

Osteometric Assessment of the Mastoids for Gender Determination in Jordanians by Discriminant Function Analysis

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Abstract The purpose of this study was, firstly, to characterize the mastoid process in terms of its size, its surface area, its flare and its medial convergence angle on a sample of Jordanian subjects; and secondly, to assess the validity of the mastoid process in determining the gender of the study subjects. The sample of the study comprised 192 3D skull images with known sex, 96 each male and female, those were obtained by rendering DICOM images from cone-beam computerized tomography of the subjects. Radiographic measurements, using customized software, accurately characterized the subjects' mastoids. Discriminant function analysis revealed that mastoid process correctly classified the sex in 90.6 percent of the subjects and the intermastoidale distance was found to be the best determinant for sex. A discriminant function equation specific for young and middle age Jordanians has been derived from the mastoid variables.

Keywords: mastoid process, discriminant function, mastoid flare, mastoid medial convergence, surface rendering, cone beam CT, 3D skull image, Solid Planner software

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1. Introduction

Subsequent to drastic events such as natural disasters, outbreak of wars or air traffic accidents, positive identification of victims' gender becomes, perhaps, the most difficult task to encounter. [1] Extreme burns; disfigurement, and severe decomposition of bodies render the determination of gender by examination of remains and their radiographs extremely difficult, if not impossible. A major role in gender identification, however, could be played by the osteological criteria that may set the foundation for full identification [2,3].

Human skeleton is comprised of calcified hard tissue that may sustain severe conditions yet retain important features that may lead to valuable information. The dimorphic variations of gender develop during the intrauterine life and later manifest as differences in bone weight, length, size, and mineral density. There are certain factors such as the role of growth bouts and their pattern, and the attachments of muscles to bones could play a significant role in dimorphic features and have a direct bearing on gender differentiation. [4] Skeletal gender identification relies on dimorphic expression of bony characteristics produced through different patterns, rates

and period of adolescent growth. [5] Males having both a longer and more intense growth bouts than females, therefore this extended growth pattern creates difference in size, classically seen in skull, where the growth spurts affect most structures [6].

The secondary sexual changes are influenced by hormones, which play role in development of musculoskeletal system. [7] These changes emerge at adolescence are seen earlier and for a shorter period in girls compared to boys who undergo pubertal changes 2-3 years later, but sustain them for a longer period. Various bones are used as tools in sexual dimorphism, most commonly pelvis and skull. [8] Development of cranium is influenced by growth of neurocranium. Cranial characteristics such as larger male brow ridges, eyes appearing lower in the face, and larger nasal apparatus, are results of extended normal downward and forward growth of the male face relative to the female face. This is due to more intense and extended male growth spurts. The growth of female facial features begins to slow around 13th years of life and maturation is completed soon afterward, while males enter a growth bout that continues through adolescence with maturation completed in early adulthood [9].

In addition to the morphological traits presented by various bones of the craniofacial structures, morphometric

measurement methods employing linear, proportional and/or angular dimensions have been used for gender identification. It has been reported that morphological characters such as mastoid processes, among others give valuable idea of gender. [4,5] Employing supraorbital margin, glabella, mastoid process, crista supramastoid and mandible in sexual dimorphism, Graw et. al., in 1999 [10] and Graw in 2001 [11] reported reliable results related to sex reached 70-91% accuracy. Williams and Rogers in 2006 [12] assessed mastoid size in addition to some other cranial structures, for sex determination, and considered these morphological features as high-quality gender identifiers. Kranioti et. al., in 2008 [13] carried out osteometric measurements on cranio-facial skeletons including mastoid height of 90 males and 88 females. Their results indicated that males were statistically significantly greater than females in all dimensions. Other researchers among them Pavia and Segre in 2003 [14], Patil and Modi in 2005 [15] evaluated the role of mastoid process, in addition to some other parameters, as sexual dimorphism feature; the results of those studies indicated that mastoids were found most reliable gender identifiers, yielding a very high level of accuracy.

2. The Present Study

The objective of this study is twofold, the first to characterize the mastoid process of the temporal bone in terms of its size (length, width, height), its surface area, and its medial convergence angle measured on volumetric images of skulls reconstructed by using a purpose-made software which rendered "Digital Imaging and Communications in Medicine" (DICOM) images obtained from cone-beam computed tomography (CBCT) of the study subjects. The second objective is to assess the reliability of the mastoid's morphometric parameters in determining the gender of the study subjects with the aid of the discriminant function analysis.

3. Materials and Methods

The investigated sample comprised 192 cone-beam computed tomography (CBCT) images of Jordanian adult patients whose age ranged between 17 and 78 years and their average age was 50.2 years. The study sample was equally divided between the two sexes, i. e., there were 96 CBCT images of either sex. The studied subjects were selected from a larger group of patients who were listed for implant-retained prostheses. The exclusion criteria involved images with gross artifacts and those that did not show anatomic details of the base or the lateral sides of the skull, particularly the mastoid.

Prior to conducting the investigation, and in compliance with the policy of the Clinical Research Authority at the Jordan University Hospital (JUH), signed written informed consents were obtained from all the subjects selected for the study. They were made aware that their CBCT images were included in this investigation as a part of the advanced graduate dental education programs. The experimental protocol was examined and approved by the Ethics Committee and was, therefore performed in accordance with the ethical standards laid down in 1964 Declaration of Helsinki (Edited in 2013) [16].

The CBCT images were acquired with a WhiteFox scanner (WhiteFox, de Götzen SrL ITALY) set at a current voltage of 105 Kv and 9.00 mA, the scan time was set at 9.0 seconds. The CT data were exported from the WhiteFox software (WhiteFox Control 3D-00022, version 2.11.1) in DICOM multi-file format and imported into a custom-made "SolidPlanner Pro" software version 3.2, (Solid Models Co., Amman Jordan) [17] on a Pavilion dv6 Laptop (HP USA) with a dedicated 1GB video card (Rad con HD 6750 AMD). All measurements were performed on the 3D surface models of the skulls on a 17-in, high resolution LCD Laptop color screen. The purpose-designed software (SolidPlanner) converted the DICOM images into 3D surface models of the scanned skulls using the marching cubes algorithm based on surface rendering. Bone surface of the skulls was extracted from the 2D CBCT images by extracting *iso* surfaces of Hounsfield values of 3000. The customized "SolidPlanner" software provided various views of the skull by rotating and translating the rendered image.

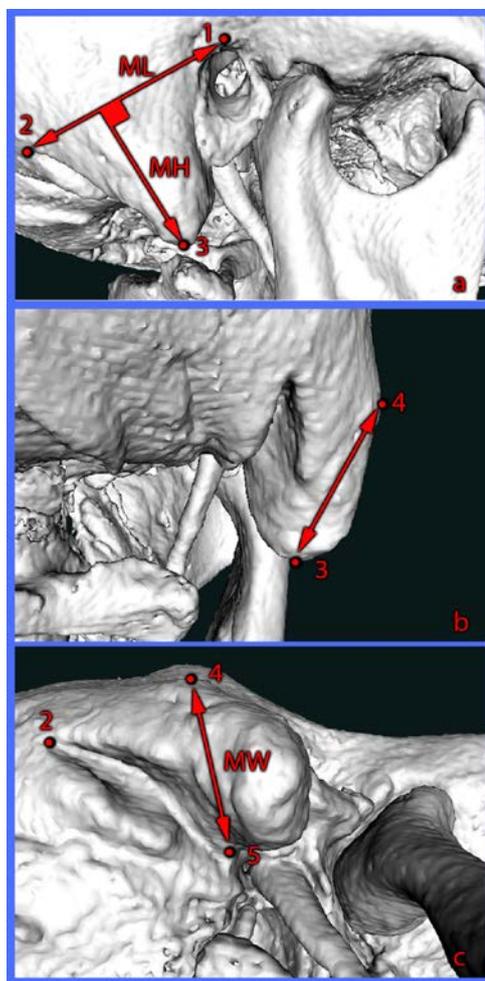


Figure 1. 3D skull images illustrating the employed anatomic landmarks: (a) a skull lateral view at the mastoid region showing the porion (1), the posterior end of incisura mastoidea (2), and the mastoidale (3); the view is also showing the line joining the two points 1 and 2, representing the mastoid length ML; and a perpendicular line from 3 on the 1-2 line, representing the mastoid height MH; (b) a postero-anterior view showing the most laterally prominent point on the convex lateral surface of the body of mastoid (4); the view is also showing the line joining points 4 and 3, the mastoidale; (c) a ventral view showing the highest point on the surface of the mastoid process within the digastric fossa (5); the view is also showing the line joining points 4 and 5 representing the mastoid width MW

Five anatomic landmarks were selected and digitized on the left and right sides of each 3D model of rendered CBCT skull image for the entire study sample. The selected landmarks on each surface were: (1) porion, (2) posterior end of incisura mastoidea, (3) mastoidale, (4) most prominent point on the convex lateral surface of the body of mastoid, (5) the highest point on the mastoid

surface within the digastric fossa (Figure 1 a, b, c). Accordingly, nine measurement targets were defined; eight of which were linear and measured to the nearest 0.01 mm using point-to-point mathematical equations; the ninth was an angular value measured to the nearest 0.1° angle and calculated by using triangulation equations (Table 1; Figure 1a, b, c; Figure 2).

Table 1. Description of the delineated distances for the craniometric measurements

Measurement	Abbreviation	Description
Mastoid height	MH	The height of the mastoid process measured from its tip, the mastoidale, and perpendicular to a line between porion (top of the external auditory meatus) and the posterior end of incisura mastoidea (the groove medial to the mastoid process from which the digastric muscle originates).
Mastoid length	ML	Antero-posterior diameter, the length of the mastoid process measured from porion to the posterior end of incisura mastoidea.
Mastoid width	MW	Medio-lateral diameter, the distance between the highest point on the surface of mastoid process within the digastric fossa to the most protruding point on its lateral surface.
Intermastoidale distance	IMD	Distance between right and left mastoidale, the lowest point on the tip of the mastoid process.
Intermastoid lateral surface distance	IMLSD	Distance between the most prominent point on the convex lateral surface of left and right mastoids.
Mastoid flare	MF	Average distance between the tip of mastoid and the most prominent point on its convex lateral surface.
Mastoid Medial Convergence Angle	MMCA	The angle formed between the line starting from the most laterally prominent point on the mastoid right surface, passing through the right mastoidale and a similar line on the left side.
Mastoid size	MS	Size of the mastoid process = $(MH * ML * MW) / 100$
Mastoid surface area	SA	Surface area of a cone = $\pi(ML/2) * MH$

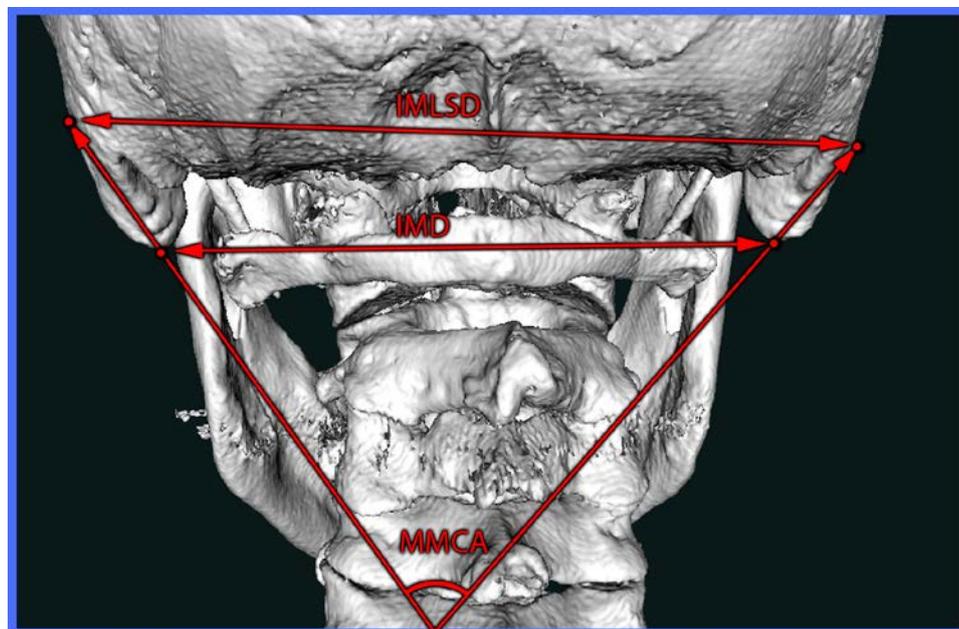


Figure 2. a view of the back of skull showing the intermastoid lateral surface distance (IMLSD), the intermastoidale distance (IMD), and the mastoid medial convergence angle (MMCA)

3.1. Osteometric Measurements of the Mastoids

The planned linear and angular measurements of the mastoids were carried out by three examiners, using high-resolution screen computers. Before starting measurements, the three examiners (D.O, D.S, and H.Th) were trained by the fourth examiner (W.A) in relation to landmarks

identification in order to eliminate inter-examiner and intra-examiner variations. The training exercise involved conducting series of tests in which the different examiners measured the same sample at the same time and each examiner measured the same sample at different times. The data sets of the training exercise and the examination results of the entire sample were statistically analyzed using the Statistical Package for the Social Sciences (SPSS) version 15..

3.2. Statistical Analyses

The inter-examiner variations among the three examiners were analyzed using one-way analysis of variance (ANOVA) and the intra-examiner variations for each observer were analyzed by using Student *t*-test. The accuracy of the rendering software was expressed by means of the absolute error (AE) and the absolute percentage error (APE):

$$\text{AE} = \frac{\text{the physical (Caliper) measurement value} - \text{CBCT measurement value}}{\text{the physical (Caliper) measurement value}}$$

The mastoid measurement data sets were statistically treated using canonical discriminant function analysis to specify a parameter or combination of parameters that best separate the two sexes. For this purpose, stepwise discriminant function analysis was used (utilizing the Wilks lambda method). A leave one out classification procedure was applied to demonstrate the accuracy of the analysis.

4. Results

4.1. Osteometric Measurements of the Mastoids

The calibration test results of the three examiners showed an excellent concordance among them indicated by the one-way ANOVA, which yielded an *f* value of 0.024.

The intra-examiner variation evaluation results, using Student *t* test, showed consistency of measurements that were carried out by the same observer at different times (*t* = 0.954).

The calculated mean male values of all variables were significantly larger than female measurements at 95% level of confidence except for the mastoid flare "MF"; the mastoid medial convergence angle "MMCA"; and the mastoid width "MW" (Table 2).

Table 2. Group statistics for mastoid measurements (n=192).

Measured variable	Male (N=96)		Female (N=96)		<i>t</i> -value	<i>p</i> -value
	Mean (mm)	Stdev	Mean (mm)	Stdev		
IMLSD	127.92	5.89	120.67	5.09	9.12	0.000
IMD	108.89	5.82	98.42	4.37	14.12	0.000
MF	19.09	5.03	22.24	3.35	5.10	0.000
MMCA	97.01	52.74	113.64	17.96	2.92	0.004
MS	114.48	55.78	89.16	63.55	2.93	0.004
SA	1085	406.13	737	278.93	6.92	0.000
ML	30.96	5.58	25.72	4.63	7.08	0.000
MW	15.97	2.77	17.91	7.93	2.26	0.024
MH	21.60	5.29	17.79	3.71	5.78	0.000

The best of the calculated functions was obtained by the inter-mastoidale distance "IMD" (Table 3) which showed the lowest Wilk's Lambda (0.49), the highest eigenvalue (1.05), the highest canonical correlation (0.72) and the highest classification accuracy (87.5%). The second best function was obtained by the inter-mastoids' lateral surface distance "IMLSD". Contrastingly, the function obtained by the mastoid width "MW" proved to be the least efficient and showed far less discriminative capacity.

This function included the highest Wilk's Lambda (0.97) of all the other functions, the lowest eigenvalue (0.03), the lowest canonical correlation (0.16) and one of the lowest classification accuracy (62%). A cross validation using leave-one-out approach was applied for checking how accurately the studied subjects were classified and allocated to the gender groups. Stepwise discriminant analysis selected four variables (IMD, MMCA, MS and ML) as the most significant contributors to gender discrimination.

Table 3. Showing the calculated discriminant functions of the investigated variables

Measured Variable	Wilk's Lambda	Eigenvalue	Canonical correlation	<i>F</i> -value	Significance	Classification Accuracy
IMLSD	0.695	0.438	0.552	83.24	0.000	78.6%
IMD	0.488	1.049	0.716	199.39	0.000	87.55%
MF	0.880	0.137	0.347	26.02	0.000	69.3%
MMCA	0.957	0.045	0.208	8.55	0.004	58.9%
MS	0.957	0.045	0.208	8.61	0.004	61.5%
SA	0.798	0.252	0.449	47.95	0.000	69.8%
ML	0.791	0.264	0.457	50.18	0.000	69.3%
MW	0.974	0.027	0.162	5.14	0.024	62.0%
MH	0.850	0.176	0.387	33.41	0.000	68.2%

The applied stepwise model revealed that the IMD was the best single predictor of gender with 87.5% prediction

accuracy. The contribution of the selected discriminant parameters to gender prediction is presented in Figure 3.

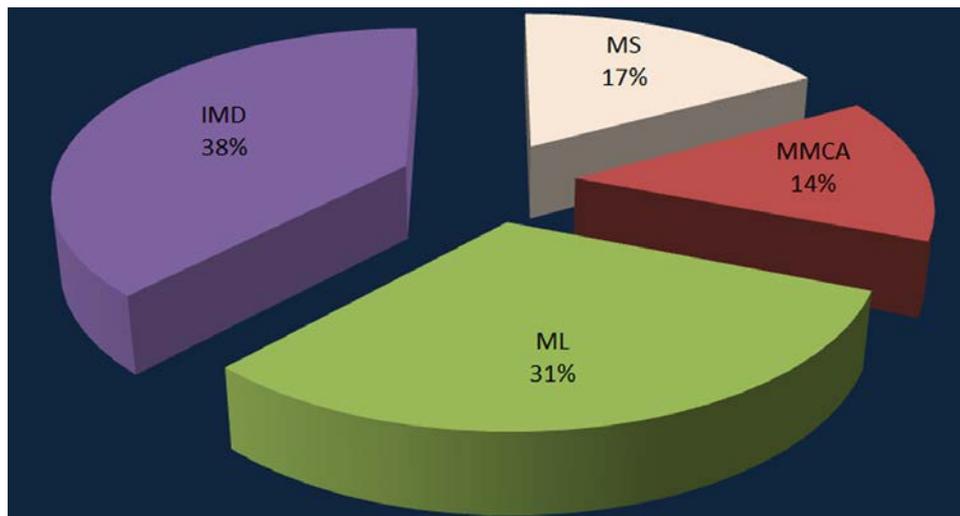


Figure 3. The absolute contribution fraction of the discriminant variables to gender determination

The discriminant function predictive equation derived from the coefficients of the four best predictors selected by the stepwise analysis is:

$$\text{DF} = 0.972 * \text{IMD} + 0.348 * \text{MMCA} \\ + (-0.430) * \text{MS} + 0.781 * \text{ML}$$

Where the group centroid discriminant score for males was 1.225 and for females -1.225 as indicated by the discriminant analysis, the sectioning point was equal to zero, i. e., the average of the male and female centroid discriminant scores, that is:

$$\text{Cut score} = \frac{1}{2} * [1.225 + (-1.225)] = 0.0$$

It follows, that any DF score equals to or above zero, the sectioning point, probably indicating a male subject, whereas scores below zero likely indicate female subjects.

5. Discussion

A general consensus exists among researchers in the fields of anatomy, physical anthropology, forensic medicine and related sciences on the role played by the mastoids in sex determination. The known fact that the mastoid process is most resistant to damage, due to its anatomic position at the base of skull has made the mastoids a focus of researchers interest and encouraged them considering this bone as an important morphometric trait in their studies of gender identification of human skeletal remains.

All previous studies that dealt with measurement of the mastoids for sex determination were conducted on dry skulls obtained from exhumed identified cadavers of known sex, age and color in which the osteometric linear measurements were carried out directly on the skull using calipers, or on a two-dimensional xerographic copy of the mastoid area of the skull. [9, 18-23]

In the present study, our investigation was conducted on 3D reconstructed skull models obtained from CBCT scanned images of 192 real patients (96 males and 96 females) for whom all linear and angular craniometric

measurements were carried out using a computer-guided program, a part of our customized 3D rendering software, the accuracy of its measurements is known to be submillimeter accurate. [17]

The results of this study were in general agreement with those of previous reports in emphasizing the suitability and validity of the mastoids for sex determination from skulls. Compared with most important studies, the accuracy of gender identification obtained in this investigation, 90.6% of 192 subjects, was comparable to some and more accurate than most of the past reports. In the year 2012 Gupta et. al.[24] found that 90% of the 70 skulls they screened for sex determination were correctly classified. The classification accuracy achieved in this investigation agreed with that reported by Gupta et. al. [14] and compared favorably to the 85% accuracy reported by Keen in 1950 [25], the 82% found by Giles and Elliot in 1963 [26], the 80% reported by Kajanoja in 1966 [27] and the 76.7% accuracy reported by Sumati et. al., in 2010. [21]

The present investigation's results highlighted the significant differences between males and females in all measurements of their mastoids. Whereby, the mean values of the mastoid size, its total surface area, its height, and its antero-posterior diameter were significantly more in males than in females. These results were consistent with the findings reported by Keen in 1950 [25]; Giles and Elliot in 1963 [26]; Sumati et. al., in 2010 [21]; who all concluded that females have smaller mastoids than males. Roger in 2005 [28] emphasized the value of mastoid size as highly quality trait in determining sex. Similar to the past reports' conclusion, our results also revealed significantly greater mean mastoid size values among males (114.5 mm³) than females (89 mm³) at $p= 0.004$. This finding could be attributed to the fact that female skulls preserve a juvenile type of small size mastoid process. Whereas, the larger size mastoid of males could be ascribed to the attachment of more vigorous musculature, such as the sternocleidomastoid muscle. This is confirmed by the relatively rougher and more irregular surface of the mastoid process observed in males than in females. Moreover, in male subjects, the stronger muscles

attached to their mastoids had affected this bony process to maintain an upright position, i. e., a relatively more vertical and less medially inclined in direction which was more significantly manifested in males than in females of our sample, as indicated by the greater intermastoidale distance (IMD) and greater distance between the lateral surfaces of the left and right mastoids (IMLSD) in males than in females; and it was further substantiated by the greater mastoid flare (MF) and greater mastoid medial convergence angle (MMCA) in females than in males.

All our measurements of the nine mastoid-related parameters of our sample were analyzed with the highly objective discriminant function and it showed that four variables (IMD, MMCA, MS, and ML) when put together, correctly determined the sex in 90.6 percent of our 192 subjects. Of all the nine variables, the intermastoidale distance (IMD) was found to be the best sex determinant that, when used alone, correctly assessed the sex in 87.5 percent of the sample.

This efficient statistical tool, the discriminant function analysis, had also been used in determining the gender of skulls based on mastoid process by Sumati et. al., in 2010 [21] for North Indian population; Nagaoka et. al., in 2008 [19] for Japanese people; Sujaritham et. al., in 2011 [22] for Thai population; Patil and Mody in 2005 [15] for people of Central India; Bernard and Moore-Jensen in 2009 [20] in Wichita-Kansas, USA; Gupta et. al., in 2012 [24] in South India. All these studies showed that the sex within a given population could be best described by a specific discriminant equation.

To this end, the discriminant function equation derived in this study is unique to our sample of adult and middle age Jordanian population.

6. Conclusions

Mastoid process correctly sexed 90.6 percent of the sample of 192 equally distributed male and female subjects. Amongst the sex discriminatory function of nine mastoid related variables, four parameters proved to be the best sex identifiers. When considered individually, their ranking stands as follows: intermastoidale distance > mastoid length > mastoid size > mastoid medial convergence angle. The discriminant function equation derived in the present study is specific for Jordanian population.

Disclosure

The authors declare they have neither financial disclosure nor conflict of interest.

Ethical Approval

The ethics committee of the Jordan University – Faculty of Dentistry approved the present study. The Faculty committee approval was granted after considering the written consent that was obtained from all the subjects of the study sample who were made aware that their CBCT images were going to be included in this study before the investigation started.

Consent

All patients were made aware that their cone beam CT images were selected for inclusion in the present investigation. Accordingly, they all signed written informed consents in compliance with the policy of the Clinical Research Authority at the Jordan University Hospital.

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