm3 between 17th and 30th gestational weeks, respectively. The mean volumetric growth of vertebral bodies was found to increase from 15.53 to 72.43 mm^3 for vertebra C4 (Baumgart *et al*., 2013), from 32.54 to 158.14 mm^3 for vertebra T6 (Szpinda *et al*., 2013a) and from 14.50 to 41.65 mm^3 for vertebra L3 (Szpinda *et al*., 2013b). It has been observed that the volume ratios of both the odontoid and body ossification centers of the examined sample decreased from 0.22 to 0.19 and from 0.21 to 0.20, respectively, with age. A similar was observed again with respect to the body ossification centers of other vertebrae; 0.23 to 0.21 for C4 (Baumgart *et al*., 2013), 0.28 to 0.21 for T6 and 0.24 to 0.14 for L3 (Szpinda *et al*., 2013a). In a study conducted by Verbeek *et al*. (2020), on 66 patients, the volumes of odontoid process fractures were evaluated. It was determined that the mean volume values were between 1453 and 4495 mm^3 according to the fracture type and the volume did not show any age-related changes. In our study, the mean odontoid process volume was 1745 mm^3 ± 709.92 mm3 (779-4405 mm^3), and while the volume increased until the age of 18, it decreased with advancing age. In a previous study by us, the morphometric features of the odontoid process were evaluated with CBCT and it was determined that the morphometric features of the odontoid process differ according to age and sex (Magat & Ozcan, 2019). In a 1994 study, it was stated that the anatomy of the odontoid process shows a structural heterogeneity and the base of the odontoid process is separated from other areas in the axis by a lower bone density and a reduced trabecular interconnection (Amling *et al*., 1994).

Children from diverse racial and environmental backgrounds may exhibit different growth rates and patterns, making population-specific formulas for cervical bone age calculation clinically valuable (Al-Hadlaq *et al*., 2007). Different methodologies and statistical analyses also contribute to variability in age and sex estimations of cervical vertebrae. Castellana / Kosa (2001) uniquely measured ossification centers of the axis in 106 fetuses (16–40 weeks), developing regression models for age determination, later verified by Baumgart *et al*. (2016). Baumgard *et al*. (2016), reported that axis ossification centers' volumetric growth followed a logarithmic function, slowing with fetal age, thus limiting accurate age prediction from volume increases alone. In this study, odontoid process volume varied with age, with mean volumes showing a clear separation among age groups: <1357.99 mm^3 for those over 45, to 1837.29 mm^3 in the 12-18 group. Discriminant function scores identified age categories, with values below -0.601 indicating those over 45 and values above 0.143 indicating ages 12-18, achieving 94.7 % accuracy for the 12-18 group. This suggests that odontoid process volume effectively predicts whether an individual is above or below 18 years.

CONCLUSION

Our findings show that odontoid process volume varies by age and sex, decreasing with age and being larger in males. The discriminant functions derived from this data offer practical applications for identification in forensic contexts. With increased anatomical research on the craniocervical junction, surgical interventions and techniques will improve, making procedures more accessible. CBCT enables preoperative 3D imaging of the odontoid process, and this study is the first to develop regression equations for age and sex estimation based on its volume. Although discrimination scores were moderate, odontoid process volume shows strong potential in predicting under-18 versus older individuals. Further studies with larger, diverse samples are recommended, as factors like environment, race, diet, and genetics may influence these results.

CONFLICT OF INTEREST. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethics approval and consent to participate. A written informed consent was obtained from all participants. For participants under the age of 16, informed consent was obtained from their parents or legal guardians. All experiments were performed in accordance with relevant guidelines and regulations of the Declaration of Helsinki.

This study was approved by the Ethics Committee at Necmettin Erbakan University of Dentistry Faculty (Approved number: 2019.06).

MAGAT, G.; OZCAN, S. & GULEC, M. Evaluación radiológica del volumen del proceso odontoideo mediante el uso de modelos tridimensionales (3D) digitales para la estimación del sexo y la edad: Un estudio retrospectivo de tomografía computarizada de haz cónico. *Int. J. Morphol., 43(2)*:614-621, 2025.

RESUMEN: El proceso odontoides es una parte anatómica muy importante para la unión craneovertebral. El primer objetivo de este estudio fue demostrar que las diferencias dependientes de la edad y el sexo en el volumen del proceso odontoides en una población turca se pueden definir, visualizar y medir mediante tomografía computarizada de haz cónico (CBCT). El segundo objetivo fue evaluar el grado de dimorfismo sexual y edad del individuo a través de proceso odontoides. El tercer objetivo fue desarrollar fórmulas de discriminación basadas en el volumen del proceso odontoides. Se analizaron retrospectivamente imágenes CBCT de 150 personas (75 mujeres, 75 hombres, rango de edad de 12 a 73 años, edad media de 27,34 años). Los volúmenes del proceso odontoides se midieron utilizando el software InVivo Dental. Se encontró que los hombres tenían un volumen del proceso odontoides significativamente mayor que las mujeres (p = 0,001). Estadísticamente, se detectó una disminución en el volumen del proceso odontoides con la edad (p <0,0001). El punto de división del volumen medio del proceso odontoides fue <1745 mm^3 para mujeres y >2733 mm^3 para hombres. Según el análisis de la función discriminante, el 73,3 % de las mujeres y el 42,7 % de los hombres del total fueron clasificados correctamente. Según las puntuaciones del centroide del grupo, los valores inferiores a -0,601 indican individuos mayores de 45 años, mientras que los valores superiores a 0,143 indican individuos en el grupo de edad de 12 a 18 años. En total, el 94,7 % del grupo de edad de 12 a 18 años y el 8 % de los individuos de 45 años o más fueron clasificados correctamente. Según los resultados obtenidos de este estudio, las puntuaciones discriminantes del sexo y de la edad fueron moderadas. Sin embargo, los resultados del presente estudio muestran que el volumen del proceso odontoides tiene un gran potencial para predecir la edad de los individuos menores de 18 años y mayores.

PALABRAS CLAVE: Proceso odontoides; Volumen; Modelado 3D; Determinación de edad y sexo.

REFERENCES

Aggrawal, A. Estimation of age in the living: in matters civil and criminal. *J. Anat*., 2009. doi:10.1111/j.1469-7580.2009.01048.x

Akhlaghi, M.; Khalighi, Z.; Vasigh, S. & Yousefinejad, V. Sex determination using mandibular anthropometric parameters in subadult Iranian samples. *J. Forensic Leg. Med., 22*:150-3, 2014.

Akobo, S.; Rizk, E.; Loukas, M.; Chapman, J. R.; Oskouian, R. J. & Tubbs, R. S. The odontoid process: a comprehensive review of its anatomy, embryology, and variations. *Childs Nerv. Syst., 31(11)*:2025-34, 2015.

Al-Hadlaq, A.; Al-Qarni, M.; Al-Kahtani, A. & Al-Obaid, A. Comparative study between hand-wrist method and cervical vertebral maturation method for evaluation of skeletal maturity in Saudi boys. *Pak. Oral Dent. J., 27(2)*:187-92, 2007.

Albert, M.; Mulhern, D.; Torpey, M. A. & Boone, E. Age estimation using thoracic and first two lumbar vertebral ring epiphyseal union. *J. Forensic Sci., 55(2)*:287-94, 2010.

Altan, M.; Nebioglu Dalc, Ö. & Iseri, H. Growth of the cervical vertebrae in girls from 8 to 17 years. A longitudinal study. *Eur. J. Orthod., 34(3)*:327-34, 2012.

Amling, M.; Hahn, M.; Wening, V. J.; Grote, H. J. & Delling, G. The microarchitecture of the axis as the predisposing factor for fracture of the base of the odontoid process. A histomorphometric analysis of twenty-two autopsy specimens. *J. Bone Joint Surg. Am., 76(12)*:1840-6, 1994.

Amores, A.; Botella, M. C. & Alemán, I. Sexual dimorphism in the 7th cervical and 12th thoracic vertebrae from a mediterranean population. *J. Forensic Sci., 59(2)*:301-5, 2014.

Baumgart, M.; Szpinda, M. & Szpinda, A. New anatomical data on the growing C4 vertebra and its three ossification centers in human fetuses. *Surg. Radiol. Anat., 35(3)*:191-203, 2013.

Baumgart, M.; Wisniewski, M.; Grzonkowska, M.; Malkowski, B.; Badura, M.; Dabrowska, M. & Szpinda, M. Digital image analysis of ossification centers in the axial dens and body in the human fetus. *Surg. Radiol. Anat., 38(10)*:1195-203, 2016.

Bethard, J. D. & Seet, B. L. Sex determination from the second cervical vertebra: a test of Wescott's method on a modern American sample. *J. Forensic Sci., 58(1)*:101-3, 2013.

Biwasaka, H.; Aoki, Y.; Sato, K.; Tanijiri, T.; Fujita, S.; Dewa, K.; Yoshioka, K. & Tomabechi, M. Analyses of sexual dimorphism of reconstructed pelvic computed tomography images of contemporary Japanese using curvature of the greater sciatic notch, pubic arch and greater pelvis. *Forensic Sci. Int., 219(1-3)*:288.e1-8, 2012.

Castellana, C. & Kósa, F. Estimation of fetal age from dimensions of atlas and axis ossification centers. *Forensic Sci. Int., 117*:31-43, 2001.

Chatterjee, P. M.; Krishan, K.; Singh, R. K. & Kanchan, T. Sex determination by discriminant function analysis using the human tibia in a Central Indian population. *Med. Sci. Law, 59(3)*:171-9, 2019.

Chatzigianni, A. & Halazonetis, D. J. Geometric morphometric evaluation of cervical vertebrae shape and its relationship to skeletal maturation. *Am. J. Orthod. Dentofacial Orthop., 136(4)*:481.e1-9, 2009.

Christensen, A. M. & Crowder, C. M. Evidentiary standards for forensic anthropology. *J. Forensic Sci., 54(6)*:1211-6, 2009.

Clark, G. A. *Heterochrony, Allometry, and Canalization in the Human Vertebral Column: Examples From Prehistoric Amerindian Populations (Growth, Bone, Mortality).* Amherst, University of Massachusetts, 1985.

Ekizoglu, O.; Hocaoglu, E.; Inci, E.; Karaman, G.; Garcia-Donas, J.; Kranioti, E.; Moghaddam, N. & Grabherr, S. Virtual morphometric method using seven cervical vertebrae for sex estimation on the Turkish population. *Int. J. Legal Med., 135(5)*:1953-64, 2021.

Gama, I.; Navega, D. & Cunha, E. Sex estimation using the second cervical vertebra: a morphometric analysis in a documented Portuguese skeletal sample. *Int. J. Legal Med., 129(2)*:365-72, 2015.

Gil, J. R.; Kim, W. T. & Seo, M. J. Congenital anomaly of combined atlas-odontoid process fusion and bipartite atlas. *Jpn. J. Radiol., 33(12)*:769-71, 2015.

He, D. W.; Huang, W. J.; Sheng, X. Y.; Wu, L. J. & Fan, S. W. Atlantoaxial joint interlocking following type II odontoid fracture associated with posterolateral atlantoaxial dislocation: a case report and review of published reports. *Orthop. Surg., 8(3)*:405-10, 2016.

Hellsing, E. Cervical vertebral dimensions in 8-, 11-, and 15-year-old children. *Acta Odontol. Scand., 49(4)*:207-13, 1991.

Kibii, J. M.; Pan, R. & Tobias, P. V. Morphometric variations of the 7th cervical vertebrae of Zulu, White, and Colored South Africans. *Clin. Anat., 23(4)*:399-406, 2010.

Korres, D. S.; Lazaretos, J.; Papailiou, J.; Kyriakopoulos, E.; Chytas, D.; Efstathopoulos, N. E. & Nikolaou, V. S. Morphometric analysis of the odontoid process: using computed tomography--in the Greek population. *Eur. J. Orthop. Surg. Traumatol., 26(2)*:119-25, 2016.

Kósa, F. & Castellana, C. New forensic anthropological approachment for the age determination of human fetal skeletons on the base of morphometry of vertebral column. *Forensic Sci. Int., 147 Suppl*.:S69-74, 2005.

Krishan, K.; Chatterjee, P. M.; Kanchan, T.; Kaur, S.; Baryah, N. & Singh, R. A review of sex estimation techniques during examination of skeletal remains in forensic anthropology casework. *Forensic Sci. Int., 261*:165.e1-8, 2016.

Magat, G. & Ozcan, S. Gender and age estimation using the morphometric analysis of odontoid process: is there a relationship with dental maturation? *J. Craniofac. Surg., 30(5)*:1597-600, 2019.

Marlow, E. J. & Pastor, R. F. Sex determination using the second cervical vertebra--A test of the method. *J. Forensic Sci., 56(1)*:165-9, 2011.

Miller, C. A.; Hwang, S. J.; Cotter, M. M. & Vorperian, H. K. Cervical vertebral body growth and emergence of sexual dimorphism: a developmental study using computed tomography. *J. Anat., 234(6)*:764-77, 2019.

Miller, C. A.; Hwang, S. J.; Cotter, M. M. & Vorperian, H. K. Developmental morphology of the cervical vertebrae and the emergence of sexual dimorphism in size and shape: A computed tomography study. *Anat. Rec. (Hoboken), 304(8)*:1692-708, 2021.

Moffat, D. A.; Ramsden, R. T. & Shaw, H. J. The styloid process syndrome: aetiological factors and surgical management. *J. Laryngol. Otol., 91(4)*:279-94, 1977.

Monum, T.; Prasitwattanseree, S.; Das, S.; Siriphimolwat, P. & Mahakkanukrauh, P. Sex estimation by femur in modern Thai population. *Clin. Ter., 168(3)*:e203-e207, 2017.

O'Reilly, M. T. & Yanniello, G. J. Mandibular growth changes and maturation of cervical vertebrae--a longitudinal cephalometric study. *Angle Orthod., 58(2)*:179-84, 1988.

Pickering, T. R. & Carlson, K. J. Baboon taphonomy and its relevance to the investigation of large felid involvement in human forensic cases. *Forensic Sci. Int., 144(1)*:37-44, 2004.

Rhee, C. H.; Shin, S. M.; Choi, Y. S.; Yamaguchi, T.; Maki, K.; Kim, Y. I.; Kim, S. S.; Park, S. B. & Son, W. S. Application of statistical shape analysis for the estimation of bone and forensic age using the shapes of the 2nd, 3rd, and 4th cervical vertebrae in a young Japanese population. *Forensic Sci. Int., 257*:513.e1-513.e9, 2015.

Rodriguez Paz, A.; Banner, J. & Villa, C. Validity of the probabilistic sex diagnosis method (DSP) on 3D CT-scans from modern Danish population. *Rev. Med. Leg., 10(2)*:43-9, 2019.

Rozendaal, A. S.; Scott, S.; Peckmann, T. R. & Meek, S. Estimating sex from the seven cervical vertebrae: an analysis of two European skeletal populations. *Forensic Sci. Int., 306*:110072, 2020.

Srivastava, S. K.; Nemade, P. S.; Aggarwal, R. A. & Bhoale, S. K. Congenital absence of posterior elements of C2 vertebra with atlanto-axial dislocation and basilar invagination: a case report and review of literature. *Asian Spine J., 10(1)*:170-5, 2016.

Stemper, B. D.; Yoganandan, N.; Pintar, F. A.; Maiman, D. J.; Meyer, M. A.; DeRosia, J.; Shender, B. S. & Paskoff, G. Anatomical gender differences in cervical vertebrae of size-matched volunteers. *Spine (Phila Pa 1976), 33(2)*:E44-9, 2008.

Szpinda, M.; Baumgart, M.; Szpinda, A.; Wozniak, A.; Malkowski, B.; Wisniewski, M.; Mila-Kierzenkowska, C. & Króliczewski, D. Cross-sectional study of the ossification center of the C1-S5 vertebral bodies. *Surg. Radiol. Anat., 35(5)*:395-402, 2013a.

Szpinda, M.; Baumgart, M.; Szpinda, A.; Wozniak, A. & Mila-Kierzenkowska, C. New patterns of the growing L3 vertebra and its 3 ossification centers in human fetuses - a CT, digital, and statistical study. *Med. Sci. Monit. Basic Res., 19*:169-80, 2013b.

Taitz, C. Anatomical observations of the developmental and spondylotic cervical spinal canal in South African blacks and whites. *Clin. Anat., 9(6)*:395-400, 1996.

Tatarek, N. E. Variation in the human cervical neural canal. *Spine J., 5(6)*:623-31, 2005.

Torimitsu, S.; Makino, Y.; Saitoh, H.; Sakuma, A.; Ishii, N.; Hayakawa, M.; Inokuchi, G.; Motomura, A.; Chiba, F.; Hoshioka, Y.; *et al*. Stature estimation in Japanese cadavers based on the second cervical vertebra measured using multidetector computed tomography. *Leg. Med. (Tokyo), 17(3)*:145-9, 2015.

Tsuji, S.; Inoue, S.; Tachibana, T.; Maruo, K.; Arizumi, F. & Yoshiya, S. Post-traumatic torticollis due to odontoid fracture in a patient with diffuse idiopathic skeletal hyperostosis: a case report. *Medicine (Baltimore), 94(36)*:e1478, 2015.

Verbeek, B. M.; Janssen, S. J.; Pielkenrood, B. J. & Schwab, J. H. Quantitative 3-dimensional Computed Tomography (Q3DCT) analysis of odontoid fractures. *J. Clin. Neurosci., 7*1:164-9, 2020.

Villa, C.; Buckberry, J. & Lynnerup, N. Evaluating osteological ageing from digital data. *J. Anat., 235(2)*:386-95, 2019.

Wescott, D. Sex variation in the second cervical vertebra. *J. Forensic Sci., 45*:462-6, 2000.

Yoganandan, N.; Bass, C. R.; Voo, L. & Pintar, F. A. Male and female cervical spine biomechanics and anatomy: implication for scaling injury criteria. *J. Biomech. Eng. 139(5)*, 2017.

Zhou, B.; Liu, L.; Song, Y. & Ling, T. Congenital odontoid process separation with atlantoaxial dislocation associated with Klipple-Feil syndrome and cervical angular kyphosis secondary to C6 wedging vertebra. *Spine J., 16(2)*:e53-4, 2016.

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