ORIGINAL ARTICLE

Eastern Journal of Medicine

East J Med 30(3): 367-381, 2025
DOI: 10.5505/ejm.2025.71780

Sex Estimation from Mandible by Computerized Tomography Images and Discriminant Function Analysis in an Eastern Turkish Population

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ABSTRACT

The mandible is one of the best alternatives for sex estimation owing to its significant sexual dimorphism. The current study, which included a large case series and was conducted in an Eastern Turkish adult population, sought to assess the ability of mandibular measurements to estimate sexual dimorphism and investigate correlations between mandibular measurements and age and sides.

On mandibular CT scans, 24 parameters for 240 cases were measured twice by two researchers. The mean values were compared based on sex, mandibular side, and age. Sex estimation rates were determined using univariate, linear, and stepwise discriminant analysis.

Male mandibles had higher linear measures. The maximum accurate sex estimation rate from the mandible was obtained in the multivariate DFA at 97.5% in males and 96.7% in females. Males and females had higher rates on the left and right sides, respectively.

The data obtained with this study on this Eastern Turkish population, which both confirms previous research and suggests new ideas, and the high sex estimation rates obtained from these data, are thought to be an extremely useful database for future studies in the fields of forensic anthropology and archaeology for sex estimation.

Keywords: sex estimation, accuracy rate, mandible, CT scans, discriminant function analysis, forensic medicine

Introduction

Identification of bodies that are unrecognizably dismembered, burned, or deformed during natural disasters, fires, airplane crashes, other accidents where multiple deaths occur, bomb explosions, wars, and mass graves is of great importance in forensic anthropology. The mandible, a durable bone that forms the lower third of the face and is resistant to external factors, is an important element of the skull bones and is defined as the most dysmorphic bone after the pelvis (1-5).

Scientists have been interested in mandibular measurements since the early 1900s. The first measurements of the mandible, containing "condylar width," "angle width," "greatest height of mandible," and "distance between both mental foramina," were reported by Fawcett and Lee in 1902 (6). Morant described a biometric technique for measuring 28 Tibetan mandibles in 1923 (7). In a later 1926 article, Morant stated that in measurements taken on 49 male and 49 female mandibles, the proportional sex difference was very similar in terms of indexes and angles between male and female, and that for the small numbers obtained, the difference was not significant (8). Morant and Martin noted certain racial and sexual characteristics in two 1936 studies on Egyptian series to indicate racial and sexual distinctions. Still, they stated that a final sex estimation could not be produced due to the small number of skulls on which sex could be determined with confidence (9, 10). In 1964, Giles measured dry mandibles and estimated sex with an

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Received: 05.04.2025, **Accepted:** 21.05.2025

accuracy rate of 85% using the multivariate discriminant function (11).

Following these pioneering experiments, researchers continued to estimate sex using both mandible morphology and morphometric characteristics. Sex estimation accuracy rates have ranged from 45.2% to 99% in studies aimed at predicting sex based on morphological features on dry bones, with variations depending on the selected morphological characteristics, observer differences, and populations (1, 2, 12-17). Morphological studies were conducted using linear, angle, and area measurements, some of which were taken on dry bones and autopsy materials (3, 4, 18-36), while others used radiological techniques such as panoramic radiographs or orthopantomography (37-49) and computed tomography (CT) images (5, 49-65). Sex estimation accuracy rates varied from 60% to 97% in research utilizing dry bone or postmortem material, 56.3% to 95% in research using panoramic radiography or orthopantomography, and 78.5% to 99% in research using CT scans.

Variations in accuracy rates have been caused by numerous study-related factors, including variations in population ancestry and number, population distribution by sex or age group, methodology used, variations in observers in morphological studies, variations in the location and quantity of measurements in morphometric studies, and variations in statistical techniques. Iscan highlighted the population-specific diversity of morphological and morphometric features in bones, as noted by many anthropologists, and emphasized that these features should be studied for large populations worldwide (66).

The current study, which included a large case series and was conducted in the Eastern Turkish adult population, sought to assess the ability of mandibular measurements to estimate sexual dimorphism, investigate correlations between mandibular measurements and age and sides, and compare the mandibular measurements of the Eastern Turkish adult population to those of other populations obtained through a literature review.

Materials and Methods

Study Population, Selection, Exclusion, and Equalization of Cases: This study was designed as a retrospective analysis of 240 patients who had previously had mandible CT images taken in the Radiology Department of a University Medical Center located in Eastern Türkiye. In this study, mandible body length (mm) was considered as the main characteristic. According to previous morphometric research on Turkish populations (61, 65), the standard deviation for mandible body length ranges from 0.45 to 0.61. Thus, 0.53 was selected as the standard deviation. Type I error is 0.05 for the 95% confidence coefficient and roughly 80% power value, and the researcher estimated an effect size of 0.2. With these data, the Z test determined that a sample size of 29 was required. 40 male and 40 female patients from each of the three age groups—21-40 years, 41-60 years, and 61 and over—were included in the study. Four cases for each age and sex were sought during the case selection process, but when this was not feasible, a subject from a different age group was included. The optimum mean and median age values for the age groups have been determined by the initial assumption that four cases could be found for each age group. The ages of the cases to be added to the study were selected to replace those not available in the data bank in a way that minimizes the alteration in these mean and median ages. In the age group of 61 years and above, forty cases were selected for each sex, with the most regular age distribution possible if age equalization was not feasible. As a result, it was ensured that there would be no statistically significant difference in the mean age data for either sex. The retrospective review of the radiological archives started on December 31, 2022. This retrospective review was terminated when a sufficient number of cases were obtained and measured for each sex and age group, taking into account the inclusion and exclusion criteria.

The medical histories of the patients were retrieved from the hospital information management system (ENLIL® HIMS) following approval from the Ethics Committee. Patients were excluded from the study if they had any inherited or acquired mandibular bone disease, trauma, cancer, or anomalies, or if the CT images had artifacts or did not show the entire mandible.

CT Imaging, and Scanning Parameters: The CT images were obtained using a 16-cross-sectional multislice CT machine (Somatom Sensation 16; Siemens Medical Solutions, Erlangen, Germany), which was configured as follows: KV / Effective mAs / Rotation time (sec) values 120/120 / 0.75; gantry rotation period 420 ms; physical detector collimation, 16 × 0.6 mm; section thickness, 0.75 mm; final section collimation 32 × 0.63 mm; feed/rotation, 6 mm; Kernel, U90u; increment 0.5 mm; resolution 512 × 512 pixels. The axial images were uploaded to

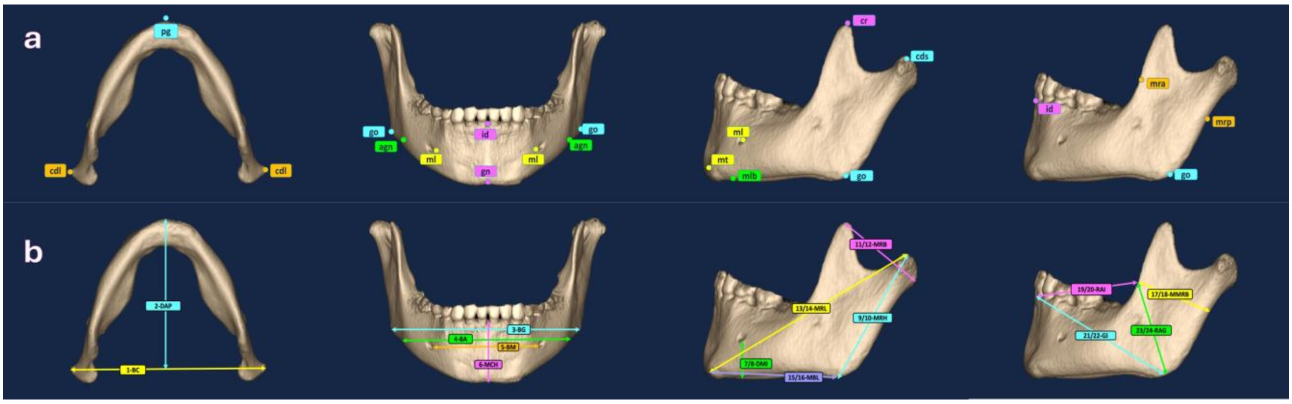

Fig. 1 (a) Anatomical landmarks and **(b)** single and bilateral measurements of the mandible for sex estimation [cdl: condyle lateralis, pg: pogonion; go: gonion; agn: antegonial notch; ml: mental foramen; gn: gnathion; id: infradentale; mt: mental tubercle; mlb: mentale-body; cds: condylion superior; cr: mra: mandibular ramus anterior; mrp: mandibular ramus posterior; BC: Bi-condylar breadth; DAP: Distance between anterior and posterior; BG: Bi-gonial breadth; BA: Bi-antegonial notch breadth; BM: Bi-mental foramens breadth; MCH: Mandibular corpus height; DMI: Distance from mental foramen to inferior rim; MRH: Maximum mandibular ramus height; MRB: maximum mandibular ramus breadth; MRL: Maximum mandibular ramus length; MBL: Maximum mandibular body length; MMRB: Minimum mandibular ramus breadth; RAI: Distance from anterior edge of ramus mandible to infradentale; GI: Distance from gonion to infradentale; RAG: Distance from anterior edge of ramus mandible to gonion]

The workstation (Leonardo, Siemens Medical Solutions, Erlangen, Germany) for DICOM processing. The workstation was then used to generate multiplanar images and 3-dimensional (3D) reconstructions using the "Volume Rendering Plus InSpace MPR" capability of the "SyngoVia" CT software. Anatomical morphometric classification, measurements, and fusion evaluation were performed on sagittal and axial images using freehand ROI selection processes and electronic calipers.

Measurements: The morphometric measurements for the current study were determined by going over the measurements from the previous research papers (3-5, 18-65). The study comprised twenty-one anatomical landmarks (Figure 1/a) and twenty-four linear measuring parameters expressed in millimeters (Figure 1/b). Six of these 24 measurements—which we hypothesized to be sexually dysmorphic—were measured for the first time in this work, while the other 18 were previously reported in the literature. Anatomical landmarks and measuring parameters are described in Table 1.

The mandibular measurements were applied again, two months apart, by two researchers (forensic medicine specialists I.M. and G.D.M.), who were blind to the sex of the cases, to determine the repetition or reproducibility of the data. The study parameter for each variable was determined by averaging the measurements made by both observers.

Statistical Analysis: Absolute and relative technical measurement errors (TEM) were computed by the guidelines provided by Langley et al. (67) to investigate the variability between repeated measurements made by a single observer (i.e., repeatability or intraobserver error) and the variability between two observers (interobserver error). The sample size (N = 240 patients), the number of observers (K = 2), and the number of measurements per observer (M = 2) were used as the means in the computation of absolute TEM. The relative TEM was determined for the two observations on one mandible, and the mean of the 240 relative TEM values was used to compute the intraobserver relative TEM. The mean relative TEM from both measurements was utilized as the relative TEM to determine the interobserver relative TEM. Relative TEM was calculated for each measurement using the data from both observers. Less than 1.5% for intra-examiner error and less than 2% for inter-examiner error represent the relative or percentage TEM within the allowed parameters in the current study. For the other statistical calculations, SPSS (ver. 25) statistical software was utilized. Cronbach's alpha based on standardized items was used to calculate the intraobserver and interobserver reliability of measurements.

For continuous variables, descriptive statistics were shown as mean and standard deviation values; for categorical variables, they were shown as count and percentage. The unpaired t-test was employed to compare the means of two independent or unrelated groups, and Fisher's exact probability test was used to compare the two group proportions. A one-way ANOVA test was performed to compare the means of two or more independent groups to determine if there was statistical support for a significant difference in the related population means. Post hoc analysis was performed using Tukey's test. A 5% threshold for statistical significance was used.

The accuracy of univariate sex estimation for each of the parameters was determined using univariate linear DFA. In the next stage, multivariate linear DFA was performed with the defined parameters, followed by stepwise DFA with the parameters selected by the program.

Ethical Approval: This study was conducted with the approval of the Non-Interventional Clinical Research Ethics Committee of Van Yuzuncu Yil University Faculty of Medicine (decision number: 03, dated: 20.01.2023)

Results

Mandibular measurements were made on the CT scans of 240 people, comprising 40 cases for each age group and each sex. The 120 females had an average age of 50.7 years (SD, 18.3; median, 50.5; min, 21; max, 86), and the 120 males had an average age of 51.0 years (SD, 18.4; median, 50.5; min, 22; max, 90). For each parameter, intraobserver and interobserver absolute TEM was less than 1.5%, relative TEM was less than 2%, and the reliability for all the measured features was between 0.995 and 0.999.

Each of the 24 measurements on the male mandible was larger than on the female mandible ($p<0.000$) (Table 2). Of the nine measurements taken bilaterally, 5 (55.6%) in males (DMI, MRH, MRL, RAI, RAG), 7 (77.8%) in females (DMI, MRH, MRB, MRL, MMRB, RAI, RAG), and 5 (55.6%) in the overall population (DMI, MRH, MRL, RAI, RAG) were larger on the left side, while the others were larger on the right side. The right-sided predominance of MBL and GI was also statistically significant ($p<0.05$, for each) in both sexes and the overall population; the other measurement differences were not significant ($p>0.05$, for each) (Table 3).

The MCH measurement decreased significantly with age, although the BC, DAP, and BM parameters increased significantly ($p<0.05$ for each). Between 41 and 60 years old, the parameters of L-MMRB, R-MMRB, and R-GI reached their lowest levels ($p<0.05$). The remaining age-group-based parameter variations were not determined to be statistically significant ($p > 0.05$ for each) (Table 4).

Univariate DFA accuracy estimated the sex with accuracy rates ranging from 56.7% to 83.3% in males, 54.2% to 80.8% in females, and 60.4% to 80.8% in the overall population. The measurement results showed that the overall population and males had the highest accuracy rate with L-MRL, while females had the highest rate with L-MRH, R-MRH, and L-MRL.

Within multivariate linear DFAs, sex could be accurately estimated at the rate of 81.7% for males and 85.8% for females in the evaluation made using six single parameters for measurements. The accuracy rates for sex estimation in multivariate DFA were 93.3% for males and 90.8% for females, with nine parameters assessed for the left side; 90.8% for males and 95% for females, with nine parameters measured for the right side. The results cited above indicated that measures taken from the left side were more dysmorphic in males, and measurements taken from the right side were more dysmorphic in females. Sex could be accurately estimated at 93.3% for males, 95.8% for females, and 94.6% for the study population using the 18 traditional measurement parameters. By incorporating all 24 parameters, the accurate sex estimation rate in multivariate DFA increased to 97.5% in males, 96.7% in females, and 97.1% in the overall population. Utilizing all 24 parameters in the stepwise DFA, the system determined that the best combination of parameters was "BC + BG + MCH + RMRH + LMRL + RMRL + LMBL + LRAG." The stepwise DFA using this combination produced accurate sex estimation rates of 95% for males, 96.7% for females, and 95.8% for the overall population (Table 5).

Discussion

For the 24 linear measurements used in this study evaluating mandibular measurements in Eastern Turkey, values were obtained from previous studies on other populations (3-5, 18-65). The results showed that BA in both sexes was higher than the values defined in two studies in the literature (52, 54) and that L-DMI and R-DMI in both sexes were higher than the values defined in four studies in the literature (4, 27, 52, 60), even though 13 of the 24 measurements in both sexes were between the lower and upper values previously defined in the literature. The mean of L-MRL and R-MRL measurements was lower than the mean values in

Table 1: Anatomical Landmarks and Measuring Points on Mandible

Landmarks		
cdl	Condylus Lateralis	The most lateral point of the bilateral mandibular condyles
pg	Pogonion	The most projecting median point on the anterior surface of the chin.
gn	Gnathion	The midpoint of the lower border of the mandible
id	Infradentale	The apex of the septum is between the central incisors in the mandible.
ml	Mental Foramen	The bilateral small foramina are located in the anterolateral region of the mandible.
agn	Antegonial Notch	The bilateral concavities are located at the junction between the body and the ramus of the mandible.
go	Gonion	The outermost and most noticeable bilateral points on the angle of the mandible.
mt	Mental Tuberculum	The bilateral triangular bony elevations are located on both sides of the mental protuberance on the outside of the mandible.
ml-b	Mental - Body	The point where a vertical line drawn from the mandible intersects the lower border of the mandibular body
cr	Coronion	The most superior points of the bilateral coronoid process in the mandible
cds	Condylus Superior	The most superior points of the bilateral condylar process in the mandible.
mra	Mandibular Ramus Anterior	The most concave points were located at the anterior edge of both mandibular ramuses.
mrp	Mandibular Ramus Posterior	The most concave points were located at the posterior edge of both mandibular ramuses.
Single Measurements		
BC	Bi-condylar breadth: The linear distance between both condylus lateralis (cdl-cdl).	
DAP	Distance between anterior and posterior of mandible: The projective linear distance from gnathion (gn) to the line between bilateral mandibular condyles (cdl-cdl).	
BG	Bi-gonial breadth: Distance between both gonions (go-go)	
BA	Bi-antegonial notch breadth: Distance between both antegonial notches (agn _ agn)	
BM	Bi-mental foramen breadth: Distance between both mental foramina (mt – mt)	
MCH	Mandibular ramus height: Distance from gnathion to infradentale (gn – id)	
Bilateral Measurements		
DMI	Distance between mental foramen (ml) and inferior rim of chin (mlb)	
MRH	Mandibular ramus height: Distance from gonion to condylus superior (gn – cds)	
MRB	Maximum mandibular ramus breadth: The linear distance between the posterior point of the condylar process (cds) and the most anterior point of the coronoid process (cr).	
MRL	Mandibular ramus length: Distance from condylus superior (cds) to gnathion (gn)	
MBL	Mandibular body length: Distance from gnathion (gn) to gonion (gn).	
MMRB	Minimum mandibular ramus breadth: Distance from mandibular ramus anterior (mra) to mandibular ramus posterior (mrp)	
RAI	Distance from mandibular ramus anterior (mra) to infradentale (id)	
GI	Distance from gonion (go) to infradentale (id)	
RAG	Distance from mandibular ramus anterior (mra) to gonion (go)	

The literature (18-20, 29, 52, 60). Data regarding the measurements of bilateral RAI, GI, and RAG in both sexes were not found in the literature (Table 2). Male mandibles were shown to have greater linear measures overall in the current research. According to Gamara et al. (41) and

Table 2: Comparisons of the Mandible Measurements by Sex

Measurements	MALES				FEMALES				TOTAL				P
	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	
BC	123,73	5,60	107,70	137,10	116,55	5,41	99,50	130,80	120,14	6,57	99,50	137,10	0.000
DAP	98,58	6,58	81,55	112,10	94,83	6,23	78,30	110,30	96,70	6,66	78,30	112,10	0.000
BG	101,56	6,53	88,50	117,30	94,90	5,45	82,00	109,95	98,23	6,87	82,00	117,30	0.000
BA	94,95	5,86	83,40	108,80	89,10	5,33	77,60	104,05	92,02	6,31	77,60	108,80	0.000
BM	47,31	2,87	40,05	55,25	45,96	2,58	35,60	53,50	46,64	2,81	35,60	55,25	0.000
MCH	32,41	4,82	17,15	42,90	29,20	4,87	14,60	38,60	30,80	5,10	14,60	42,90	0.000
L-DMI	15,81	1,55	12,33	20,48	14,37	1,64	8,72	18,43	15,09	1,75	8,72	20,48	0.000
R-DMI	15,72	1,73	11,23	19,58	14,24	1,69	9,58	18,83	14,98	1,86	9,58	19,58	0.000
L-MRH	72,21	5,50	57,63	85,28	64,44	4,72	51,78	76,48	68,33	6,43	51,78	85,28	0.000
R-MRH	71,53	5,02	57,38	84,08	63,41	4,97	45,38	73,98	67,47	6,43	45,38	84,08	0.000
L-MRB	40,68	2,78	33,68	47,68	37,85	2,64	30,38	43,93	39,27	3,05	30,38	47,68	0.000
R-MRB	40,91	2,75	33,88	48,43	37,78	2,79	29,78	46,53	39,35	3,18	29,78	48,43	0.000
L-MRL	115,27	4,71	103,30	127,00	106,97	5,09	95,60	117,55	111,12	6,42	95,60	127,00	0.000
R-MRL	114,85	4,86	103,25	126,30	106,81	5,17	94,55	119,60	110,83	6,43	94,55	126,30	0.000
L-MBL	64,74	4,71	54,50	78,05	62,08	4,16	53,16	74,15	63,41	4,63	53,16	78,05	0.000
R-MBL	67,55	4,69	57,55	79,50	64,04	4,12	53,95	77,60	65,80	4,74	53,95	79,50	0.000
L-MMRB	31,48	2,85	22,65	38,05	29,58	2,79	22,10	36,60	30,53	2,97	22,10	38,05	0.000
R-MMRB	31,59	3,01	23,20	39,50	29,48	3,03	22,10	38,75	30,54	3,19	22,10	39,50	0.000
L-RAI	52,66	3,31	46,10	61,40	50,19	3,29	42,40	62,50	51,42	3,52	42,40	62,50	0.000
R-RAI	52,23	3,21	45,95	60,80	49,96	3,09	40,90	58,30	51,09	3,34	40,90	60,80	0.000
L-GI	65,11	4,68	51,80	75,30	60,99	4,37	48,50	73,20	63,05	4,97	48,50	75,30	0.000
R-GI	67,17	4,81	51,65	76,10	62,65	4,27	52,25	77,05	64,91	5,07	51,65	77,05	0.000
L-RAG	37,11	3,28	29,65	43,80	32,55	3,27	23,70	40,15	34,83	3,99	23,70	43,80	0.000
R-RAG	36,49	3,60	27,03	45,18	32,18	3,33	23,93	43,38	34,34	4,08	23,93	45,18	0.000

SD: Standard Deviation; Min: Minimum; Max: Maximum; L-: Left; R-: Right; BC: Bi-condylar breadth; DAP: Distance between anterior and posterior; BG: Bi-gonial breadth; BA: Bi-antegonial notch breadth; BM: Bi-mental foramens breadth; MCH: Mandibular corpus height; DMI: Distance from mental foramen to inferior rim; MRH: Maximum mandibular ramus height; MRB: maximum mandibular ramus breadth; MRL: Maximum mandibular ramus length; MBL: Maximum mandibular body length; MMRB: Minimum mandibular ramus breadth; RAI: Distance from anterior edge of ramus mandible to infradentale; GI: Distance from gonion to infradentale; RAG: Distance from anterior edge of ramus mandible to gonion

Gamba et al. (53), females had greater MMRB values than males. Previous studies have shown that the remaining mandibular linear parameters are larger in males than in females, regardless of the measurement method (3-5, 18-21, 23-35, 37-43, 46, 48, 49, 50-58, 60-62, 65). On the other hand, although not investigated in this study, it has been revealed that the mandibular angle created by the gnathion-gonion and gonion-condyle posterior lines is broader in females than in males (19, 27, 28, 32, 51, 52, 56, 60).

Of the nine bilateral measurements, 5 (55.5%) were larger on the left side in males and the overall population, and 7 (77.8%) in females. The right-sided predominance of MBL and GI was also statistically significant ($p<0.05$ for each) in both sexes and the overall population. (Table 3). There were a few publications in the literature that

Table 3: Comparisons of the Mandible's Bilateral Measurements for the Sexes and Sides

	LEFT				RIGHT				
Males	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	p
DMI	15,81	1,55	12,33	20,48	15,72	1,73	11,23	19,58	0.765
MRH	72,21	5,50	57,63	85,28	71,53	5,02	57,38	84,08	0.548
MRB	40,68	2,78	33,68	47,68	40,91	2,75	33,88	48,43	0.650
MRL	115,27	4,71	103,30	127,00	114,85	4,86	103,25	126,30	0.632
MBL	64,74	4,71	54,50	78,05	67,55	4,69	57,55	79,50	0.001
MMRB	31,48	2,85	22,65	38,05	31,59	3,01	23,20	39,50	0.838
RAI	52,66	3,31	46,10	61,40	52,23	3,21	45,95	60,80	0.472
GI	65,11	4,68	51,80	75,30	67,17	4,81	51,65	76,10	0.019
RAG	37,11	3,28	29,65	43,80	36,49	3,60	27,03	45,18	0.326
Females	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	p
DMI	14,37	1,64	8,72	18,43	14,24	1,69	9,58	18,83	0.670
MRH	64,44	4,72	51,78	76,48	63,41	4,97	45,38	73,98	0.247
MRB	37,85	2,64	30,38	43,93	37,78	2,79	29,78	46,53	0.888
MRL	106,97	5,09	95,60	117,55	106,81	5,17	94,55	119,60	0.865
MBL	62,08	4,16	53,16	74,15	64,04	4,12	53,95	77,60	0.011
MMRB	29,58	2,79	22,10	36,60	29,48	3,03	22,10	38,75	0.851
RAI	50,19	3,29	42,40	62,50	49,96	3,09	40,90	58,30	0.694
GI	60,99	4,37	48,50	73,20	62,65	4,27	52,25	77,05	0.038
RAG	32,55	3,27	23,70	40,15	32,18	3,33	23,93	43,38	0.540
Overall Population	Mean	SD	Min.	Max.	Mean	SD	Min.	Max.	p
DMI	15.09	1.75	8.72	20.48	14.98	1.86	9.58	19.58	0.637
MRH	68.33	6.43	51.78	85.28	67.47	6.43	45.38	84.08	0.301
MRB	39.27	3.05	30.38	47.68	39.35	3.18	29.78	48.43	0.842
MRL	111.12	6.42	95.60	127.00	110.83	6.43	94.55	126.30	0.727
MBL	63.41	4.63	53.16	78.05	65.80	4.74	53.95	79.50	0.000
MMRB	30.53	2.97	22.10	38.05	30.54	3.19	22.10	39.50	0.980
RAI	51.42	3.52	42.40	62.50	51.09	3.34	40.90	60.80	0.457
GI	63.05	4.97	48.50	75.30	64.91	5.07	51.65	77.05	0.000
RAG	34.83	3.99	23.70	43.80	34.34	4.08	23.93	45.18	0.347

p: Unpaired t test results; SD: Standard Deviation; Min: Minimum; Max: Maximum; DMI: Distance from mental foramen to inferior rim; MRH: Maximum mandibular ramus height; MRB: Maximum mandibular ramus breadth; MRL: Maximum mandibular ramus length; MBL: Maximum mandibular body length; MMRB: Minimum mandibular ramus breadth; RAI: Distance from anterior edge of ramus mandible to infradentale; GI: Distance from gonion to infradentale; RAG: Distance from anterior edge of ramus mandible to gonion

thoroughly evaluated the right and left differences in measurements. Some studies reported no statistical difference in mandible measurements on both sides but did not specify which parameters had higher values on the right or left side (19, 26, 51). Baban and Mohammad found that MRH was higher on the left side in males and on the right side in females (5). According to Toneva et al., bilateral anthropometric measures revealed greater values on the right side in 14 out of 17 measurements for males and higher values on the left side in 9 out of 17 measurements for females (60). Bertsatos et al. reported higher right side values in 6 out of 11 measurements in males and higher left side values in 7 out of 11 in females for bilateral linear measurements (29). Bento et al. reported greater left-side values in 4 out of 6 bilateral measurements in both sexes (32). Researchers did not make statistical comparisons in these studies. Sairam et al. reported significantly higher linear measurement values on the left side in three out of four male mandibles, on the right side in two out of four, and on the left side in one out of four female mandibles (49). As a result,

Table 4: Comparisons of the Mandible Measurements by Age Groups

Parameters	AGE GROUPS	Mean	SD	Min.	Max.	P	Parameters	AGE GROUPS	Mean	SD	Min.	Max.	P
BC	21-40	118,57[a]	6,45	102,60	131,25	0,008	LMRL	21-40	110,50	6,31	95,60	122,80	0,570
	41-60	120,07[ab]	5,87	99,50	132,95			41-60	111,39	6,04	97,35	127,00	
	61-61+	121,79[b]	7,02	106,40	137,10			61-61+	111,47	6,91	96,61	126,10	
	Total	120,14	6,57	99,50	137,10			Total	111,12	6,42	95,60	127,00	
DAP	21-40	95,52[a]	7,03	78,30	111,85	0,022	RMRL	21-40	110,78	5,94	96,40	126,30	0,940
	41-60	96,27[ab]	5,89	82,35	109,50			41-60	111,03	6,43	94,90	125,75	
	61-61+	98,32[b]	6,78	81,55	112,10			61-61+	110,68	6,94	94,55	123,40	
	Total	96,70	6,66	78,30	112,10			Total	110,83	6,43	94,55	126,30	
BG	21-40	98,69	6,73	82,60	117,30	0,202	LMBL	21-40	64,10	4,34	54,50	74,15	0,257
	41-60	97,11	6,20	82,00	110,40			41-60	62,99	4,65	53,55	78,05	
	61-61+	98,88	7,55	84,55	116,80			61-61+	63,15	4,86	53,16	73,80	
	Total	98,23	6,87	82,00	117,30			Total	63,41	4,63	53,16	78,05	
BA	21-40	92,04	6,09	77,60	107,70	0,359	RMBL	21-40	65,49	4,17	56,55	76,05	0,652
	41-60	91,30	5,86	77,85	104,00			41-60	65,72	5,04	53,95	79,50	
	61-61+	92,73	6,93	79,05	108,80			61-61+	66,18	5,01	55,40	76,15	
	Total	92,02	6,31	77,60	108,80			Total	65,80	4,74	53,95	79,50	
BM	21-40	46,52[ab]	2,49	40,05	53,70	0,024	LMMRB	21-40	30,76[ab]	2,54	25,15	35,70	0,042
	41-60	46,10[a]	2,90	35,60	53,70			41-60	29,86[a]	3,40	22,10	38,05	
	61-61+	47,29[b]	2,91	40,95	55,25			61-61+	30,97[b]	2,81	24,10	37,00	
	Total	46,64	2,81	35,60	55,25			Total	30,53	2,97	22,10	38,05	
MCH	21-40	32,58[b]	3,47	25,85	42,90	0,000	RMMRB	21-40	31,01[b]	2,81	24,15	38,75	0,020
	41-60	31,96[b]	4,22	21,40	39,60			41-60	29,73[a]	3,59	22,10	39,50	
	61-61+	27,87[a]	5,96	14,60	39,05			61-61+	30,88[ab]	3,02	23,95	37,40	
	Total	30,80	5,10	14,60	42,90			Total	30,54	3,19	22,10	39,50	
LDMI	21-40	15,06	1,49	11,33	19,73	0,303	LRAI	21-40	51,65	3,50	45,80	61,40	0,292
	41-60	14,89	1,83	8,72	18,43			41-60	50,92	2,96	44,30	58,70	
	61-61+	15,32	1,89	10,73	20,48			61-61+	51,70	4,01	42,40	62,50	
	Total	15,09	1,75	8,72	20,48			Total	51,42	3,52	42,40	62,50	
RDMI	21-40	14,90	1,74	12,13	19,58	0,382	RRAI	21-40	51,20	3,32	40,90	59,10	0,242
	41-60	14,82	2,03	9,58	18,83			41-60	50,60	2,90	43,05	60,50	
	61-61+	15,21	1,81	10,43	19,18			61-61+	51,48	3,75	41,85	60,80	
	Total	14,98	1,86	9,58	19,58			Total	51,09	3,34	40,90	60,80	

LMRH	21-40	67,23	6,03	52,98	79,13	0,101	LGI	21-40	63,03	4,26	52,60	71,65	0,124
	41-60	68,34	6,12	56,93	85,28			41-60	62,26	5,35	48,50	73,35	
	61-61+	69,41	6,98	51,78	84,48			61-61+	63,86	5,16	53,80	75,30	
	Total	68,33	6,43	51,78	85,28			Total	63,05	4,97	48,50	75,30	
RMRH	21-40	66,92	5,84	45,83	80,23	0,473	RGI	21-40	64,89[ab]	4,20	51,65	77,05	0,024
	41-60	67,25	6,10	53,23	78,88			41-60	63,82[a]	5,35	52,25	76,10	
	61-61+	68,24	7,28	45,38	84,08			61-61+	66,01[b]	5,40	55,05	75,70	
	Total	67,47	6,43	45,38	84,08			Total	64,91	5,07	51,65	77,05	
LMRB	21-40	39,51	3,07	31,43	47,68	0,476	LRAG	21-40	35,29	3,39	27,15	43,80	0,336
	41-60	39,36	3,33	30,38	45,88			41-60	34,36	4,00	26,60	43,35	
	61-61+	38,94	2,74	32,53	45,58			61-61+	34,84	4,49	23,70	43,10	
	Total	39,27	3,05	30,38	47,68			Total	34,83	3,99	23,70	43,80	
RMRB	21-40	39,71	3,30	29,78	48,43	0,417	RRAG	21-40	34,87	3,34	25,68	44,68	0,236
	41-60	39,28	3,35	32,18	46,88			41-60	33,77	3,81	26,93	43,83	
	61-61+	39,06	2,86	33,38	45,68			61-61+	34,37	4,90	23,93	45,18	
	Total	39,35	3,18	29,78	48,43			Total	34,34	4,08	23,93	45,18	

SD: Standard Deviation; Min: Minimum; Max: Maximum; L-: Left; R-: Right; BC: Bi-condylar breadth; DAP: Distance between anterior and posterior; BG: Bi-gonial breadth; BA: Bi-antegonial notch breadth; BM: Bi-mental foramens breadth; MCH: Mandibular corpus height; DMI: Distance from mental foramen to inferior rim; MRH: Maximum mandibular ramus height; MRB: Maximum mandibular ramus breadth; MRL: Maximum mandibular ramus length; MBL: Maximum mandibular body length; MMRB: Minimum mandibular ramus breadth; RAI: Distance from anterior edge of ramus mandible to infradentale; GI: Distance from gonion to infradentale; RAG: Distance from anterior edge of ramus mandible to gonion.
Superscripts a and b indicate within-group statistical change.

Table 5: Results of Sex Estimation with Univariate, Multivariate, and Stepwise Discriminant Function Analyses

Univariate Discriminant Function Analyses									
Measurements	Males			Females			Total		
	Correctly Matched	Incorrectly Matched	Accuracy Rate	Correctly Matched	Incorrectly Matched	Accuracy Rate	Correctly Matched	Incorrectly Matched	Accuracy Rate
BC	89	31	74.2	86	34	71.7	175	65	72.9
DAP	80	40	66.7	78	42	65.0	158	82	65.8
BG	79	41	65.8	87	33	72.5	166	74	69.2
BA	82	38	68.3	87	33	72.5	169	71	70.4
BM	72	48	60.0	75	45	62.5	147	93	61.3
MCH	80	40	66.7	65	55	54.2	145	95	60.4
L-DMI	79	41	65.8	81	39	67.5	160	80	66.7
R-DMI	76	44	63.3	77	43	64.2	153	87	63.8
L-MRH	92	28	76.7	97	23	80.8	189	51	78.8
R-MRH	94	26	78.3	97	23	80.8	191	49	79.6
L-MRB	83	37	69.2	76	44	63.3	159	81	66.3
R-MRB	82	38	68.3	82	38	68.3	164	76	68.3
L-MRL	100	20	83.3	94	26	78.3	194	46	80.8
R-MRL	96	24	80.0	97	23	80.8	193	47	80.4
L-MBL	68	52	56.7	78	42	65.0	146	94	60.8
R-MBL	81	39	67.5	82	38	68.3	165	75	68.8
L-MMRB	77	43	64.2	77	43	64.2	154	86	64.2
R-MMRB	78	42	65.0	77	43	64.2	155	85	64.6
L-RAI	78	42	65.0	75	45	62.5	153	87	63.8
R-RAI	71	49	59.2	77	43	64.2	148	92	61.7
L-GI	82	38	68.3	80	40	66.7	162	78	67.5
R-GI	85	35	70.8	88	32	73.3	173	67	72.1
L-RAG	87	33	72.5	90	30	75.0	177	63	73.8
R-RAG	88	32	73.3	89	31	74.2	177	63	73.8

Parameters	Males Correctly Matched	Males Incorrectly Matched	Males Accuracy Rate	Females Correctly Matched	Females Incorrectly Matched	Females Accuracy Rate	Total Correctly Matched	Total Incorrectly Matched	Total Accuracy Rate
Multivariate Discriminant Function Analyses									
Single 6 Parameters	98	22	81.7	103	17	85.8	201	39	83.8
9 Parameters of the Left Side	112	8	93.3	109	11	90.8	221	19	92.1
9 Parameters of the Right Side	109	11	90.8	114	6	95.0	207	33	92.9
Traditional 18 Parameters	112	8	93.3	115	5	95.8	227	13	94.6
All Parameters	117	3	97.5	116	4	96.7	233	7	97.1
Stepwise Discriminant Function Analyses									
Parameters	Males Correctly Matched	Males Incorrectly Matched	Males Accuracy Rate	Females Correctly Matched	Females Incorrectly Matched	Females Accuracy Rate	Total Correctly Matched	Total Incorrectly Matched	Total Accuracy Rate
Selected Parameters by System (*)	114	6	95.0	116	4	96.7	230	10	95.8

(*) (Discriminant Functions (D) were defined as D=-966.589 + 3.730 BC + 2.273 BG + .998 MCH + 1.512 RMRH + 3.541 LMRL + 3.606 RMRL + 3.402 LMBL + 1.520 LRAG for males, and D= -839.932+ 3.528 BC + 2.117 BG + .884 MCH + 1.278 RMRH + 3.315 LMRL + 3.390 RMRL + 3.275 LMBL + 1.219 LRAG for females)

Toneva et al. defined right-side dominance in both sexes (60), Bento et al. defined left-side dominance in both sexes (32), Bertsatos et al. defined right-side dominance in males and left-side dominance in females [29], and Sairam et al. defined left-side dominance in males and right-side dominance in females (49). In the present study, we found right-side dominance in both sexes, pronounced in females. These results suggest that mandibular asymmetry may exist. Thiesen et al. also described a facial asymmetry commonly observed in the general population that may not be noticeable at first glance, related to deficiencies in embryological development or maturation of the medial and lateral nasal prominences and maxillary and mandibular prominences of the lower and midface (68). Previous studies did not provide sufficient consideration of the differences in mandibular measures between adult age groups. Toneva et al. (59) state that it is unclear how aging affects the classification accuracy of the factors related to mandibular size and shape. Unlike the above-mentioned study, Sambhana et al. found that the mandibles of the patients aged 0-75 showed significant changes with age in the equivalent values of BC, BG, MCH, MRH, MRB, and MMRB (40). The current study found a statistically significant decrease in MCH and a statistically significant increase in BC, DAP, and BM with aging. L-MMRB, R-MMRB, and R-GI parameters were at their lowest levels in the 41-60 age group (Table 3). Age-related alterations in the mandibles have been described in the literature for several reasons, including amyloidosis, temporomandibular joint osteoarthritis, osteoporosis, and tooth loss (69).

Univariate DFA was able to estimate the sex in the current study with accuracy rates ranging from 56.7% to 83.3% in males and from 54.2% to 80.8% in females. Using six single-sided measurement variables in multivariate DFA, the accurate sex estimation rate was 81.7% in males and 85.8% in females. Utilizing multivariate DFA with all 24 measures resulted in higher accurate sex estimation rates of 97.5% for males, 96.7% for females, and 97.1% for the overall population. Accurate sex estimation rates of 95% for males, 96.7% for females, and 95.8% for the whole population were obtained by the stepwise DFA utilizing the combination that the system had chosen (Table 5). Loth and Henneberg studied mandible morphology and flexure on the posterior ramus in 1996 (12). They found sex estimation accuracy rates of 98.8% in females and 99.1% in males among normal African blacks. The study also found that white Americans had a 91.7% accurate sex estimation rate, American Indians had 92.4%, and black Americans had 90.6%. The same levels of accuracy in sex estimation have not been obtained in any of the following studies based on morphological characteristics of the mandibular ramus and corpus. Following research on the morphological appearance of the mandible, reported sex estimation accuracy rates ranged from 45.2% to 94% in females, 70.3% to 94.7% in males, and 62.5% to 80.6% in the overall population. (1, 2, 13-17). Sex estimation accuracy rates for morphometric measurements on dry bones, as defined by anthropological and/or forensic studies, have been reported to range from 37.5% to 94% in females, 35.8% to 90.6% in males, and 57.3% to 95.0% in the overall population (3, 4, 18-36). Studies of the measurements on panoramic radiographs and orthopantomographs have reported accuracy rates ranging from 44.7% to 95.5% for females, 50.3% to 94% for males, and 56.3% to 89% for the overall population (37-49). Accurate sex estimation rates with measures obtained by CT studies were reported as between 67.5% and 99.5% in females, 64.2% and 98.5% in males, and 78% and 95.8% in the overall population (5, 50-65).

The literature consisted of limited studies examining the impact of mandibular measurements taken from the right or left side on the accuracy rates for sex estimation. Alves and Deana reported a sex prediction accuracy rate of 70% for the right side and 67% for the left side in a DFA in the Brazilian population (4). Bertsasos et al. determined that in multivariate DFA, the right side had slightly higher sex estimation accuracy rates (82.7%) than the left side (84.9%) (29). Sairam et al. reported that the sex estimation accuracy rate was slightly higher on the right (79.5%) than the left (77%) utilizing only ramus measurements and on the left (79.5%) than the right (76%) utilizing all mandibular parameters (49). However, no study in the literature has examined side differences between males and females. According to the results of the current investigation, the accuracy rates for sex estimation in multivariate DFA were higher on the left side in men (93.3%) than in females (90.8%), and on the right side in females (95%) than in males (90.8%). This result showed that measurements obtained from the left side were more dysmorphic in males and from the right side in females.

Various accuracy rates were reported in the previous research by mandible measures for sex estimation. The variation in the origin, size, and demographic characteristics of the study population, differences in the methodology and statistical analysis methods, and variations among the observers are some potential causes of this variability.

In the current study, each of the mandible linear measurements exhibited a low degree of sexual dimorphism when examined using univariate DFA, while accurate sex estimation rates were found to be 97.5% for males, 96.7% for females, and 97.1% for the overall population in the Eastern adult Turkish population when all parameters were analyzed using multivariate DFA.

The data obtained with this study on this Eastern Turkish society, which both confirms previous research and suggests new ideas, is thought to be an extremely useful database for future studies in the fields of forensic anthropology and archaeology for sex estimation.

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