Research Paper

Sex Estimation via Morphometric Analysis of Three-Dimensional Digitally Configured Craniofacial Computed Tomography Images in a Sample of the Egyptian Population

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ABSTRACT

Background: Identification and verification of identity are mandatory in a variety of civil and criminal contexts. Sex estimation from morphometric craniofacial measurements in a sample of the Egyptian population.

Methods: This study employed a cross-sectional design, involving 303 computed tomography images (165 males and 138 females). Twenty craniofacial measurements were studied in relation to the corresponding sex.

Results: Most of the measurements were greater in males than in females. Bimastoid breadth, length of the cranial base, anteroposterior diameter of the right and left frontal sinuses, bizygomatic breadth, right maxillary sinus height, left maxillary sinus length, right and left maxillary sinus volume, and right mandibular ramus length showed a highly statistically significant difference between sex groups (P value < 0.001). Discriminant scoring was calculated to estimate sex from craniofacial measurements, and 80.6% of males and 78.9% of females in the original grouped cases were correctly classified.

Conclusion: Craniofacial measurements can be used as a reliable method for sex estimation. The establishment of a comprehensive national database for craniofacial measurements is recommended for documentation purposes.

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Introduction

Sex estimation is a crucial component of determining the biological profile, which is essential in forensic investigations [1]. Forensic anthropologists traditionally undertake this task by performing non-metric macroscopic examination of the skeletal structures [2, 3]. However, these qualitative analyses may result in significant inter-observer errors and are often subjective. [4].

With the introduction of computed tomography (CT) in the early 1970s, it became feasible to produce radiological cross-sections of the whole body [5]. The overall spatial concept of CT imaging enables a better understanding of the tissue complexities compared to multiple 2-dimensional (2D) axial images [6]. The 3-dimensional (3D) images offer interactive landmark identification and computer-generated image manipulation (translation, rotation, and segmentation) [7].

Through the use of non-invasive CT, digital data can be generated and subsequently processed via automated image analysis methods. Forensic facilities have performed CT images for anthropometric research. CT images can be used to create three-dimensional bone models, and forensic specialists can further analyze these images to gather valuable information. Using morphometric measurements obtained from CT images may provide an affordable and quick procedure for sex estimation [8]. Moreover, CT images provide more accurate morphometric sex estimation than conventional tools, such as calipers [9].

With the development of new techniques and validations, the pelvis remains the most reliable skeletal indicator of sex. Nonetheless, other skeletal parts, such as postcranial metrics and morphology and metrics of the skull, should be helpful when the pelvis is fragmented or lost [10, 11]. Since the mandible is usually recovered in an intact state and is the largest, strongest, and most dimorphic bone in the skull, it can be beneficial in estimating sex in situations where an intact skull is not found [12].

The maxillary sinus (MS) is a cavity inside the maxillary body and is defined as the largest paranasal sinus [13]. The unique structure of the MS and its sex-based variations play an important role in forensic sciences [14].

The frontal sinus (FS) is an imaged anatomical landmark with a distinctive shape and may be described as having fingerprint-like individuality. Measurements of the frontal sinus can be utilized in personal identification [15].

It is widely accepted that population-specific standards yield precise estimates of biological attributes (such as sex, age, and stature) in the human skeleton. Population-specific standards are necessary and greatly needed. Standards for morphometric craniofacial sexing are particularly developed for the population under research [16].

Numerous anthropological studies validated the use of CT imaging as an alternative to traditional identification methods, and craniofacial metrics have been considered valuable tools in the study of sexual dimorphism [17-21].

Hence, the use of craniofacial measurements obtained from 3D CT images for sex estimation among a sample of the contemporary Egyptian population was proposed in the current study. The study was conducted at the Diagnostic and Interventional Radiology Department in Kasr Alainy Hospitals, Faculty of Medicine, Cairo University.

To the best of our knowledge, this is the largest study of the contemporary Egyptian population for sex estimation using 3D CT scans with the largest sample size and the greatest number of measured craniofacial parameters.

Methods

The current study is a cross-sectional investigation of sex estimation from craniofacial measurements obtained from CT images using Mimics software. The study was conducted at the Diagnostic and Interventional Radiology Department, Kasr Alainy Hospitals, Faculty of Medicine, Cairo University, from February 2023 to March 2024.

Twenty craniofacial parameters were measured from each CT image to be studied concerning the corresponding sex.

Sample size

Three hundred and three CT images of Egyptian participants were included in the current study, based on data from earlier similar studies. Epi-calc 2000 was used for sample size calculation [22]. Assuming 80% power, a 0.05 level of significance, a 30% null hypothesis value, and an estimated proportion of 22%, the sample size included 242 participants. Given the 10% dropout rate, the final sample size consisted of 266 participants.

Ethical consideration

The Ethical Committee of the Department of Forensic Medicine and Clinical Toxicology and the Research Ethics Committee of Kasr Alainy (Code: MD-396-2022), Faculty of Medicine, Cairo University, approved the study.

All included subjects were informed and provided consent for the aim and procedures of the CT examination, in accordance with ethically approved guidelines. The participants were given the option to provide their scans for this study, and all the scans were anonymized before analysis.

Selection of the participants

The participants were recruited from cases admitted to the Diagnostic and Interventional Radiology Department at Kasr Alainy Hospitals to undergo scanning for various reasons during the study period.

Egyptians by origin and residence, both sexes, aged 20 years or older, and with normal bone morphology, were included in the study. At the same time, people with any craniofacial (disease/tumor/anomaly/fracture or trauma/surgery), orthodontic treatment, hormonal disturbance (acromegaly), and CT with a single deficient measurement or with poor quality were excluded.

The examination was performed using a Siemens Somatom Emotion 16 Slice scanner (model 78830) at the Diagnostic and Interventional Radiology Department, Kasr Alainy Hospitals, on the second floor. The most commonly accepted protocol for CT examination of the skull involves the acquisition of axial images with a 1 mm slice thickness, as well as multiplanar and 3D reformatted images in both bone and soft tissue windows [23].

The resolution of the CT images [24] was spatial full width at half maximum (FWHM) 0.5–0.625 mm, the image window was cerebrum + bone, and the image order was craniocaudal. Laptop device (Dell Latitude E6420) Intel Core i7 2nd generation, 8 GB DDR3, Windows 10 Home Edition, and 14.0" HD (1366x768) wide-view outdoor-viewable LED with Direct Vue technology.

Mimics software version 20.0.0.691 (Materialise NV, Leuven, Belgium) (Fig. 1):

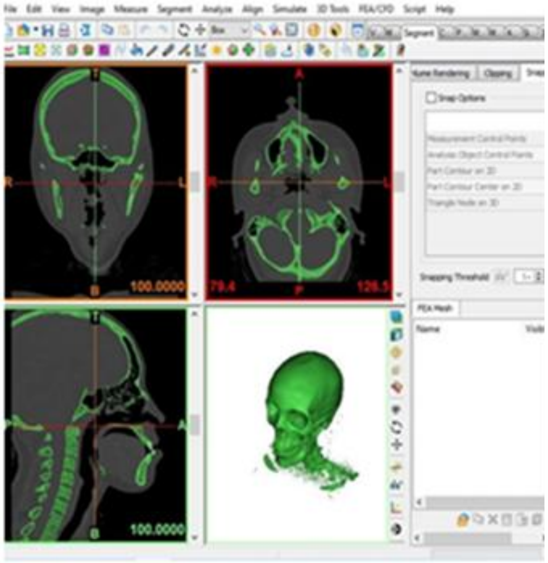

Figure 1. Mimics software.

Materialise Interactive Medical Image Control System (MIMICS) is an image-processing software program developed by the Belgian company Materialise, which specializes in additive manufacturing technology for dental, medical, and other industries. Stacks of any 2D image data can be analyzed via Mimics software, and 3D surface models, 3D designs, and 3D measurements can also be produced [25, 26].

Craniofacial measurements

The patient was placed in a supine position; no contrast was used, and no prior preparations were made.

Skull measurements were categorized as cranial or facial [27, 28]. Several authors identified these measurements for sex estimation purposes.

Cranial measurements (Fig. 2):

Bimastoid breadth (BIM) is the distance between the outermost prominent points on the lateral surfaces of the two mastoid processes [29]. Length of the cranial base (LCB) (Sella-Nasion line) is the distance between the sella, the midpoint of the sella turcica, and the nasion, the most anterior point of the frontonasal suture that joins the frontal and nasal bones [29]. Anterior wall thickness of the frontal sinus (AWT FS) is the distance between the inner and outer tables of the anterior wall of the frontal sinus. It was measured in the axial plane at the level of the orbital roof [30]. The right (RT) and left (LT) anteroposterior diameter of the frontal sinus (APD FS) is the longest distance between the most anterior and posterior points of the frontal sinus on axial view [30].

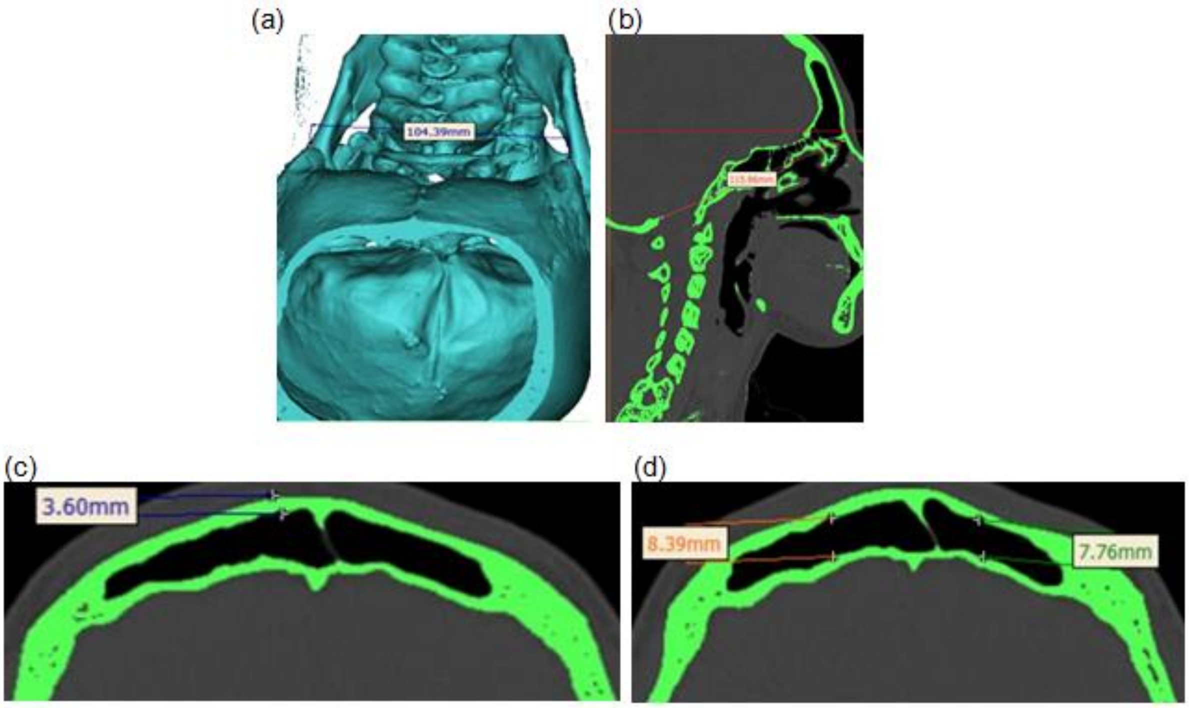

Figure 2. Cranial measurements (a) Bimastoid breadth (b) Length of the cranial base (c) Anterior wall thickness of the frontal sinus (d) Right and left anteroposterior diameters of the frontal sinus.

Facial measurements (Fig. 3):

Right and left orbital height (OH) is the longest distance between the upper and lower orbital rims [31]. The right and left depth of the canine fossa (CF) is the distance from the infraorbital margin to the alveolar process above the second bicuspid tooth [32]. Bizygomatic breadth (BZB) is the distance between the most lateral points on the zygomatic arches in the coronal plane [33]. Right and left maxillary sinus length (MS L) is the distance between the most anterior point and the most posterior point of the medial wall of the sinus on axial view [34]. Right and left maxillary sinus width (MSW) is the distance from the medial wall to the outermost point of the lateral wall of the sinus on axial view [34]. Right and left maxillary sinus height (MS H) is the distance from the lowest point of the sinus floor to the highest point of the sinus roof on the coronal view [34]. The right and left volumetric value of the maxillary sinus (MS VL) is the segmentation of the maxillary sinus [34]. Right and left mandibular ramus length (MRL) is the distance between the most prominent upper part of the condyloid process and the most inferior, posterior, and lateral point on the external angle of the mandible [35].

Approach steps for Mimics software:

1- Choose the CT image from the File.

2- The coronal, axial, and sagittal axes are selected and adjusted according to the coveted parameter.

- Coronal axis: Maxillary sinus height.
- Sagittal axis: Length of the cranial base.
- Axial axis: Anterior wall thickness, anteroposterior diameter of the frontal sinus, and maxillary sinus length and width.

3- Select Measure, and between the two specific landmark points of the measurement, draw a straight line.

4- A 3D tool is selected to configure the CT image and convert it, allowing for the measurement of the bimastoid breadth, orbital height, depth of the canine fossa, bizygomatic breadth, and mandibular ramus length.

5- Segmentation of the maxillary sinus: In the 3D model, to prevent burnout of the maxillary antrum, we wrap the sinus to produce a closed cavity and choose an air threshold to be enclosed inside the sinus.

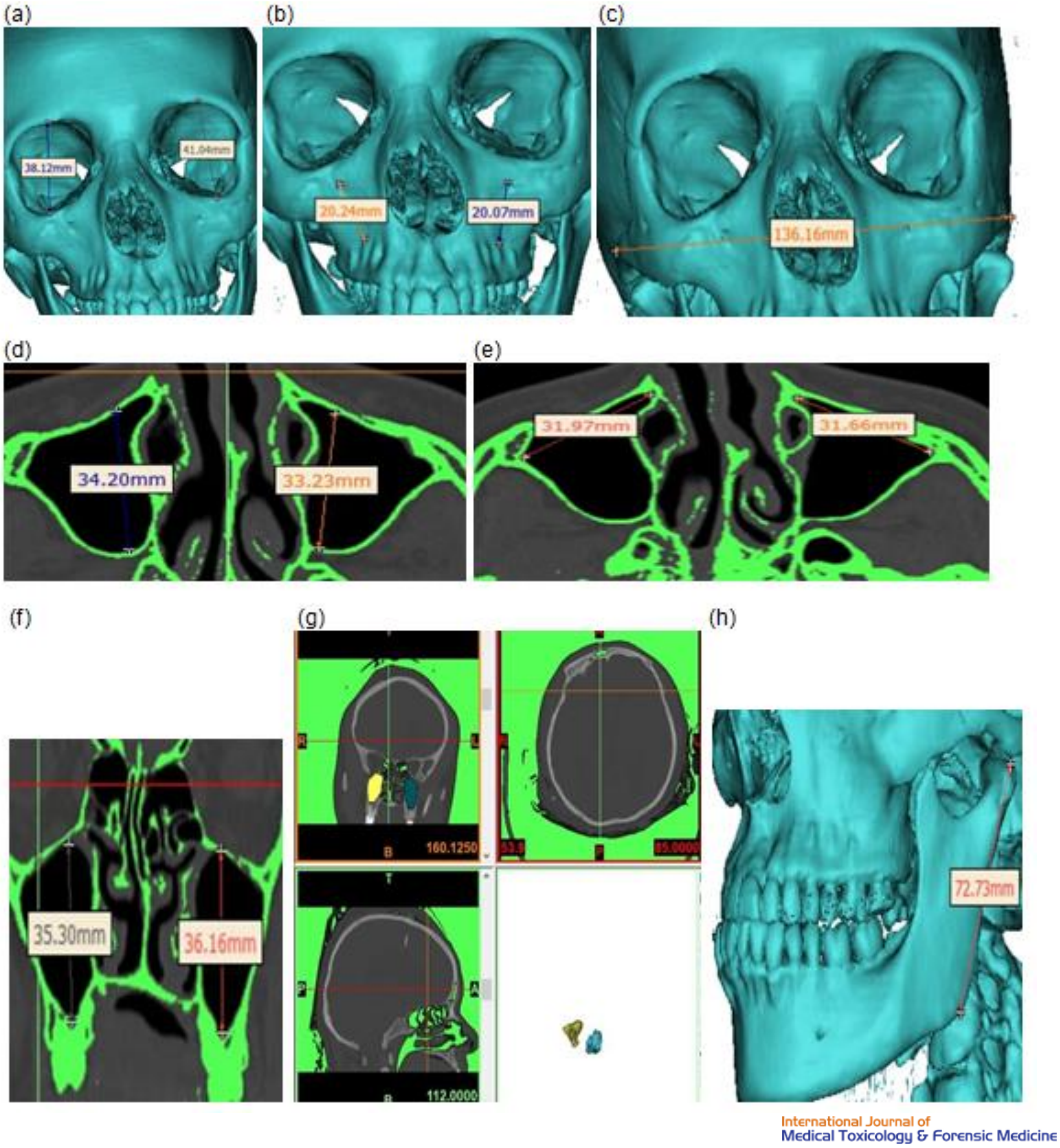

Figure 3. Facial measurements (a) Right and left orbital height (OH) (b) Right and left depth of the canine fossa (CF) (c) Bizygomatic breadth (BZB) (d) Right and left maxillary sinus length (MS L) (e) Right and left maxillary sinus width (MS W) (f) Right and left maxillary sinus height (MS H) (g) Right and left volumetric values of the maxillary sinus (MS VL) (h) Left mandibular ramus length (MRL).

Craniofacial measurements were performed on each CT image by a forensic specialist via Mimics software. To assess intra-observer error, thirty randomly selected CT images were reassessed by the same forensic specialist two weeks later. To assess inter-observer error, the plastic surgeon and the radiologist performed measurements on randomly selected CT images using Mimics software.

Statistical analysis

The Statistical Package for the Social Sciences (SPSS) version 28 (IBM Corp., Armonk, NY, USA) was used for data coding. The mean and standard deviation were used to summarize the quantitative variables. The data were double-checked for normality using normality plots and the Shapiro-Wilk test and were found not to have deviated from a normal distribution. An unpaired t-test was used to compare the mean differences between sexes to detect significant values [36]. Area under curve (AUC) analysis: each craniofacial measurement was used to construct a receiver operating characteristic (ROC) curve to detect the best cut-off value of significant parameters for the detection of males (sensitivity and specificity) [37]. Discriminant function analysis was used for differentiating groups [categorical dependent variable], e.g., sex, when the independent variables are quantitative, e.g., craniofacial measurements [38]. The stepwise analysis was used to reach the final model. The Intraclass correlation coefficient (ICC) was calculated to assess intra- and inter-observer errors for the craniofacial measurements. ICC values were interpreted as follows: poor (< 0.5), moderate (0.5 - < 0.75), good (0.75 - < 0.9), or excellent (> 0.9) reliability [39]. P-values < 0.05 were considered statistically significant, and values < 0.001 were considered highly statistically significant [38].

Results

The total sample included 303 participants with an average age of 44.40 ± 17.52 (range: 20–80) years (males: 46.59 ± 19.17, females: 41.78 ± 14.98). Males outnumbered females, representing 165 participants (54.5%) and 138 participants (45.5%), respectively.

There was excellent intra- and inter-observer reliability regarding all craniofacial measurements (ICC values were > 0.9) as shown in Table 1.

Males had higher mean values of craniofacial measurements than females, except for the AWT of FS, which was equal in both, as shown in Tables 2 and 3.

Table 1. Intraclass correlation coefficient (ICC) of the craniofacial measurements

Craniofacial measurements	Intra-observer				Inter-observer			
	ICC	95% Confidence Interval		P value	ICC	95% Confidence Interval		P value
		Lower Bound	Upper Bound			Lower Bound	Upper Bound	
BIM	0.999	0.998	0.999	< 0.001**	0.988	0.990	0.995	< 0.001**
LCB	0.999	0.999	0.999	< 0.001**	0.977	0.980	0.988	< 0.001**
AWT of FS	0.997	0.996	0.997	< 0.001**	0.970	0.977	0.990	< 0.001**
APD of RT FS	0.998	0.997	0.998	< 0.001**	0.968	0.972	0.981	< 0.001**
APD of LT FS	0.991	0.989	0.993	< 0.001**	0.971	0.983	0.989	< 0.001**
RT OH	0.990	0.987	0.992	< 0.001**	0.981	0.977	0.984	< 0.001**
LT OH	0.998	0.998	0.999	< 0.001**	0.982	0.988	0.992	< 0.001**
BZB	0.998	0.998	0.998	< 0.001**	0.970	0.978	0.998	< 0.001**
Depth of RT CF	0.998	0.997	0.998	< 0.001**	0.965	0.971	0.998	< 0.001**
Depth of LT CF	0.999	0.998	0.999	< 0.001**	0.960	0.978	0.997	< 0.001**
RT MS H	0.998	0.997	0.998	< 0.001**	0.955	0.965	0.989	< 0.001**
LT MS H	0.995	0.994	0.996	< 0.001**	0.965	0.974	0.996	< 0.001**
RT MS W	0.994	0.992	0.995	< 0.001**	0.966	0.975	0.997	< 0.001**
LT MS W	0.997	0.996	0.997	< 0.001**	0.967	0.976	0.997	< 0.001**
RT MS L	0.995	0.994	0.996	< 0.001**	0.958	0.966	0.990	< 0.001**
LT MS L	0.996	0.995	0.997	< 0.001**	0.960	0.975	0.996	< 0.001**
RT MS VL	0.995	0.994	0.996	< 0.001**	0.955	0.964	0.996	< 0.001**
LT MS VL	0.995	0.994	0.996	< 0.001**	0.956	0.965	0.996	< 0.001**
RT MRL	0.984	0.980	0.987	< 0.001**	0.970	0.982	0.994	< 0.001**
LT MRL	0.997	0.996	0.997	< 0.001**	0.976	0.985	0.996	< 0.001**

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ICC = Intraclass correlation coefficient.
**P value < 0.001 is highly significant.
RT = Right, LT = Left, BIM = Bimastoid breadth, LCB = Length of the cranial base, AWT = Anterior wall thickness, FS = Frontal sinus, APD = Anteroposterior diameter, OH = Orbital height, BZB = Bizygomatic breadth, CF = Canine fossa, MS = Maxillary sinus, H = Height, W = Width, L = Length, VL = Volume and MRL = Mandibular ramus length.

Table 4 shows the AUC analysis for the detection of males from craniofacial measurements, where the most sensitive cranial measurement was APD of LT FS (the sensitivity was 60.9%, and the specificity was 66.4%). The most sensitive facial measurement was RT MRL (the sensitivity was 81.8%, and the specificity was 53.9%).

A receiver operating characteristic (ROC) curve was constructed using each measurement separately to detect males, as shown in Fig. 4.

Discriminant function analysis for the estimation of sex from the most sensitive craniofacial measurements is shown in Table 5 and the following equation. Negative scores identified positive scores and females. The function at the group centroid of the discriminant score was 0.798 in males and -0.923 in females.

<u>Discriminant score (Estimation of sex from craniofacial measurements)</u>

Discriminant function = -21.462 +0.607*BIM +0.369*LCB -1.343*AWT of FS +1.409*APD of RT FS +0.398*BZB -0.503*Depth of RT CF +0.479*RT MS H +1.980*RT MRL -1.087*LT MRL

Table 6 presents the accuracy of the sex estimation model based on measured craniofacial measurements, where 80.6% of males and 78.9% of females in the original grouped cases were correctly classified according to the discriminant score. Cross-validation was performed by applying this score to half of the sample and then applying it to the other half. The results

(a)

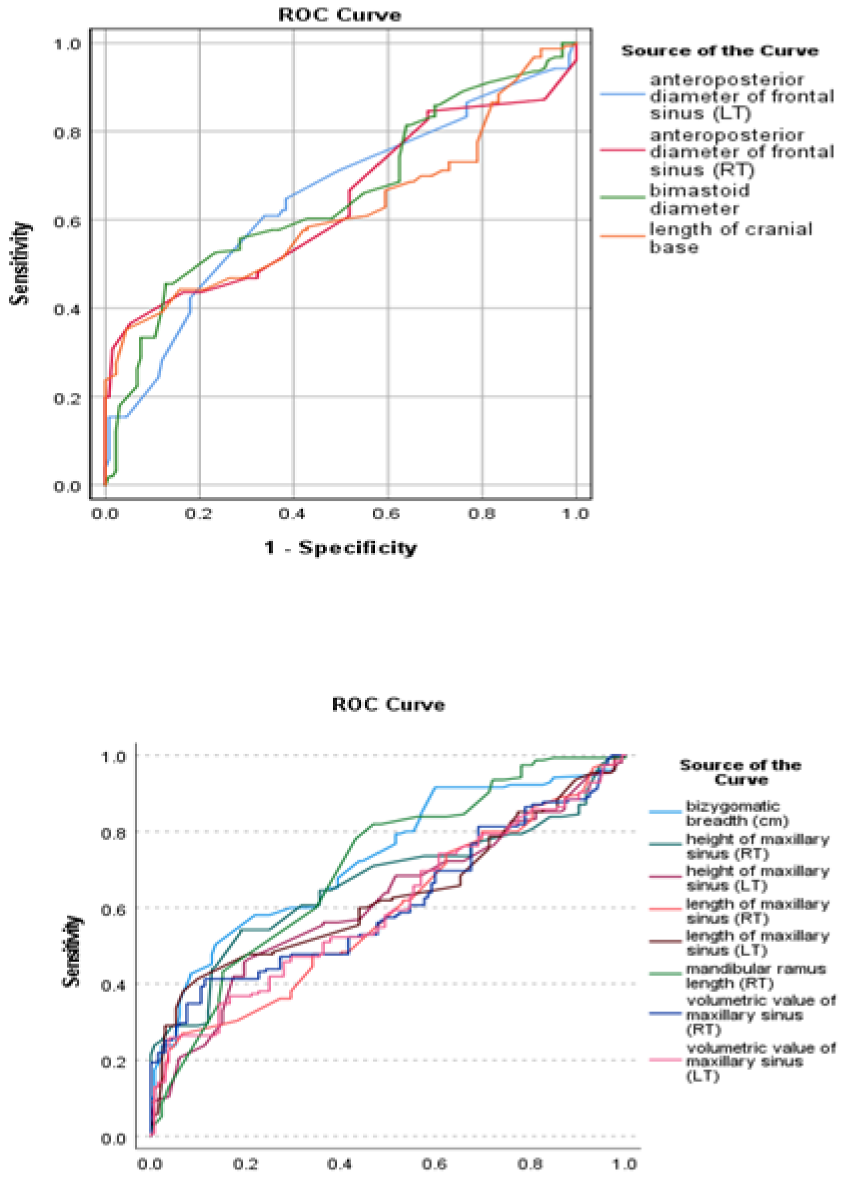

Figure 4. Receiver operating characteristic (ROC) curves (a) ROC curve for the detection of males from cranial measurements (b) ROC curve for the detection of males from facial measurements.

Table 2. Comparison of cranial measurements between males and females

Cranial measurements (cm)	Sex								P value
	Male				Female				
	Mean	SD ±	Min	Max	Mean	SD ±	Min	Max	
BIM	10.13	0.59	8.82	11.30	9.85	0.50	8.50	11.30	< 0.001**
LCB	12.27	0.84	9.00	14.00	11.94	0.81	9.00	13.30	< 0.001**
AWT of FS	0.45	0.21	0.10	1.10	0.45	0.18	0.10	1.10	0.96
APD of RT FS	0.82	0.36	0.10	1.70	0.67	0.21	0.11	1.20	< 0.001**
APD of LT FS	0.80	0.31	0.10	1.50	0.68	0.23	0.10	1.30	< 0.001**

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Unpaired t-test
SD = Standard deviation, Min = Minimum and Max = Maximum.
**P value < 0.001 is highly significant.
RT = Right, LT = Left, BIM = Bimastoid breadth, LCB = Length of the cranial base, AWT = Anterior wall thickness, FS

Table 3. Comparison of facial measurements between males and females

Facial measurements (cm)	Sex								P value
	Male				Female				
	Mean	SD ±	Min	Max	Mean	SD ±	Min	Max	
RT OH	3.46	0.30	2.57	4.30	3.39	0.27	2.80	4.10	0.017*
LT OH	3.47	0.31	2.61	4.40	3.41	0.29	2.83	4.10	0.093
BZB	12.66	0.92	10.00	14.70	12.05	0.79	9.50	13.60	< 0.001**
Depth of RT CF	2.58	0.72	1.60	4.20	2.50	0.68	1.30	4.50	0.297
Depth of LT CF	2.67	0.69	1.40	4.10	2.59	0.60	1.20	4.50	0.302
RT MS H	3.39	0.66	1.90	4.70	3.05	0.42	1.60	3.90	< 0.001**
LT MS H	3.32	0.61	1.60	4.80	3.11	0.48	1.20	4.20	0.001*
RT MS W	2.73	0.58	1.60	4.00	2.64	0.52	1.40	3.70	0.145
LT MS W	2.72	0.61	1.20	3.80	2.66	0.57	1.20	3.70	0.405
RT MS L	3.46	0.44	2.50	4.20	3.30	0.40	1.40	4.18	0.001*
LT MS L	3.49	0.51	2.20	4.50	3.29	0.43	1.30	4.40	< 0.001**
RT MS VL	5.63	2.49	1.58	11.59	4.56	1.51	1.08	8.15	< 0.001**
LT MS VL	5.55	2.41	0.77	11.59	4.70	1.77	0.62	10.62	< 0.001**
RT MRL	6.02	0.66	4.00	7.30	5.58	0.68	4.00	6.80	< 0.001**
LT MRL	5.86	0.78	3.30	7.40	5.69	0.88	3.30	6.70	0.026*

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Unpaired t-test
SD = Standard deviation, Min = Minimum and Max = Maximum.
*P value < 0.05 is significant, **P value < 0.001 is highly significant.
RT = Right, LT = Left, OH = Orbital height, BZB = Bizygomatic breadth, CF = Canine fossa, MS = Maxillary sinus, H = Height, W = Width, L = Length, VL = Volume and MRL = Mandibular ramus length.

Table 4. Area under curve analysis for detection of males from craniofacial measurements

	Area Under the Curve	P value	95% Confidence Interval		Cut-off	Sensitivity %	Specificity %
			Lower Bound	Upper Bound			
BIM	0.664	< 0.001**	0.600	0.728	10.17	53.4	76.6
LCB	0.626	< 0.001**	0.560	0.693	12.29	58.1	57
APD of RT FS	0.629	< 0.001**	0.568	0.699	0.72	47.3	68
APD of LT FS	0.637	< 0.001**	0.583	0.713	0.79	60.9	66.4
BZB	0.736	< 0.001**	0.678	0.795	12.75	52	85.9
RT MS H	0.666	< 0.001**	0.602	0.731	3.36	54.7	82
LT MS H	0.617	0.001*	0.551	0.683	3.39	56.8	64.1
RT MS L	0.589	0.009*	0.523	0.656	3.47	48	67.2
LT MS L	0.628	< 0.001**	0.561	0.694	3.43	60.8	56.3
RT MS VL	0.606	0.002*	0.539	0.672	5.29	52.7	57
LT MS VL	0.595	0.005*	0.528	0.661	5.31	52	61.7
RT MRL	0.715	< 0.001**	0.652	0.774	5.77	81.8	53.9

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*P value < 0.05 is significant, **P value < 0.001 is highly significant.
RT = Right, LT = Left, BIM = Bimastoid breadth, LCB = Length of the cranial base, FS = Frontal sinus, APD = Anteroposterior diameter, BZB = Bizygomatic breadth, MS = Maxillary sinus, H = Height, L = Length, VL = Volume and MRL = Mandibular ramus length.

Table 5. Canonical discriminant function coefficients for estimation of sex from craniofacial measurements

	Function	P value
BIM	0.607	< 0.001**
LCB	0.369	< 0.001**
AWT of FS	-1.343	< 0.001**
APD of RT FS	1.409	< 0.001**
BZB	0.398	< 0.001**
Depth of RT CF	-0.503	< 0.001**
RT MS H	0.479	< 0.001**
RT MRL	1.980	< 0.001**
LT MRL	-1.087	< 0.001**
(Constant)	-21.462	< 0.001**

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Unstandardized coefficients
**P value < 0.001 is highly significant.
RT = Right, LT = Left, BIM = Bimastoid breadth, LCB = Length of the cranial base, AWT = Anterior wall thickness, APD = Anteroposterior diameter, FS = Frontal sinus, BZB = Bizygomatic breadth, CF = Canine fossa, MS = Maxillary sinus, H = Height and MRL= Mandibular ramus length.

showed that 78.2% of males and 76.8% of females in the cross-validated grouped cases were correctly classified.

Discussion

Many standards can be used for craniofacial identification and analysis. These standards originate from a variety of sources, such as maxillofacial, orthodontic, surgical, anthropological, anatomical, and forensic literature. With advancements in clinical imaging and technology, various techniques for data collection, including computed tomography, are now available. Practitioners struggle to determine the most suitable craniofacial standards and understand their reliability [40].

For cranial measurements, our study's results showed a highly statistically significant difference between sex groups regarding BIM, LCB, and APD of RT and LT FS (P value < 0.001). However, the AWT of FS did not significantly differ between sex groups.

Our results concurred with those of Cekdemir et al. (2021) [8] and Okumus (2022) [29], who demonstrated that BIM is associated with sexual dimorphism. Chin et al. (2014) [41] noted that LCB was significantly different between males and females. Abdel-Fattah et al. (2020) [42] reported that the frontal sinus dimensions were significantly different between sexes.

However, Ominde & Igbigbi (2021) [43] demonstrated that the AWT of FS was thicker in males than in females. This is because structures such as the anterior wall thickness and the anteroposterior wall of the frontal sinus are thinner and are susceptible to measurement bias [42].

For facial measurements, the results of our study showed a highly statistically significant difference between sex groups regarding BZB, RT MS H, LT MS L, RT and LT MS VL, and RT MRL, with P values (< 0.001). In contrast, a significant difference between sex groups was found regarding RT OH, LT MS H, RT MS L, and LT MRL with P values (< 0.05). However, no significant difference was found between sex groups regarding LT OH, depth of RT, LT CF, or RT or LT MSW.

Our findings concurred with those of Cekdemir et al. (2021) [8] and Caton & Dixson (2022) [44], who demonstrated that BZB exhibits sexual dimorphism.

Supporting our results, previous studies in various populations have reported significant sexual dimorphism in orbital measurements [45, 46, 47]. In contrast, Patra et al. (2021) [48] noted no significant differences between sex groups regarding orbital dimensions. The morphometric analysis of MS can be used as a reliable tool in sex estimation [14, 49, 50, 51, 52]. MRL is valuable in sex estimation [53, 54, 55]. However, De Oliveira et al. (2015) [56] reported that MRL was not effective in discriminating sex.

The discrepancy in values between males and females is justified by the fact that significant cranial changes in males are linked to increased muscle mass after puberty. In contrast, the female cranium retains some juvenile features [57].

The AUC analysis detected males from cranial measurements, where the most sensitive measurement was APD of LT FS (60.9%), followed by LCB (58.1%), BIM (53.4%), and finally APD of RT FS (47.3%), and from facial measurements, where the most sensitive measurement was RT MRL (81.8%), followed by LT MS L (60.8%), LT MS H (56.8%), RT MS H (54.7%), RT MS VL (52.7%), BZB and LT MS VL (52%), and finally RT MS L (48%).

Using discriminant function analysis, the most sensitive craniofacial measurements used to estimate sex were BIM, LCB, AWT of FS, APD of RT FS, BZB, depth of RT CF, RT MS H, and RT and LT MRL. The accuracy of the sex estimation model, based on measured craniofacial measurements, was calculated, and 80.6% of males and 78.9% of females in the original grouped cases were correctly classified according to the discriminant score.

Madadin et al. (2015) [58] reported that BIM was the most reliable indicator for sex with an accuracy of 69.4%. Given that any muscle attachment grows more quickly and prominently in males than in females, the variation in the growth of the mastoid process may account for the size difference between males and

Table 6. Accuracy of the discriminant function analysis model in classification into males and females evaluated at group means

Classification of Results					
		Sex	Predicted Group Membership: Male	Predicted Group Membership: Female	Total
Original	Count	Male	133	32	165
		Female	29	109	138
	%	Male	80.6	19.4	100.0
		Female	21.1	78.9	100.0
Cross-validated	Count	Male	129	36	165
		Female	32	106	138
	%	Male	78.2	21.8	100.0
		Female	23.2	76.8	100.0

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females.

According to Cekdemir et al. (2021) [8], the variables with the highest sensitivity were BZB (80.9%) and LCB (85.3%). The double combined use of LCB and BZB produced the highest discriminative potential (93.6%), whereas LCB, BZB, and BIM produced the most favorable results of triple combined use (94.2%).

In Sathawane et al. (2020) [59] and Deshpande et al. (2022) [60] studies, MS H was the best variable for sex prediction. Ravali (2017) [61] and Patel et al. (2020) [62] reported that the LT MS W was the most sensitive measurement for detecting males. However, a study reported that the MS dimensions had low discriminative power (18%) for sex prediction and were therefore not validated in the studied Egyptian population [63].

A study conducted on the mandibular ramus to estimate sex reported that the MRL showed high sensitivity (77.6%) [64].

Geographical diversity or ethnic population differences may be the cause of variations in sex estimation accuracy rates and differences in the most effective sex-discriminating variables [65].

The employment of various sample sizes, inclusion criteria, measurement techniques, software, and imaging methods, or analyses could account for the variations between the studies. Moreover, disparities may arise due to several factors, particularly variations in group ancestry, including environmental factors, stature, body build, skeleton size, pneumatization process of sinuses in different age and sex groups, and the presence of teeth [66]. Significant population variation in sexual dimorphism has been documented. This variation illustrates that both genetic and environmental factors impact methods used for estimating sex from human skeletal remains. [67]. Sex variations prevail in human anthropometry, ranging from the chromosomal components that determine phenotypic expression to the apparent variations in anatomical structure [68].

A comparative study conducted on sex estimates in adult skulls using direct measurement and tomographic image reconstruction found no significant differences between the two methods. However, the direct measurement of dry skulls demonstrated higher accuracy than the tomographic analysis. These findings support the use of three-dimensional CT imaging as a reliable sex estimation method that may facilitate human identification without physically handling cadavers or skulls [69].

In anthropological research, CT scans are used to replace antiquated population-specific skeletal collections or to overcome the cultural, religious, legal, ethical, and practical challenges associated with assembling contemporary representative skeletal collections. CT imaging represents a practical, reproducible, and accurate method for morphometric studies due to its high contrast resolution and clear visualization of bony anatomy [70]. Furthermore, a virtual skeletal database eliminates the need for physical storage space and labor-intensive, time-consuming skeletal processing methods [71].

Conclusion

In the present study, a healthy population comprising both sexes were selected. A set of craniofacial measurements was applied to the CT images of the Egyptian population for sex estimation. The following conclusions can be drawn from the results:

- Most of the craniofacial measurements were greater in males than in females. Craniofacial measurements can be used as a reliable method for sex estimation.
- A highly statistically significant difference between sex groups was found for BIM, LCB, APD of RT and LT FS, BZB, RT MS H, LT MS L, RT and LT MS VL, and RT MRL.
- The most sensitive measurement for detecting males from cranial measurements was APD of LT FS (the sensitivity was 60.9%, and the specificity was 66.4%).
- The most sensitive measurement to detect males from facial measurements was RT MRL (the sensitivity was 81.8%, and the specificity was 53.9%).

A discriminant score was calculated to estimate sex from craniofacial measurements, and 80.6% of males and 78.9% of females in the original grouped cases were correctly classified.

Recommendations

The current study provides a successful estimation of sex depending on the normal values of the craniofacial measurements. Thus, paving the way for the following recommendations:

- Applications of morphometric analysis of three-dimensional digitally configured computed tomography images of the craniofacial profile:

- **Medico-legal:**

- Presumptive identification in civil and criminal cases.

- Differentiation and studying the variance between ethnic groups.

- Disaster victim identification (DVI).

- **Clinical:** Planning aesthetic surgeries and procedures, orthodontic treatment, and diagnostic radiology, including cases of hormonal and metabolic disturbances.

- **Industrial:** Designing glasses, face masks, headgear, and helmets.

    - Establishing a major national database for craniofacial measurements for documentation.

    - Searching for the applicability of comparing real anthropometric measurements and CT measurements for a better outcome.

Morphometric standards determined for sex differences should be studied to detect variations related to different populations. Therefore, there is a need for multicentric studies.

Ethical Considerations

This study was conducted in accordance with the principles outlined in the Declaration of Helsinki. The study protocol was approved by the Ethical Committee of the Department of Forensic Medicine and Clinical Toxicology and the Research Ethics Committee of Kasr Alainy (Code: MD-396-2022), Faculty of Medicine, Cairo University.

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Conflicts of Interest

The authors declared no conflict of interest.

References

[1] Chiba F, Inokuchi G, Hoshioka Y, Sakuma A. Age estimation by evaluation of osteophytes in thoracic and lumbar vertebrae using postmortem CT images in a modern Japanese population. Int J Legal Med. 2022;136(1):261–7. [DOI: 10.1007/s00414-021-02714-9]

[2] Rösing FW, Graw M, Marré B, Ritz-Timme S, Rothschild MA, Rötzscher K, Schmeling A, Schröder I, Geserick G. Recommendations for the forensic diagnosis of sex and age from skeletons. Homo. 2007;58:75–89. [DOI: 10.1016/j.jchb.2005.07.002]

[3] Nagaoka T, Shizushima A, Sawada J, Tomo S, Hoshino K, Sato H, Hirata K. Sex determination using mastoid process measurements: standards for Japanese human skeletons of the medieval and early modern periods. Anthropol Sci. 2008;116:105–13. [DOI: 10.1537/ase.070605]

[4] Walrath DE, Turner P, Bruzek J. Reliability test of the visual assessment of cranial traits for sex determination. Am J Phys Anthropol. 2004;125:132–137. [DOI: 10.1002/ajpa.10373]

[5] Eltatawy DN, Elsharawy FA, Elbarbary AA, Elsheikh RG, Badawy ME. Multi-detector computed tomography as a diagnostic tool in assessment of thoracic aortic anomalies in pediatric patients. Egypt J Radiol Nucl Med. 2021;52(1):39. [DOI: 10.1186/s43055-020-00399-5]

[6] Peyrin F, Engelke K. CT imaging: basics and new trends. In: Fleck I, Titov M, Grupen C, Buvat I, editors. Handbook of Particle Detection and Imaging. 2nd ed. Cham: Springer; 2021. p.1173–215. [DOI: 10.1007/978-3-319-93785-4_36]

[7] Shivdeo A, Lokwani R, Kulkarni V, Kharat A, Pant A. Comparative evaluation of 3D and 2D deep learning techniques for semantic segmentation in CT scans. Electr Eng Syst Sci. 2021:1–9. [DOI: 10.48550/arXiv.2101.07612]

[8] Cekdemir YE, Mutlu U, Karaman G, Balci A. Estimation of sex using morphometric measurements performed on cranial computerized tomography scans. La Radiol Med. 2021;126(2):306–15. [DOI: 10.1007/s11547-020-01233-8]

[9] Ramsthaler F, Kettner M, Gehl A, Verhoff MA. Digital forensic osteology: morphological sexing of skeletal remains using volume-rendered cranial CT scans. Forensic Sci Int. 2010;195:148–52. [DOI: 10.1016/j.forsciint.2009.12.010]

[10] Spradley MK, Jantz RL. Sex estimation in forensic anthropology: skull versus postcranial elements. J Forensic Sci. 2011;56(2):289–96. [DOI:

10.1111/j.1556-4029.2010.01635.x]

[11] Klales AR. Practitioner preferences for sex estimation from human skeletal remains. In: Sex estimation of the human skeleton: history, methods, and emerging techniques. 1st ed. Academic Press; 2020. p.11–23. [DOI: 10.1016/C2017-0-03550-4]

[12] Fekonja A, Čretnik A. Gender and age differences in mandibular ramus and body measurements: a radiographic study. J Hard Tissue Biol. 2022;31(1):9–14. [DOI: 10.2485/jhtb.31.9]

[13] Abdalla MA. Maxillary sinus dimensions of different human age groups by CT scan imaging. Modern Med. 2021;28(2):235–41. [DOI: 10.31689/rmm.2021.28.2.235]

[14] Tanaka LE, Franco A, Abib RF, Manhães-Junior LRC, de Castro Lopes SLP. Age- and sex-related changes of the volume of maxillary sinuses quantified via cone beam computed tomography. Res Soc Dev. 2021;10(14):115–26. [DOI: 10.33448/rsd-v10i14.22220]

[15] Kenawy S, Ellabban M, Fadel A. A novel frontal sinus index protocol for gender determination: a retrospective lateral cephalometric study for Egyptians. Egypt Dent J. 2021;67(3):2199–204. [DOI: 10.21608/edj.2021.76583.1639]

[16] Franklin D, Cardini A, Flavel A, Kuliukas A. Estimation of sex from cranial measurements in a Western Australian population. Forensic Sci Int. 2013;229(1–3):158.e1–8. [DOI: 10.1016/j.forsciint.2013.03.005]

[17] Rooppakhun S, Surasith P, Vatanapatimakul N, Kaewprom Y, Sitthiseripratip K. Craniometric study of Thai skull based on three-dimensional computed tomography data. J Med Assoc Thai. 2010;93(1):90–8. [Link]

[18] Tambawala SS, Karjodkar FR, Sansare K, Prakash N. Sexual dimorphism of maxillary sinus using cone beam computed tomography. Egypt J Forensic Sci. 2016;6(2):120–5. [DOI: 10.1016/j.ejfs.2015.08.002]

[19] Tunis TS, Sarig R, Cohen H, Medlej B, Peled N, May H. Sex estimation using computed tomography of the mandible. Int J Legal Med. 2017;131(6):1691–1700. [DOI: 10.1007/s00414-017-1554-1]

[20] Adel R, Ahmed HM, Hassan OA, Abdelgawad EA. Assessment of craniometric sexual dimorphism using multidetector computed tomographic imaging in a sample of Egyptian population. Am J Forensic Med Pathol. 2019;40(1):19–26. [DOI: 10.1097/PAF.0000000000000439]

[21] Toneva DH, Nikolova SY, Zlatareva DK, Hadjidekov VG, Lazarov NE. Sex estimation by mastoid triangle using 3D models. Homo. 2019;70(1):63–73. [DOI: 10.1127/homo/2019/1010]

[22] Del Águila MR, González-Ramírez AR. Sample size calculation. Allergol Immunopathol. 2014;42(5):485–92. [DOI: 10.1016/j.aller.2013.03.008]

[23] Parmar HA, Ibrahim M, Mukherji SK. Optimizing craniofacial CT technique. Neuroimaging Clin N Am. 2014;24(3):395–405. [DOI: 10.1016/j.nic.2014.03.004]

[24] Islam SM, Goonewardene MS, Farella M. A review on three-dimensional facial averaging for the assessment of orthodontic disorders. Innov Adv Comput Informat Syst Sci Eng. 2015;313(1):391–7. [DOI: 10.1007/978-3-319-06773-5_53]

[25] Asif MK, Nambiar P, Khan IM, Aziz ZABCA, Noor NSBM, Shanmuhasuntharam P, Ibrahim N. Enhancing the three-dimensional visualization of a foreign object using Mimics software. Radiol Case Rep. 2019;14(12):1545–9. [DOI: 10.1016/j.radcr.2019.10.001]

[26] Kaur R, Juneja M. A hybrid approach for enhancement of abdominal CT images. Comput Electr Eng. 2022;102(1):108291. [DOI: 10.1016/j.compeleceng.2022.108291]

[27] Absalan F, Moghadam ARE, Rezaian J. Morphometric cranial standards for sex estimation of a population in two ethnic groups in southwest Iran. Transl Res Anat. 2023;31(1):100249. [DOI: 10.1016/j.tria.2023.100249]

[28] Battan SK, Sharma M, Gakhar G, Garg M, Singh P, Jasuja OP. Cranio-facial bones evaluation based on clinical CT data for sex determination in northwest Indian population. Leg Med. 2023;64:102292. [DOI: 10.1016/j.legalmed.2023.102292]

[29] Okumus O. Determination of age and sex using bimastoid diameter: a cone beam computed tomography study. Odovtos Int J Dent Sci. 2022;24(2):157–63. [DOI: 10.15517/ijds.2022.48365]

[30] Venkatesh G, Gugapriya TS, Vinay Kumar N, Arun Kumar A, Deulkar S. Radio-anatomical observation of volume, anterior wall thickness and pneumatization pattern of frontal sinus. Panacea J

Med Sci. 2024;14(2):506–11. [DOI: 10.18231/j.pjms.2024.092]

[31] Mukhopadhyay S, Galui S, Biswas R, Saha S, Sarkar S. Oral and maxillofacial injuries in children: a retrospective study. J Korean Assoc Oral Maxillofac Surg. 2020;46(3):183–90. [DOI: 10.5125/jkaoms.2020.46.3.183]

[32] Appelt S, Kramer B, Hutchinson EF. Neurovascular territories of the canine fossa: analysis of a South African population. Morphologie. 2023;107(356):22–7. [DOI: 10.1016/j.morpho.2022.02.001]

[33] González-Colmenares G, Sanabria Medina C, Rojas-Sánchez MP, León K, Malpud A. Sex estimation from skull base radiographs in a contemporary Colombian population. J Forensic Leg Med. 2019;2(1):77–81. [DOI: 10.1016/j.jflm.2019.01.006]

[34] Ulcay T, Kamaşak B. Evaluation of craniometric measurements in human skulls. J Health Sci Med. 2021;4(1):38–44. [DOI: 10.32322/jhsm.804341]

[35] Karmarkar PH, Mhapuskar A, Prasad Hiremutt DR, Kale IP, Tepan M, Rao P. Mandibular ramus: an indicator for gender determination. Cureus. 2023;15(1):e34192. [DOI: 10.7759/cureus.34192]

[36] Chan YH. Biostatistics 102: quantitative data – parametric & non-parametric tests. Singapore Med J. 2003;44(8):391–6. [Link]

[37] Chan YH. Biostatistics 104: correlational analysis. Singapore Med J. 2003;44(12):614–9. [Link]

[38] Chan YH. Biostatistics 303: discriminant analysis. Singapore Med J. 2005;46(2):54–62. [Link]

[39] Liljequist D, Elfving B, Skavberg Roaldsen K. Intraclass correlation – a discussion and demonstration of basic features. PLoS One. 2019;14(7):e0219854. [DOI: 10.1371/journal.pone.0219854]

[40] Wilkinson C, Liu CYJ, Shrimpton S, Greenway E. Craniofacial identification standards: a review of reliability, reproducibility, and implementation. Forensic Sci Int. 2024;359(1):379–99. [DOI: 10.1016/j.forsciint.2024.111993]

[41] Chin A, Perry S, Liao C, Yang Y. The relationship between the cranial base and jaw base in a Chinese population. Head Face Med. 2014;10(1):31. [DOI: 10.1186/1746-160X-10-31]

[42] Abdel-Fattah H, Gamal HM, Hadeel S, Reda A. Frontal sinus variations and prevalence of frontal recess cells among adult Egyptians: computerized tomography study. Med J Cairo Univ. 2020;88(6):1143–56. [DOI: 10.21608/mjcu.2020.110851]

[43] Ominde B, Igbigbi P. Frontal sinus dimensions: an aid in gender determination in adult Nigerians. Int J Forensic Odontol. 2021;6(1). [Link]

[44] Caton NR, Dixson BJW. Beyond facial width-to-height ratios: bizygomatic width is highly sexually dimorphic when adjusting for allometry. Biol Lett. 2022;18(10):211. [DOI: 10.1098/rsbl.2022.0211]

[45] Ominde BS, Iju W, Igbigbi PS. Retrospective CT study on orbital dimensions and their role in sex determination. Acta Sci Anat. 2022;1(4):2–12. [Link]

[46] Chakraborty P, Bhattacharya A, Ghosh A, Bhattacharya A, Ghosal AK. Morphometric study of different orbital dimensions in dry skull in eastern India – a cross-sectional study. J Anat Radiol Surg. 2023;12(2):AO09. [DOI: 10.7860/JCDR/2023/55329/2878]

[47] Packirisamy V, Aljarrah K, Nayak SB. Morphometric evaluation of the orbital region for sex determination in a Saudi Arabian population using 3DCT images. Anat Sci Int. 2024;99(1):118–26. [DOI: 10.1007/s12565-023-00742-6]

[48] Patra A, Singla RK, Mathur M, Chaudhary P, Singal A, Asghar A, Malhotra V. Morphological and morphometric analysis of the orbital aperture and their correlation with age and gender: a retrospective digital radiographic study. Cureus. 2021;13(9):e17739. [DOI: 10.7759/cureus.17739]

[49] Leao de Queiroz C, Terada AS, Dezem TU, Gomes de Araújo L, Galo R, Oliveira-Santos C, Alves da Silva RH. Sex determination of adult human maxillary sinuses on panoramic radiographs. Acta Stomatol Croat. 2016;50(3):215–21. [DOI: 10.15644/asc50/3/3]

[50] Khaitan T, Kabiraj A, Ginjupally U, Jain R. Cephalometric analysis for gender determination using maxillary sinus index: a novel dimension in personal identification. Int J Dent. 2017;2017(1):211–20. [DOI: 10.1155/2017/7026796]

[51] Abate A, Cavagnetto D, Lanteri V, Maspero C.

Three-dimensional evaluation of the maxillary sinus in patients with different skeletal classes and cranio-maxillary relationships assessed with cone beam computed tomography. Sci Rep. 2023;13(1):2098. [DOI: 10.1038/s41598-023-29391-5]

[52] Aşantoğrol F, Coşgunarslan A. The effect of anatomical variations of the sinonasal region on maxillary sinus volume and dimensions: a three-dimensional study. Braz J Otorhinolaryngol. 2022;88(1):118–27. [DOI: 10.1016/j.bjorl.2021.05.001]

[53] Vinay G, Mangala Gowri SR, Anbalagan J. Sex determination of human mandible using metrical parameters. J Clin Diagn Res. 2013;7(12):2671–3. [DOI: 10.7860/JCDR/2013/7621.3728]

[54] Motawei SM, Helaly AMN, Aboelmaaty WM, Elmahdy K, Shabka OA, Liu H. Length of the ramus of the mandible as an indicator of chronological age and sex: a study in a group of Egyptians. Forensic Sci Int Rep. 2020;2(3):100066. [DOI: 10.1016/j.fsir.2020.100066]

[55] Ingaleshwar P, Bhosale S, Nimbulkar G, Britto F, Chandrappa PR, Hosur MB. Mandibular ramus: an indicator for gender determination – a digital panoramic study in Bagalkot population. J Oral Maxillofac Pathol. 2023;27(1):66–70. [DOI: 10.4103/jomfp.jomfp_62_22]

[56] De Oliveira FT, Soares MQS, Sarmento VA, Rubira CM, Lauris JR, Rubira-Bullen IR. Mandibular ramus length as an indicator of chronological age and sex. Int J Legal Med. 2015;129(1):195–201. [DOI: 10.1007/s00414-014-1077-y]

[57] Buran F, Can I, Ekizoğlu O, Balcı A, Guleryuz H. Estimation of age and sex from bimastoid breadth with 3D computed tomography. Rom J Legal Med. 2018;26(1):56–61. [DOI: 10.4323/rjlm.2018.56]

[58] Madadin M, Menezes RG, Al Dhafeeri O, Kharoshah MA, Al Ibrahim R, Nagesh KR, Ramadan SU. Evaluation of the mastoid triangle for determining sexual dimorphism: a Saudi population-based study. Forensic Sci Int. 2015;254:244.e1–4. [DOI: 10.1016/j.forsciint.2015.06.019]

[59] Sathawane RS, Sukhadeve VA, Chandak RM, Lanjekar AB, Moon GV. Sex determination by maxillary sinus dimensions using cone-beam computed tomography and discriminant function: an analytical study. Int J Forensic Odontol. 2020;5(1):19–22. [DOI: 10.48165/jiafm.2023.45.1.15]

[60] Deshpande AA, Munde AD, Mishra SS, Kawsankar KD, Sawade RV, Mandar B. Determination of sexual dimorphism of maxillary sinus using cone-beam computed tomography in a rural population of western Maharashtra – a retrospective, cross-sectional study. J Family Med Prim Care. 2022;11(4):1257–61. [DOI: 10.4103/jfmpc.jfmpc_389_21]

[61] Ravali CT. Gender determination of maxillary sinus using CBCT. Int J Appl Dent Sci. 2017;3(4):221–4. [DOI: 10.22502/jlmc.v8i2.382]

[62] Patel UP, Makardar UK, Layeeqeu KM, Balkund K. Identification of sex from maxillary sinus in western Maharashtra population. Indian J Forensic Med Toxicol. 2020;14(4):607–11. [DOI: 10.37506/ijfmt.v14i4.11552]

[63] Hadhoud RM, Abdelhakim E. Validity of computed tomography maxillary sinuses dimensions measuring in sex determination in Egyptian sample. Ain Shams J Forensic Med Clin Toxicol. 2022;38(1):87–91. [DOI: 10.21608/ajfm.2022.213901]

[64] Verma P, Mahajan P, Puri A, Kaur S, Mehta S. Gender determination by morphometric analysis of mandibular ramus in Sriganganagar population: a digital panoramic study. Indian J Dent Res. 2020;31(3):444–448. [DOI: 10.4103/ijdr.ijdr_547_17]

[65] Fatima M, Rashid B, Murtaza G. Diagnostic accuracy of computed tomography-based anthropometric measurements of maxillary sinuses in sex determination in Pakistani population. Ann Jinnah Sindh Med Univ. 2023;7(2):3–7. [DOI: 10.46663/ajsmu.v7i1.3-7]

[66] Kilroy GS, Tallman SD, DiGangi EA. Secular change in morphological cranial and mandibular trait frequencies in European Americans born 1824–1987. Am J Phys Anthropol. 2020;173(3):589–605. [DOI: 10.1002/ajpa.24115]

[67] Ubelaker D, DeGaglia C. Population variation in skeletal sexual dimorphism. Forensic Sci Int. 2017;278:407.e1–7. [DOI: 10.1016/j.forsciint.2017.06.012]

[68] Mahmoud HS, Ahmed GS, Zidan A, Eid A. Evaluation of maxillary sinus dimensions in sex and age determination among a sample of Egyptians using computed tomography. Egypt J Forensic Sci Appl Toxicol. 2022;22(3):17–25. [DOI: 10.21608/ejfsat.2022.85911.1209]

[69] Rosa OE, Crosato EM, Castro CC, Oliveira RE, Biazevic MGH. Comparative study of sex estimates in adult skulls using direct measurement and tomographic image reconstruction. Braz Oral Res. 2023;37:e064. [DOI: 10.1590/1807-3107bor-2023.vol37.0064]

[70] Attia MH, Farghaly YT, Abulnoor BAE, Curate F. Performance of supervised learning algorithms in sex estimation of the proximal femur: a comparative study in contemporary Egyptian and Turkish samples. Sci Justice. 2022;62(3):288–309. [DOI: 10.1016/j.scijus.2022.03.003]

[71] Colman KL, Dobbe JGG, Stull KE, Ruijter JM, Oostra RJ, van Rijn RR, van der Merwe AE, de Boer HH, Streekstra GJ. The geometrical precision of virtual bone models derived from clinical computed tomography data for forensic anthropology. Int J Legal Med. 2017;131(4):1155–63. [DOI: 10.1007/s00414-017-1548-z]