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Assesment of Cranial Traits for Gender Determination by Using 3D Models: A Retrospective CBCT Study

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Abstract

BACKGROUND/AIMS: Gender determination is the first stage in identification of human remains, as it is essential for accurately assessing other biological traits. The aim of the present study was to evaluate the cranial traits for gender determination in a Turkish subpopulation.

MATERIALS AND METHODS: For this study, 5 cranial traits including nuchal crest, mental eminence, supraorbital margin, mastoid process, and glabella were evaluated on three-dimensional (3D) reconstructions of cone beam computed tomography (CBCT) images of 239 individuals. The cranial traits were scored between 1 and 5 according to the diagram developed by Buikstra and Ubelaker. The data were analysed using descriptive statistics, Mann-Whitney U test, chi-squared test, and discrimination analysis.

RESULTS: The gender was estimated in two ways according to the mean score of cranial traits, and discriminant analysis. The accuracy rate was 94.1% according to the mean score of cranial traits and 95.8% according to the discrimination analysis. Among the cranial traits evaluated, the most distinctive structure was determined to be the glabella.

CONCLUSION: According to the results of the present study, 3D reconstructions of CBCT can be used to evaluate the cranial traits and are an effective way of determining gender with high accuracy.

Keywords: Cranium, forensic dentistry, forensic medicine, sex determination process, skull

INTRODUCTION

Forensic anthropology is often used to personally identify human remains at crime scenes or mass disasters.[1] Reliable determination of gender in the analysis of human skeletal remains represents an important goal of forensic medicine and forensic anthropology.[2,3]

Gender determination is the first stage of the identification process because the accurate definition of other biological characteristics used in determining identity (such as age, height, and weight) is closely related to gender.[4,5] Gender identification in forensic odontology and human anthropology predominantly relies on anatomical variations and various skeletal morphological features that serve to differentiate between males and females.[6,7] The skull is one of the most dimorphic parts of the human skeleton and shows significant dimensional and shape differences between genders, a feature useful for gender determination. The development of such dimorphic traits is inherently linked to fundamental developmental, biomechanical, and functional differences that are gender-specific. Although sexually dimorphic skull size and shape traits common among geographically and genetically distant populations exist, their size varies under the influence of local environmental and/or genetic factors.[8] In a study conducted on 750 skeletons, Krogman and İşcan[9] reported that the accuracy rate for gender determination was 100% if the skeleton was present as a whole, 92% when only the skull was present, and 98% when the pelvis and skull were evaluated together. Different growth and development patterns, including hormonal differences that occur during adolescence, cause

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dimensional and shape differences in the skulls of males and females. On average, male skulls are larger than female skulls. However, making morphological evaluations together with size instead of size alone contributes to the accuracy of gender determination.[10,11]

Morphological or morphometric methods are employed for gender estimation based on cranial bones. Anthropologists and forensic medical specialists traditionally conduct manual examinations of regions of sexual dimorphism, including general skull morphology, nuchal crest, orbits, glabella, mastoid process, and the mandible.[5] To make these evaluations easier, Buikstra[12] and Ubelaker and DeGaglia[2] developed a diagram based on a scoring system for the dimorphic features of these regions on the skull. Despite the simplicity and rapidity of morphological methods, visual evaluation of remains involves a certain level of subjectivity, which can lead to intra-observer and inter-observer errors. The use of morphometric methods provides a high level of confidence by reducing the subjectivity of morphological methods, but morphometric methods do not make a significant difference in the accuracy of gender estimation.[10]

Cone beam computed tomography (CBCT) is an imaging method that provides high-resolution images for the evaluation of bone structures and has some advantages compared to traditional computed tomography (CT). In addition to its advantages such as relatively small size, portability and low cost, has technical advantages such as good spatial resolution and reduction of metal artifacts.[13] Today, gender determination studies are conducted on the bones of individuals with known gender, using CT, magnetic resonance imaging, and CBCT. The findings obtained with these imaging methods are useful for examining social differences.[5,13-15]

Recently, it has been reported that volumetric images that allow three-dimensional (3D), reconstruction of bone structures are suitable data sources for sex determination.[14] Using 3D reconstructions for evaluation provides advantages such as not requiring a maceration process in decomposed corpses, shortening the examination time, preventing damage to bone tissue, reducing subjectivity, and intra-observer and inter-observer errors, and the availability of large data sets of recent samples from various populations.[5,10,14] It appears that the results of studies using CT images for gender estimation are similar to classical anthropological methods.[8,16] In a study conducted on 3D digital models of cranial CTs, the gender of the study population was determined correctly with a rate of over 90% (91.8% and 92.9%).[5] Franklin et al.[8] determined gender with 90% accuracy in their study using volumetric processed CT scans. The literature demonstrates the improved accuracy, reproducibility, and reliability of CBCT over traditional methods.[17] With CBCT technology, it is possible to obtain high-quality, distortion-free images that provide precise localization and identification of bone structures.[17,18]

It is known that the morphological features of the human skull vary significantly around the world. Both genetic and environmental differences within populations affect morphology, and morphological differences in the skull are observed between populations.[19] For this reason, it is thought that conducting studies on gender determination in different societies will increase reliability. The aim of this study is to investigate the feasibility of determining gender in a Turkish subpopulation using the diagram developed by Buikstra[12] and Ubelaker and DeGaglia[2] for conventional manual gender determination on 3D reconstruction images obtained with the CBCT technique, which is increasingly used in dental practice.

MATERIALS AND METHODS

This study was approved by the Non-Interventional Clinical Research Ethics Committee of Pamukkale University Faculty of Dentistry (approval number: 02, date: 23.01.2024).

CBCT images, which were taken between March 2019 and January 2024 and are in the archive of Pamukkale University Faculty of Dentistry, Department of Oral and Maxillofacial Radiology, were included in this study. In our institution, it is standard procedure to obtain informed consent from all patients prior to examination, including consent for the use of their radiographic data in scientific research. The inclusion criteria for the CBCT images included in the study were determined as having a field of view (FOV) (of 21x19, all anatomical structures to be evaluated in the study being viewable, having sufficient diagnostic quality, and having the age of the individuals 18 years or older. In addition, movement or metal artifact, evidence or history of trauma that would affect the anatomical structures to be evaluated, and the presence of a disease or syndrome affecting growth and development were used as exclusion criteria in the study. All CBCT images will be obtained with the Newtom 5G XL (Cefla, Imola, Italy) with the parameters 110 kVp, 3.00-8.73 mA, 3.6-5.4s scanning time, and voxel size 0.125-0.250 mm^3. All CBCT images were evaluated by a dentomaxillofacial radiologist (10 years of experience) twice, one month apart. Another dentomaxillofacial radiologist (8 years of experience) evaluated 20% of the images to assess the inter-observer agreement.

The study population included 133 (55.6%) females and 105 (44.4%) males. The individuals were grouped into age groups: 18-30 years (group 1), 31-50 years (group 2), and above 50 (group 3). After the CBCT images were selected from the archive according to the inclusion and exclusion criteria, a new data file was created without patient information. Both observers made evaluations blind to the actual gender of the participants. For the study, 5 cranial traits defined by Buikstra[12] and Ubelaker and DeGaglia[2] (Table 1), including nuchal crest, mental eminence, supraorbital margin, mastoid process, and glabella, were scored between 1-5 on the 3D reconstruction CBCT images. (Figure 1) Scoring according to the figure indicated 1= female, 2= probably female, 3= ambiguous gender, 4= probably male, 5= male. For each cranial trait, the scoring distribution and mean score were calculated according to gender. For supraorbital margin and mastoid process, the score was calculated as the mean of the right and left scores. Gender estimation was performed in two ways. The first method was by calculating the average score of five cranial traits manually; those with an average below 3 were classified as female; those with an average of 3 were considered ambiguous; and those with an average above 3 were classified as male. The second method involved determining gender using discrimination analysis.

Statistical Analysis

IBM SPSS v 22.0 (for Windows, SPSS Inc., Chicago, IL) was used for statistical analysis. For evaluation of intra-observer and inter-observer reliability, the Kappa value was calculated. For the frequencies, descriptive statistics were used. The Mann-Whitney U test was used to compare the ages of genders. The relationship between age groups and gender estimation and the relationship between actual gender and estimated gender were analyzed by a chi-squared test. Discriminant analysis was used to classify individuals into male and female groups based on cranial trait scores obtained from 3D CBCT reconstructions. This method was used to develop a statistical model that maximizes the

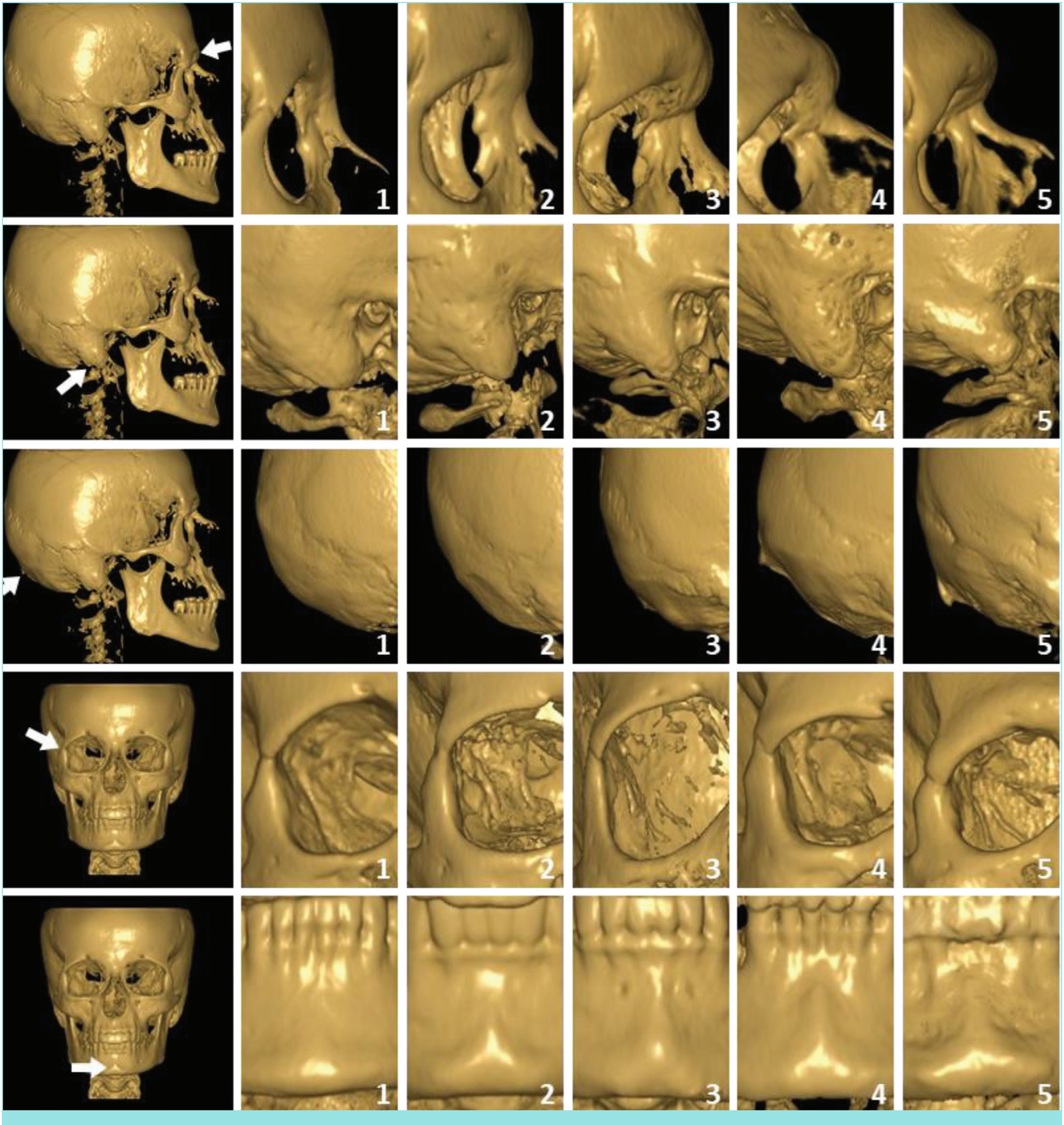

Figure 1. Scoring for cranial traits identified by Buikstra[12] and Ubelaker and DeGaglia.[2].

differentiation between the two groups by identifying the traits with the highest discriminatory power. The analysis involved calculating standardized discriminant function coefficients and structure matrix values to determine the relative contribution of each cranial trait. Model performance was evaluated using Wilks' Lambda and canonical correlation to ensure the effectiveness of the classification.

RESULTS

According to the results of kappa analysis performed to evaluate the agreement of cranial traits, intra-observer reliability Kappa values ranged from 0.805 to 0.876, and inter-observer reliability Kappa values ranged from 0.808 to 0.850. Kappa values were high and statistically significant for all cranial traits ($p<0.001$).

One hundred thirty-three females (55.6%,) and 106 males (44.4%,) aged between 18 and 89, with the mean age of 43.38±15.99 years, were included in the study. The mean age of females was 41.91±16.23, the mean age of males was 45.22±16.25, and there was no statistically significant difference in age between sexes (p=0.107). When the study population was grouped according to age, there were 60 (25.1%) individuals in group 1, 101 (42.3%) in group 2, and 78 (32.6%) in group 3.

The distribution of cranial trait scores according to gender is shown in Table 2. Mental eminence was the cranial trait scored most frequently as 3, indicating ambiguity, while glabella was the cranial trait most frequently scored at 1 and 5.

According to the mean cranial trait scores, the correct gender estimation rate was calculated as 95.5% for females and 92.5% for males. The accuracy rate for the entire study population was 94.1%.

Table 1. Examination of the cranial structures

Cranial trait	**Scoring procedure**
Nuchal crest	The skull is positioned so that the occipital region can be clearly seen, and the prominence and roughness of the nuchal crest are viewed from the side.
Mental eminence	The mandible can be assessed from frontal and lateral views, and the prominence of the chin is scored according to how far it projects from the mandible.
Supraorbital margin	It is scored by evaluating the sharpness of the supraorbital margin from lateral, anterior and inferior views.
Mastoid process	The skull is examined from the lateral aspect so that the mastoid process is clearly visible. The volume of the mastoid process relative to the temporal bone and the degree of outward protrusion are evaluated.
Glabella	The skull is positioned laterally and scored according to the level of glabellar prominence.

Table 2. Distribution of the genders according to the scores of cranial traits

	Gender	**Score 1 n (%)**	**Score 2 n (%)**	**Score 3 n (%)**	**Score 4 n (%)**	**Score 5 n (%)**
Nuchal crest	**Female**	30 (100%)	50 (94.3%)	38 (56.7%)	11 (19.6%)	4 (12.1%)
	Male	0 (0%)	3 (5.7%)	29 (43.3%)	45 (80.4%)	29 (87.9%)
	Total	**30 (12.6%)**	**53 (22.2%)**	**67 (28%)**	**56 (23.4%)**	**33 (13.8%)**
Mental eminence	**Female**	10 (100%)	59 (93.7%)	59 (61.5%)	5 (8.3%)	0 (0%)
	Male	0 (0%)	4 (6.3%)	37 (38.5%)	55 (91.7%)	10 (100%)
	Total	**10 (4.2%)**	**63 (26.4%)**	**96 (40.2%)**	**60 (25.1%)**	**10 (4.2%)**
Supraorbital margin (R-L)	**Female**	62 (75.6%)	111 (69.4%)	79 (50.6%)	12 (20.7%)	2 (9.1%)
	Male	20 (24.4%)	49 (30.6%)	77 (49.4%)	46 (79.3%)	20 (90.9%)
	Total	**82 (17.2%)**	**160 (33.5%)**	**156 (32.6%)**	**58 (12.1%)**	**22 (4.6%)**
Mastoid process (R-L)	**Female**	98 (90.7%)	101 (81.5%)	50 (40%)	17 (21.5%)	0 (0%)
	Male	10 (9.3%)	23 (18.5%)	75 (60%)	62 (78.5%)	42 (100%)
	Total	**108 (22.6%)**	**124 (25.9%)**	**125 (26.2%)**	**79 (16.5%)**	**42 (8.8%)**
Glabella	**Female**	60 (98.4%)	50 (90.9%)	21 (58.3%)	1 (2.6%)	1 (2%)
	Male	1 (1.6%)	5 (9.1%)	15 (41.7%)	37 (97.4%)	48 (98%)
	Total	**61 (25.5%)**	**55 (23%)**	**36 (15.1%)**	**38 (15.9%)**	**49 (20.5%)**

R: Right, L: Left.

The rate of gender indeterminacy was 2.3% in females, and 3.8% in males. Distribution of correctly estimated, incorrectly estimated, and ambiguous genders according to their actual gender is shown in Table 3. When the relationship between age groups and gender estimation was evaluated, it was found that age did not have a statistically significant effect (p=0.833) (Table 4).

According to the results of discriminant analysis shown in Table 5, the standardized coefficients indicated that glabella had the strongest effect on gender determination (0.672). The structure matrix further supported these findings, revealing the highest correlation between the discriminant function and glabella (0.809), followed by mental eminence (0.500) and nuchal crest (0.496). The analysis also produced a high canonical correlation of 0.870. The model showed a high accuracy of 96.2% for females and 95.3% for males (Table 6).

DISCUSSION

Gender determination is an important step in the identification process when developing a biological profile. Since gender-related differences are largely population-based and change over time, morphological and metric methods need to be continuously adapted to specific populations.[14] Although dimensional differences between the genders are still the most important aspect of gender determination, accuracy in predicting gender depends on various factors.[20]

Ethical concerns related to macroscopic procedures, advancements in imaging techniques, and increased accessibility have made imaging methods an alternative to traditional anthropological methods.[14] In addition, in a study comparing measurements made on both direct bone images and CT images, it was reported that 3D CT gave accurate results in morphological analysis.[21] In the present study, 3D

Table 3. Distribution of estimated gender according to actual gender

	Estimated gender				
Gender	**Female n (%)**	**Male n (%)**	**Ambigious n (%)**	**Total**	**p**
Female	127 (53.1%)	3 (1.3%)	3 (1.3%)	133 (55.6%)	<0.001*
Male	4 (1.7%)	98 (41%)	4 (1.7%)	106 (44.4%)	
Total	131 (54.8%)	101 (42.3%)	7 (2.9%)	239 (100%)	

*Statistically significant (p<0.05).

Table 4. Estimation of true and false/ambigious genders according to age groups

	Determination of gender			
Age	**True**	**False/ambigous**	**Total**	**p**
Group 1	57 (23.8%)	3 (1.3%)	60 (25.1%)	0.833
Group 2	94 (39.3%)	7 (2.9%)	101 (42.2%)	
Group 3	74 (31%)	4 (1.7%)	78 (32.7%)	
Total	225 (94.1%)	14 (5.9%)	239 (100%)	

Table 5. Estimation result values according to cranial traits using discrimination analysis

	Mean score		Correlation coefficient					
	Female	**Male**	**Standardized**	**Non-standardized**	**Structure matrix**	**Wilks' Lambda**	**Canonical correlation**	**Accuracy**
Nuchal crest	2.32	3.94	0.216	0.233	0.496	0.244	0.870	95.8%
Mental eminence	2.44	3.67	0.321	0.462	0.500			
Supraorbital margin (R-L)	2.2	2.98	0.111	0.115	0.231			
Mastoid process (R-L)	1.93	3.47	0.340	0.376	0.480			
Glabella	1.74	4.19	0.672	0.785	0.809			

R: Right, L: Left.

Table 6. Distribution of estimated gender using discriminant analysis

	Estimated gender			
Gender	**Female n (%)**	**Male n (%)**	**Total**	**p**
Female	128 (96.2%)	5 (3.8%)	133	<0.001*
Male	5 (4.7%)	101 (95.3%)	106	
Total	133	106	239	

*Statistically significant (p<0.05).

reconstruction of CBCT images was evaluated. CBCT provides non-distorted high-resolution radiological data. 3D modes present valuable morphologic information and are suitable for gender determination.[22] 3D imaging methods are very useful in the evaluation of fossil or modern skeletons. We can rotate the obtained 3D structures in space, and make original measurements. In addition, internal structures can be evaluated by making cross-sectional views. It is very important that these applications can be done without destroying the bone and without requiring maceration.[21,23] Compared to CT, CBCT has advantages such as lower cost, accessibility, short scanning time, and high resolution. Despite its widespread adoption in dentistry, CBCT is not without limitations related to cone-beam projection geometry, detector sensitivity, and contrast resolution. The clarity of CBCT images is compromised by artifacts, image noise, and poor soft tissue contrast. These artifacts may arise from beam hardening, patient motion, scanner imperfections, or the cone-beam geometry itself. Image noise results from the irradiation of large volumes, which increases scattered radiation and leads to non-linear attenuation detected with flat-panel detectors. Furthermore, CBCT systems offer noticeably lower soft tissue contrast compared to conventional CT, a limitation primarily due to increased noise, X-ray beam divergence, and inherent detector-based artifacts.[24]

Additionally, the forensic process of shipping bones or skulls to specialist laboratories presents numerous challenges: financial burden, the risk of sample loss, the requirement of special permits from judicial authorities, and diplomatic procedures involved in international transfers.[5] However, an important advantage is the ability to obtain 3D images from a nearby hospital and deliver them to the specialist, using any digital storage method.

In this study, satisfactory findings were obtained in gender determination. Based on the results of this study, glabella was identified as the cranial trait with the strongest effect on gender differentiation. Similarly, in another study conducted on the Turkish population, glabella, was also recognized as the cranial feature with the greatest influence on gender differentiation.[5] In a similar study by Walker[25], which evaluated the effectiveness of cranial traits for sex determination, the highest accuracy was found for glabella when assessed individually. However, when glabella was evaluated in combination with other traits, the accuracy rate increased. According to the results of our study, the least reliable cranial trait in sex determination was found to be the supraorbital margin. This result may be related to the fact that determining the sharpness level of the supraorbital margin is based on palpation.[12] In a study conducted by Garvin et al.[26], it was found that glabella and mastoid process were the strongest discriminators for gender determination, while nuchal crest was identified as the weakest cranial trait. According to our study, the nuchal crest was the cranial trait with the second-lowest correlation coefficient level after the supraorbital margin. In the same study, the accuracy of cranial traits for gender determination was compared between different populations, and it was found that there were statistically significant differences between the populations.[26] Accordingly, it is important to conduct forensic studies on different populations and races.

An easy and standardized diagram for determining sex was developed by Buikstra[12] and Ubelaker and DeGaglia[2], and this diagram was studied in various populations.[5,21,26-29] According to this diagram, different accuracy rates were obtained ranging from 75 to 96%.[5,26-29] In this study, the accuracy rate was determined in two different ways. The first method involved scoring five cranial traits for each individual, taking the average of these scores, and then classifying the individual as female, male, or ambiguous. To our knowledge, there is no study that uses the method of sex determination based on a single value by averaging all 5 cranial trait scores. However, the results are quite satisfactory. The second method of was determining the accuracy rate through discriminant analysis. The accuracy rate was determined to be slightly better than that of the first method. In our study, the accuracy rates were 94.1% according to mean scores and 95.8% based on discriminant analysis. To the best of our knowledge, only one study has been conducted on the Turkish population using this diagram on CT images. Based on the results of the study in question, which was conducted with scoring by three different observers, the accuracy in determining gender was found to range between 91.8 and 92.9%. 5 These studies were performed directly on the skull bones[26-29] or on 3D reconstructions of cranial CT images[5,21], and a high accuracy in sex determination was achieved. These studies, which were conducted in different populations and resulted in high accuracy, support the dimorphic feature of the skull as well as the validity of these cranial-traits-based diagram.

In a study evaluating both metric and shape features in the skull, it was determined that bizygomatic breadth, maximum cranial length, and cranial base length as well as mastoid height were dimorphic. Similar to this study, it was reported that among the shape features evaluated, the glabellar region was a strong cranial trait in gender differentiation.[16] In a study conducted by Franklin et al.[8], different measurements were made on the skull to determine sex, and[16] of the measurements showed a statistically significant difference between the sexes.[8] In the light of all these findings, it can be concluded that many of the skull's traits and dimensions are dimorphic. However, variations that affect dimorphism and exhibit ambiguous characteristics can be observed. It is known that factors such as reduced muscle activity, severe malnutrition, and extreme emaciation can affect the accuracy of the methods used. Since it is known that some intrinsic and extrinsic factors can influence cranial features, evaluation of multiple structures together is suggested to positively impact accuracy.[3]

Determining sex from human skeletons using non-metric methods has been criticized for not being objective. However, non-metric methods may be the only option for bones that have been damaged or exposed to taphonomic changes in skeletal remains. Additionally, non-metric methods are useful when there is no suitable reference for metric analysis.[28] Another disadvantage is that experts cannot feel the edges and crests of the bones by holding them in their hands when making morphological evaluations on 3D images.[5] This disadvantage can be overcome with additional morphological examinations[5] and the possibility of cross-sectional evaluation.

Study Limitations

This study has some limitations. Due to its retrospective design, individual factors such as height, weight and nutrition, which may influence cranial development, could not be considered. The inability to physically palpate bones in 3D images may affect the assessment of subtle traits like the supraorbital margin. Also, the use of non-metric visual methods introduces some subjectivity despite high observer agreement. Lastly, findings are based on a single Turkish subpopulation, which may limit generalizability to other groups.

CONCLUSION

This study has shown that CBCT offers high accuracy and quality in the morphological evaluation of bone. Among the 5 different cranial traits evaluated on the skull for the study, the glabella was determined to have the strongest, and the supraorbital margin the weakest, dimorphic feature. When cranial traits were evaluated together, the accuracy rate increased compared to those from individual evaluations. The accuracy rates in determining the sex of the study population were quite high at 94.1% and 95.8%.

MAIN POINTS

- The diagram developed by Buikstra and Ubelaker for conventional manual gender determination was applicable to three-dimensional reconstruction images for determining gender in a Turkish subpopulation.
- This study has shown that cone beam computed tomography offers high accuracy and high quality in the morphological evaluation of bone.
- When cranial traits were evaluated together, the accuracy rate increased compared to individual evaluations. The accuracy rates in determining the sex of the study population were determined to be quite high as 94.1% and 95.8%.

ETHICS

Ethics Committee Approval: This study was approved by the Non-Interventional Clinical Research Ethics Committee of Pamukkale University Faculty of Dentistry (approval number: 02, date: 23.01.2024).

Informed Consent: Informed consent has been obtained from the patients.

Footnotes

Authorship Contributions

Concept: B.K.A., D.İ., Design: B.K.A., D.İ., Data Collection and/or Processing: B.K.A., Analysis and/or Interpretation: B.K.A., Literature Search: D.İ., Writing B.K.A., D.İ.

DISCLOSURES

Conflict of Interest: No conflict of interest was declared by the authors.

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