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Morphometric Analysis and Clinical Significance of Cervical Vertebrae: Example of Turkey

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ABSTRACT

Columna vertebralis is a column that bears the weight of the head and trunk. This column contains the spinal cord, which is part of the Central Nervous System. Changes occur in the anatomical structures of the vertebrae in cases of infections involving the vertebrae and fractures and deformities arising from traumatic or non-traumatic causes. The determination of such changes in the vertebrae is critically important in terms of treatment or surgical intervention. Morphometric measurements have an important place in the detection of these changes. Moreover, cervical vertebral measurements have been used in sex identification, the preliminary diagnosis of genetic diseases and age identification. We aimed for the results of our study to support clinical interventions to be made in the cervical vertebrae, forensic medicine applications and anthropological applications as a reference in the literature. 54 cervical vertebrae in the form of dry bones belonging to the neck region were used as the material. Twenty-three different parameters were measured with a digital caliper at a precision 0.01 mm. In the cervical vertebral measurements of the Turkish population in our study, we observed that the results on corpus vertebrae height and transverse diameter varied based on races, and the measurements of the Turkish population were higher. In addition, low, medium and high positive-negative relationships were determined by performing correlation analysis between the vertebrae. We think that these analyses will be helpful in the preparation of the atlas and the drawing of vertebrae.

Keywords: Vertebra, Cervical, Clinic, Morphometry

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Introduction

The columna vertebralis is a 72-75 cm long column formed by the vertical stacking of 33 vertebrae. This column carries the organs in the head, the chest cavity and the abdominal cavity and supports these organs. In the canal in it, it also contains the spinal cord, which is an important organ in the Central Nervous System (Tokpınar et al., 2019; Elhan and Arıncı, 2020). The vertebrae constituting the spinal column are divided into sections based on the regions they are in. From the top to the bottom, the first 7 vertebrae are called the vertebrae cervicales, the next 12 are called the vertebrae thoracicae, and the last 5 are called the vertebrae lumbales. Below these, there are the os sacrum and os coccygis (Mekonen et al., 2017; İmre and Kocabıyık, 2017; Yılmaz et al., 2019). The cervical (neck) region is the most mobile part of the spinal column. Therefore, it is prone to traumatic accidents. Moreover, infections such as tuberculosis and diseases such as cancer may develop in the vertebrae and create deformation and collapse. Clinical cases known as “loss of cervical lordosis” and found asymptomatically at a rate of 42% can also lead to a deformation in the cervical vertebrae. For such reasons, the deformation of the cervical vertebrae and intervertebral bodies may result in many problems including chronic pain, imbalance, neck pain, tenseness, and headaches (Kök et al., 2017; Gülcan, 2019). To solve such problems that arise, surgical intervention in the region may be required. The appropriate and successful application of surgical intervention depends on having an adequate understanding of the morphological structures of the vertebrae in the region. The developmental stages of the cervical vertebrae may help in determining skeletal age. It is aimed to make a healthy interpretation on matters other than chronological age by also assessing growth and development stages with the morphological measurements of the cervical vertebrae. Today, the number of orthodontic treatments has increased, and the accurate identification of age is also critical for orthodontic treatment (Lamparski, 1975). Timing is one of the main aspects of such treatments. Surgically assisted orthodontic treatment is recommended in individuals with severe orthodontic anomalies who have completed their growth and development. The time of starting treatment is patient-specific, and it is as important as age. Growth and development can be evaluated based on chronological age, menarche and morphological maturation at a specific height-age. Age is not sufficient alone for reflecting the entire chronological situation. Lamparski revealed for the first time that the cervical vertebrae can be used in evaluating growth and development by making measurements on cephalometric imaging results (Üzümcügil, 2016). Today, the cervical vertebrae are being used in both forensic age determination and sex determination. Morphometric evaluations such as the height and width of the vertebra and the shape of the corpus vertebrae are among the criteria used in determining sex and age. However, the reliability of this usage is still debated (Gelbrich et al., 2017; Berrocal et al., 2019).

We believe that the measurement results that we obtained as a result of this study contribute to the literature by constituting a reference for neurosurgeons, anthropologists, forensic scientists, orthopedists, radiologists and orthodontists.

Material and Methods

Fifty-four (C1-C7) cervical vertebrae in the form of dry bones were obtained from the laboratory of the Department of Anatomy at the Faculty of Medicine. Ethics committee decision was not required since measurement was made on dry bone. However, approval was obtained from the anatomy department that the study could be carried out. On the vertebrae, 23 different parameters were measured using a digital caliper at a precision of 0.01 mm. While selecting the bones, without regard to sex, those that did not have deformities were included. To eliminate measurement-related differences, all measurements were made by the same person. The measurement parameters are shown in Table 1. The measurements made with the caliper on the dry bone are shown in Figures I.

Statistical Analysis

Descriptive analyses were used in this study. In the measured data, one-sample normal distribution analysis was conducted by testing 5 parameters (skewness-kurtosis, standard deviation/mean, histograms, Q-Q plots and Shapiro Wilk Test). The normally distributed parameters and those with an adequate number of data points are presented as mean ± standard deviation (MEAN±STD), while the non-normally distributed parameters and those with an inadequate number of data points are presented as median (minimum-maximum). Pearson's correlation (r) analysis was conducted among the parameters that were normally distributed and had an adequate number of data points. The IBM SPSS 23.00 statistics program was used in the analyses in this study.

Results

Table 2 shows the minimum-maximum and mean values of the parameters measured on the cervical vertebrae in units of mm. Additionally, a and b in Figure I.b represent an anatomical variation. While there are normally two foramina transversaria, one on the right and one on the left, in each vertebra, four foramina transversaria per vertebra were detected as an anatomical variation in 4 samples among the total of 54 (a and b in Figure I.b).

In the correlation analysis, the Pearson correlation coefficient (r) was evaluated in compliance with the information in the literature (Muhaka, 2012).

Pearson Correlation Coefficient (r)

There were strong positive correlations between parameters 4 and 5, between 5 and 7, between 4 and 7, between 4 and 8 and between 6 and 8 ($0.70<r\leq0.90$, $p<0.001$). There were weak negative correlations between 3 and 10 ($-0.30<r\leq-0.50$, $p<0.01$) and between 6 and 10 ($-0.30<r\leq-0.50$, $p<0.05$). Other correlation results are shown in Table 3.

Table 1. Measured Parameters

Array	Measurement Points
1	Corpus vertebrae height (anterior)
2	Corpus vertebrae height (posterior)
3	Corpus vertebrae, facies intervertebralis transverse diameter (superior)
4	Corpus vertebrae, facies intervertebralis sagittal diameter (superior)
5	Corpus vertebrae, facies intervertebralis transverse diameter (inferior)
6	Corpus vertebrae, facies intervertebralis sagittal diameter (inferior)
7	Corpus vertebrae midline transverse width (anterior)
8	Foramen vertebrale transverse length
9	Foramen vertebrale sagittal length
10	Distances between proc. articularis superiors
11	Distances between proc. articularis inferiors
12	Corpus vertebrae diagonal length
13	Foramen vertebrale diagonal length
14	Maximum vertebrae height
15	Foramen transversarium transverse length
16	Foramen transversarium sagittal length
17	Proc. spinosus length up to its forking location (right)
18	Proc. spinosus length up to its forking location (left)
19	Lamina arcus vertebra length (right)
20	Lamina arcus vertebra length (left)
21	Lamina arcus vertebra width (right)
22	Lamina arcus vertebra width (left)
23	Distance between farthest points of massa lateralis atlantis

Table 2. Results on the morphometric parameters measured on the cervical vertebrae

Cervical vertebra positions in the anatomic position				
	C3-C6 (N=31)	**C7 (N=7)**	**Atlas (N=8)**	**Axis (N=8)**
	Mean±SD (mm)	Median (Min-Max)	Median (Min-Max)	Median (Min-Max)
1	17.26±2.10	19.82 (17.34-21.72)		18.79 (15.0-019.11)
2	14.81±2.02	19.77 (15.90-22.35)		10.70 (7.13-11.88)
3	24.65±3.32	28.10 (24.66-31.31)		
4	21.21±3.25	23.**54** (22.57-26.30)		
5	27.08±3.49	31.33 (27.12-33.10)		23.10 (21.91-23.79)
6	20.08±2.98	22.05 (20.47-25.46)		18.82 (18.37-21.14)
7	25.03±4.35	32.07 (29.09-35.23)		23.57 (19.35-25.69)
8	22.82±1.94	21.25 (20.73-29.10)	26.34 (22.40-29.71)	24.53 (20.20-28.03)
9	12.97±1.25	12.23 (10.89-14.54)	29.71 (26.44-35.02)	19.00 (16.9-19.16)
10	52.64±3.36	48.20 (43.56-56.58)	56.23 (52.14-62.04)	
11	52.75±3.76	52.83 (49.00-56.69)	52.00 (48.05-56.42)	
12	26.03±4.30	26.28 (25.89-31.34)		22.29 (21.39-23.90)
13	20.21±1.60	20.43 (18.64-21.84)	29.75 (25.91-32.86)	
14			49.35 (47.10-54.04)	
15			7.33 (5.14 -9.82)	
16			7.11 (5.47-8.42)	
17	4.57±1.07			
18	5.49±1.52			
19	13.34±2.11	11.29 (8.99-16.71)		19.16 (18.51-20.09)
20	13.67±1.99	11.09 (10.04-15.63)		19.55 (16.77-22.27)
21	15.83±2.35	20.97 (19.11-21.52)		17.82 (16.68-19.51)
22	16.03±2.32	22.21 (20.14-2371)		18.38 (17.14-19.03)
23			73.99 (66.86-86.94)	

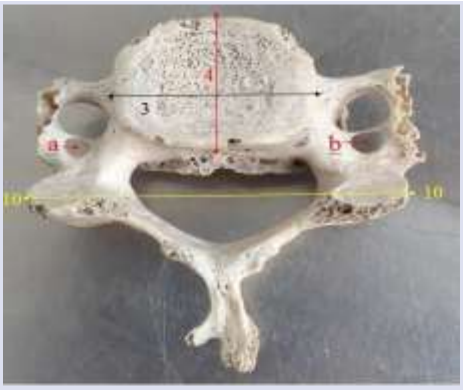
Table 3. Correlation analysis among parameters

		2	3	4	5	6	7	8	9	10	11	12
2	PC	1	0.593[C]	0.611[C]	0.423[B]	0.541[C]	0.342[B]	0.576[C]	0.091[A]	-0.094[A]	-0.019[A]	0.199[A]
	ST		***0.000	***0.000	**0.009	***0.000	*0.031	***0.000	0.575	0.574	0.908	0.226
3	PC	0.593[C]	1	0.596[C]	0.366[B]	0.640[C]	0.387[B]	0.641[C]	0.071[A]	-0.491[B-]	-0.049[A]	0.337[B]
	ST	***0.000		***0.000	*0.028	***0.000	*0.014	***0.000	0.663	**0.002	0.769	*0.036
4	PC	0.611[C]	0.596[C]	1	0.757[D]	0.648[C]	0.712[D]	0.785[D]	0.511[C]	-0.135[A]	0.233[A]	.605[C]
	ST	***0.000	***0.000		***0.000	***0.000	***0.000	***0.000	**0.001	0.445	0.171	***0.000
5	PC	0.423[B]	0.366[A]	0.757[D]	1	0.672[C]	0.842[D]	0.655[C]	0.554[C]	0.025[A]	0.321[B]	.596[C]
	ST	**0.009	*0.028	***0.000		***0.000	***0.000	***0.000	***0.000	0.886	*0.046	***0.000
6	PC	0.541[C]	0.640[C]	0.648[C]	0.672[C]	1	0.628[C]	0.752[D]	0.295[A]	-0.359[B-]	0.084[A]	.431[B]
	ST	***0.000	***0.000	***0.000	***0.000		***0.000	***0.000	0.065	*0.027	0.612	**0.006
7	PC	0.342[A]	0.387[A]	0.712[D]	0.842[D]	0.628[C]	1	0.665[C]	0.446[B]	-0.134[A]	0.260[A]	.601[C]
	ST	*0.031	*0.014	***0.000	***0.000	***0.000		***0.000	**0.004	0.423	*0.11	***0.000
8	PC	0.576[C]	0.641[C]	0.785[D]	0.655[C]	0.752[D]	0.665[C]	1	0.235[A]	-0.29[A]	0.036[A]	0.462[B]
	ST	***0.000	***0.000	***0.000	***0.000	***0.000	***0.000		0.144	0.077	0.829	**0.003
9	PC	0.091[A]	0.071[A]	0.511[C]	0.554[C]	0.295[A]	0.446[B]	0.235[A]	1	0.522[C]	0.448[B]	0.275[A]
	ST	0.575	0.663	**0.001	***0.000	0.065	**0.004	0.144		***0.000	**0.002	0.061
10	PC	-0.094[A]	-.491[B-]	-0.135[A]	0.025[A]	-.359[B-]	-0.134[A]	-0.29[A]	0.522[C]	1	0.380[B]	-0.082[A]
	ST	0.574	**0.002	0.445	0.886	*0.027	0.423	0.077	***0.000		**0.009	0.591
11	PC	-0.019[A]	-0.049[A]	0.233[A]	0.321[B]	0.084[A]	0.260[A]	0.036[A]	0.448[B]	0.380[B]	1	0.606[C]
	ST	0.908	0.769	0.171	0.056	0.612	*0.11	0.829	**0.002	**0.009		***0.000
12	PC	0.199[A]	0.337[B]	0.605[C]	0.596[C]	0.431[B]	0.601[C]	0.462[B]	0.275[A]	-0.082[A]	0.606[C]	1
	ST	0.226	0.036	***0.000	***0.000	**0.006	***0.000	**0.003	0.061	0.591	***0.000	

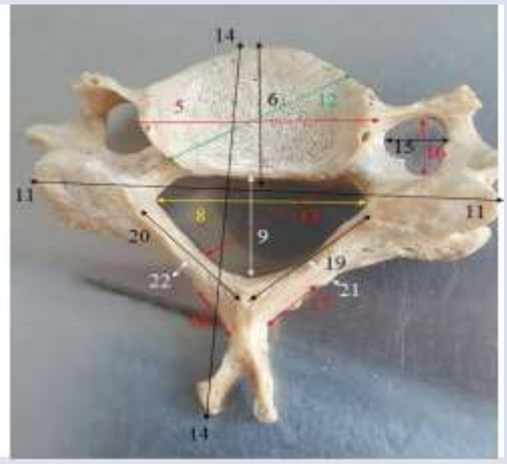
A; No correlation, B; Weak positive corrcelation, C; Moderate positive correlation, D; Strong positive correlation B-; Weak negative correlation, PC; Pearson Correlation ST; Significant (2-tailed)

* Correlation is significant at 0.05 (2-tailed). ** Correlation is significant at 0.01 (2-tailed). *** Correlation is significant at 0.001 (2-tailed).

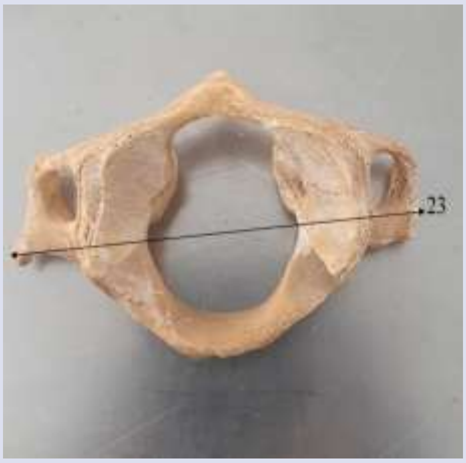
a. Parameters 1, 2 and 7



b. Parameters 3, 4 and 10



c. Parameters 5, 6, 8, 9, 11, 13, 18, 21, and 22



d. Parameter 23

Figure 1. Parameters

Discussion

The cervical vertebrae have a highly important position as they not only cover a large area but also constitute the most mobile region of the spinal column. In the defects of the cervical vertebrae caused by reasons such as trauma or illness, indications like pain in the region and disruption in body posture may make surgical intervention to the region inevitable. The cervical spine also has many congenital anomalies. These may be simple problems or clinical cases that have severe neurological and structural effects.

There are studies that have shown that in congenital malformations, there is a relationship between the category of the disease and cervical vertebra measurements (Berrocal et al., 2019). In the study measured the dimensions of the cervical vertebrae and the intervertebral spaces, the authors determined that the heights of the corpus vertebrae of C3, C4 and C7 were significantly lower in the cleft lip and palate (CLP) group in comparison to the control group. The C4/C5 and C5/C6 space measurements in the CLP group were found to be higher. The authors showed a relationship between CLP and cervical vertebra anomalies. In patients with vertebral anomalies, missing arcus posterior vertebrae and the fusion of the cervical vertebrae are among the most frequently observed anomalies (Berrocal et al., 2019).

There is a deficiency in the convex superior facets of the atlas in Down syndrome patients with occipitocervical instability. Thus, knowing the anatomical and morphological properties of the vertebrae in the region well will also contribute to the determination of congenital anomalies (Klimo et al., 2007).

Although pelvic and cranial bones are the most frequently used bones in sex identification, there are also studies showing that the use of other bones in the skeletal system such as the vertebrae also provides accurate results in sex determination. While the results of such studies may be used in sex identification in the absence of pelvic and cranial bones, they may also be used to support the result in the presence of these bones. Sex identification methods have vital importance especially in forensic anthropology. In a study that included 294 patients, cervical anteroposterior diameter (CAP), cervical transverse diameter (CTR) and maximum corpus vertebrae height (CHT) were measured. In the study conducted on a Turkish population, it was observed that the cervical vertebrae provided an accuracy rate of 83.30% in determining sex (Ekizoğlu et al., 2021). The results of the study were compatible with those we obtained in this study. Our study will provide guidelines for studies to be carried out on Turkish population. In a previous study that examined the seven cervical vertebrae to create an accurate method of sex estimation, the authors measured maximum vertebral body height (CHT), vertebral foramen anteroposterior diameter (CAP) and vertebral foramen transverse diameter (CTR). They examined the data of 295 adult individuals (157 males, 138 females) from the University of Athens and Luis Lopes skeletal reference collections. The results of the study demonstrated that CHT and CTR showed a statistically significant sexual dimorphism. They developed seven multivariate discriminant functions with accuracy rates varying between 80.3% and 84.5%. The authors argued that the results of their study will help in the identification of the sexes of European individuals from their cervical vertebrae in the absence of more precise sex determinants such as the cranium or the pelvis (Rozendaal et al., 2020).

The variability of vertebra measurements in different races prevents the standardization of such measurements. A previous study formed a reference database for the cervical vertebrae of an Indian population and made a comparison to other populations. In the study, the corpus vertebrae height (11.39 ± 1.08 mm) and transverse diameter (22.18±2.52 mm) they found were higher than the measurements of other races, while the anteroposterior diameter was lower than those of other races (Saluja et al., 2015). In our study, in the cervical vertebra measurements of our Turkish population, we identified the height of the corpus vertebrae as 14.81±2.10 mm (C3-C6) and its transverse diameter as 25.03±4.35 mm. These data showed that measurement results varied based on race, and the results in the Turkish population were higher than those in the Indian population.

Measurements were made from 15 different points on the computerized tomography images of an Indian population. As a result of the study, it was found that the pedicle dimensions of the Indian population were smaller than those of Caucasus populations on almost all vertebral levels. The authors stated that their results can be useful in the design of spinal implants that will be biomechanically compatible with the anatomy of Indian society (Banerjee et al., 2013).

Another study was conducted on CT images to collect data regarding pedicular screw surgery in the neck region. Pedicular width, height and transverse angle measurements were made from three points in 300 adult patients. It was concluded that each patient should be considered individually for a safe surgical intervention (Alsaleh et al., 2021).

For surgical interventions in the neck region to be successful, it is needed to know the detailed anatomical structure of the cervical vertebrae. We believe that the results of our study will contribute to databases that will increase the success of interventions to be made in the cervical region and provide a basis for future studies that will be carried out on the cervical vertebrae.

Conclusion

This study is the first in the literature to examine the correlation relationships between cervical vertebrae in Turkish population. In this study, we determined that especially the parameters numbered 4, 5, 6 and 8 were closely associated with each other, and there was a negative relationship between parameter 10 and parameters 3 and 6. Accordingly, we think that these analyses will be helpful in the preparation of the atlas and the drawing of vertebrae. Furthermore, this study will provide data regarding morphometric measurements and anatomical variations for the surgical intervention team in interventions to be made in the cervical region, as well as contributing to similar future studies.

Conflict of Interest

The authors declare that there is no conflict of interest is doing.

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