NO-FEE OPEN ACCESS JOURNAL indexed in Scopus

Bulletin of the International Association for Paleodontology

Volume 18, Issue 2, 2024

Established: 2007

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We thank all the reviewers for their effort and time invested to improve the papers published in this journal.

Sex determination from dry mandibles using metric methods*

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Bull Int Assoc Paleodont. 2024;18(2):78-86.

Abstract

Objectives: The article discusses sex determination as the basis for paleodemographic studies to describe ancient populations, metric methods using mandibles. Material and Methods: Two commonly used methods in anthropology for sex determination are the anthroposcopic method and the anthropometric method. The anthroposcopic method involves a macroscopic examination of skeletal materials to identify distinguishing criteria between sexes. The article notes that sex can be determined with 100% accuracy from the pelvis and 90% accuracy from the skull, provided the skeletal remains are intact. In contrast, the anthropometric method relies on statistical analysis of results obtained from metric measurements of skeletons to reveal sex differences. This method is considered more objective because it relies on numerical data, providing precise differences between sexes. Many researchers have used metric measurements to confirm morphological differences between male and female individuals, as mentioned in the article. In this study, 10 different measurements were taken on the mandible and statistically evaluated, resulting in a significant difference between sexes, which allows for sex determination with an accuracy of 80% or higher. Results: Consequently, the article highlights the importance of sex determination in palaeodemographic studies and emphasizes the utility of both anthroposcopic and anthropometric methods. It underscores the significance of the mandible as a reliable skeletal material, even when other bones are absent or fragmented, and emphasizes the precision of sex determination through metric measurements.

Keywords: forensic anthropology; forensic dentistry; mandible; sex determination; metric

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Introduction

The foundation of palaeodemographic studies on ancient populations revolves around determining the sex of individuals. This is crucial because the criteria for determining age vary based on sex. Sex determination in anthropology can be achieved through two methods: the anthroposcopic method and the anthropometric method. The anthroposcopic method involves a macroscopic examination of skeletal materials to determine distinguishing criteria between sexes. Depending on the condition of the skeletal remains, sex determination can be made with 100% accuracy from the pelvis and 90% accuracy from the skull[1]. In situations where the skull and pelvic bones are absent or fragmented, the mandible becomes a crucial skeletal material for identification, thanks to its robust structure and good preservation. Features such as the shape and size of the ramus, mass structure, height, thickness, and size of the mandibular body, which can be determined through macroscopic examination of the mandible, exhibit morphological differences between males and females. Furthermore, the anthropometric method, the other approach used for sex determination, relies on the statistical analysis of metric measurements taken from skeletons to reveal the differences between the sexes. As metric measurements rely on numerical data, they yield more objective results, providing precise distinctions between the sexes (1-3). Upon reviewing the literature, it becomes evident that many researchers have validated morphological differences between male and female individuals using data obtained from metric measurements (1-4). In this study, we conducted measurements on the mandible, specifically taking 11 different measurements. Upon statistically evaluating the obtained data, a significant difference between the sexes emerged, revealing that sex could be determined with an accuracy of 80% or more. In light of this information, it is possible to determine sex from any measurement taken from the mandible recovered from ancient populations, even when the integrity of the mandible is compromised.

Materials and Methods

The study was conducted on 101 dry mandibles obtained from the anthropology laboratory with the permission of Hitit University Anthropology Department (Table 1). The measurements were taken from the mandibles of adult male and female individuals, and the mandibles of infants, children and adolescents were excluded from the study. Annhropological analysis of the individuals (age and sex) was carried out by Çırak et al. (5). The study was initiated with the approval of the ethics committee numbered 2020-115 by the Hitit University Non-Interventional Research Ethics Committee.

Metric Method: The measurements made for sex determination from the dry mandible were determined according to the measurement points taken by the researchers in the literatüre (2, 6-12). Accordingly;

1. *Bicondylar width:* It refers to the distance between the right and left mandibular condyle (2), Figure 1.
2. *Bigonial width:* It refers to the distance between the right and left gonial angle (6) Figure 1.
3. *Condyle width:* Refers to the width of the processus condyle, Figure 5
4. *Maximum coronoid height:* It refers to the distance between the coronoid and the lower border of the mandible (8), Figure 3.
5. *Condylar height:* It refers to the distance between the mandibular condyle and the lower border of the mandible (8), Figure 3.
6. *Body height (P alignment):* It refers to the distance between the premolar and mandibular corpus (9), Figure 3.
7. *Body height (M3 alignment):* Refers to the distance between Molar 3 and Mandibular corpus, Figure 3.
8. *D1:* The distance between the points between the coronoid and condyle (midpoint of the mandibular notch) and the mandibular canal (10), Figure 3.
9. *D2:* The distance between the points between the coronoid and chondyle (midpoint of the mandibular notch) and the lower border of the mandibular body (10), Figure 3.
10. *Length between M3*: The distance between the right and left molar 3 (11), Figure 4.

Accordingly, the dry mandibles were measured with a Yamer brand 9001 - 2009 model digital caliper with an accuracy of 0.01 mm (Figure 1).

Statistical Method

In determining whether there is a statistically significant difference between sex groups, the following statistical tests were employed: the Student t-test, Mann-Whitney U test, and One-Way Analysis of Variance (ANOVA). The Student t-test and Mann-Whitney U test were utilized under the assumption of normal distribution, while the Kruskal-Wallis test was employed if the assumption was not met. Additionally, the Tukey

Figure 1. Bicondylar width, Bigonial width.

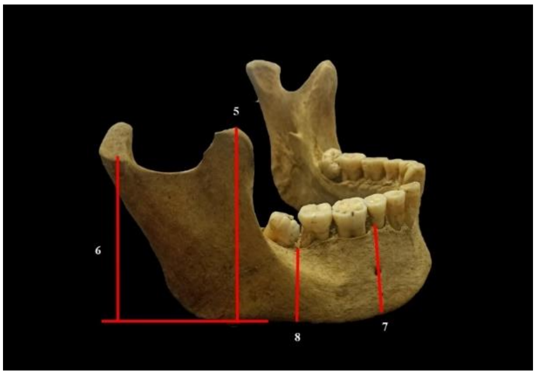


Figure 2. Maximum coronoid height, Condylar height, Corpus height (P alignment), Corpus height (M3 alignment).

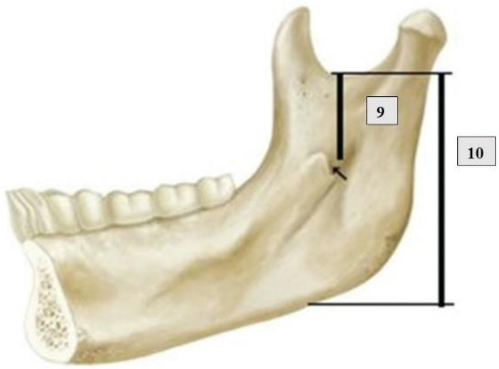


Figure 3. D1 and D2.

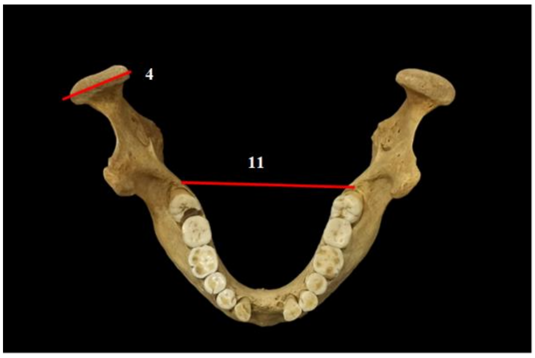


Figure 4. Condyle width and Length between M3.

test, one of the multiple comparison tests, was used to identify specific groups from which the significance originates in cases where One-Way ANOVA was applied. To predict sex, variables showing significance in the Student t-test were subjected to Logistic Regression analysis, resulting in the creation of prediction equations for each measurement. The study analyses were carried out using IBM SPSS V22 and Past 4.03 programs. In the analyses, a significance level of $p < 0.05$ was used to determine statistical significance.

Results

Measurements were taken on 101 mandibles obtained from Hitit University Anthropology Laboratory, but the data obtained from 96 mandibles were used in statistical analyses. Of the statistically analysed mandibles, 61 belonged to male and 35 to female individuals. Of the mandibles, 72 were complete (42 males, 30 females) and 24 were partial (9 males, 15 females). Initially, the analysis focused on assessing the difference between the mandibles obtained from the right and left sides of the mandibles. In assessing the difference between the right and left sides of the measurements, the paired t-test was employed if the assumption of normal distribution was met; otherwise, the Wilcoxon test was utilized.

To determine sex, 10 metric measurements were taken on the dry mandible (Table 2). The mean values (± standard deviation or range) for various measurements between females and males are as follows Table 2 (12).

In the context of sex determination, measurement variables with significant results from the Student t-test were subjected to Logistic Regression analysis, leading to the creation of prediction (probability) equations for each measurement. If the value obtained from the equation is 0.5 or above, the sex determination is classified as "Male"; if the value is below 0.5, the sex determination is classified as "Female". For each measurement, the sex determination obtained from the study dataset was compared with the actual situation, and the sensitivity (the percentage of correctly identified females) and selectivity (the percentage of correctly identified males) were calculated.

A logistic regression model was developed in the study to estimate sex based on the measurements examined (Table 3), and equations that allow for the calculation of probability values were provided. The model was built using the variables that showed statistically significant differences between males and females in the analyzed measurements. Logistic regression analyses were conducted on the 11 metric measures identified as statistically significant between sexes, and the results are presented in Table 3.

$P(Y = 1/X = x) = \frac{1}{1+e^{-(b_0+b_1X)}}$

The formula is derived by incorporating the statistically significant parameters from the models established in Table 3. The sex is estimated as "Male" if the probability value, calculated by replacing X in the equation with the value of the examined parameter, is 0.5 or above. Conversely, if this value is below 0.5, the sex is estimated as "Female".

The equation for the *Condyle Width* parameter is provided below, and the accuracy of sex determination for this model is 50% for females and 84.9% for males.

$$P(Y = 1/X = x) = \frac{1}{1 + e^{-(-7,543+0,395\ x)}}$$

The equation for the *Bicondylar Width* parameter is presented below, with an accuracy of sex determination for this model being 57.1% for females and 82.6% for males.

$$P(Y = 1/X = x) = \frac{1}{1 + e^{-(-24,647+0,21\ x)}}$$

The equation for the *Bigonial Width* parameter is provided below, with the accuracy of sex determination for this model being 36.6% for females and 84.4% for males.

$$P(Y = 1/X = x) = \frac{1}{1 + e^{-(-9,37+0,098\ x)}}$$

The equation for the *Maximum Coronoid Height* parameter is as follows. According to this model, the accuracy of sex determination is 85.7% for females and 88.6% for males.

$$P(Y = 1/X = x) = \frac{1}{1 + e^{-(-24,841+0,413\ x)}}$$

The equation for the *Condylar Height* parameter is provided below, with the accuracy of sex determination for this model being 69.9% for females and 89.5% for males.

$$P(Y = 1/X = x) = \frac{1}{1 + e^{-(-21,194+0,361\ x)}}$$

The equation for the *Body Height* (M3 alignment) parameter is provided below. According to this model, the accuracy of sex determination is 57.1% for females and 85.1% for males.

$$P(Y = 1/X = x) = \frac{1}{1 + e^{-(-12,362+0,505\ x)}}$$

Table 1. Mandible distributions between sexes.

The equation for the *Body Height* (P alignment) parameter is provided below, with the accuracy of sex determination for this model being 51.7% for females and 81.3% for males.

$$P(Y = 1/X = x) = \frac{1}{1 + e^{-(-9,615+0,324\ x)}}$$

The equation for the *D1* parameter is provided below, with the accuracy of sex determination for this model being 50% for females and 87.8% for males.

$$P(Y = 1/X = x) = \frac{1}{1 + e^{-(-7,421+0,353\ x)}}$$

The equation for the *D2* parameter is provided below, with the accuracy of sex determination for this model being 73.1% for females and 90.2% for males.

$$P(Y = 1/X = x) = \frac{1}{1 + e^{-(-13,185+0,294\ x)}}$$

The equation for the *Length between M3* parameter is presented below, indicating an accuracy of 41.2% for females and 87.5% for males in sex determination for this model.

$$P(Y = 1/X = x) = \frac{1}{1 + e^{-(-9,547+0,158\ x)}}$$

The measurements obtained from the dry mandible were analyzed using plot analysis in the Past 4.03 program. For male individuals, the lowest *condyle width* ranged from 16.91 to 24.56, while for female individuals, it ranged from 15.20 to 22. Sexual dimorphism is clearly evident in the plot analysis (Graph 1).

For male individuals, the *Maximum Coronoid Height* ranged from 56.49 to 77.09, while for female individuals, it ranged from 46.18 to 64.17, as illustrated in Graph 2. The considerable difference between the maximum coronoid height values between the sexes highlights significant sexual dimorphism.

For male individuals, the *Condylar Height* ranged from 51.59 to 77.06, while for female individuals, it ranged from 37.33 to 61.24 (Graph 3). The distinct difference in condylar height values between males and females is evident. Consequently, individuals with values above 61.24 are reliably identified as male, whereas those below 51.59 are classified as female.

For male individuals, the *Bicondylar Width* ranged from 113.94 to 132.78, whereas for female individuals, it ranged from 103.37 to 124.66 (Graph 4). Notably, bicondylar width stands out as one of the measurements exhibiting the most significant differences between male and female individuals.

	Female	%	Male	%	Total	%
Young Adult	20	45,45	24	54,55	44	43,57
Middle Adult	10	30,3	23	69,7	33	32,67
Advanced Adult	7	35	13	65	20	19,8
Adult	1	25	3	75	4	3,96
	38	37,62	63	62,38	101	100

Table 2. Sexual dimorphism between measurements (mm).

	Female	Male	p
Condyle Width	19,02 ± 2,08	20,74 ± 2,103	0,003[a]
Bicondylar Width	116,42 ± 5,907	123,3 ± 5,685	0,001[a]
Bigonial Width	95,77 ± 8,449	102,1 ± 7,844	0,007[a]
Maximum Coronoid Height	55 ± 5,25	66,03 ± 4,845	<0,001[a]
Condylar Height	53,66 ± 6,302	65,83 ± 5,385	<0,001[a]
Body Height M3 Alignment	23,63 ± 2,179	27,65 ± 3,266	<0,001[a]
Body Height P Alignment	29,87 ± 2,977	32,59 ± 2,821	<0,001[a]
D1: Points between coronoid-condyle and mandibular canal	20,58 ± 3,265	23,95 ± 2,883	<0,001[a]
D2: Points between coronoid-condyle and mandibular canal	40,3(30,6 – 52,6)	51,5(24,8 – 57,9)	<0,001[b]
Length Between M3	61,9(55 – 68,7)	66(47,9 – 72,8)	0,002[b]

a: Student t test; mean±standard deviation
b: Mann-Whitney U test; median (minimum-maximum)
Note: The number of observations is different because not all values could be obtained in all skeletal measurements.

Table 3. Models obtained by logistic regression analysis.

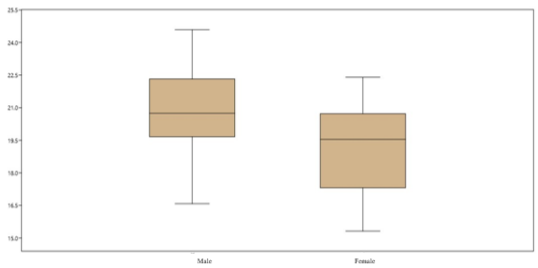
	Beta Coefficient	Standard Error	p*	Exp(B)	95% Confidence Interval	
					Lower Limit	Upper Limit
Condyle Width	0,395	0,147	0,007	1,484	1,113	1,979
Bicondylar Width	0,210	0,077	0,006	1,233	1,061	1,433
Bigonial Width	0,098	0,040	0,013	1,103	1,021	1,192
Maximum Coronoid Height	0,413	0,100	<0,001	1,512	1,242	1,840
Condylar Height	0,361	0,091	<0,001	1,435	1,201	1,715
Body Height M3 Alignment	0,505	0,127	<0,001	1,658	1,293	2,125
Body Height P Alignment	0,324	0,095	0,001	1,383	1,147	1,667
D1: Points between coronoid-condyle	0,353	0,101	<0,001	1,423	1,168	1,733

and mandibular canal						
D2: Points between coronoid and condyle and mandibular canal	0,294	0,070	<0,001	1,341	1,168	1,540
Length Between M3	0,158	0,064	0,014	1,172	1,033	1,329

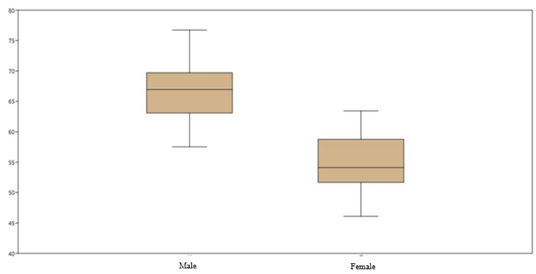
*Univariate Logistic Regression analysis; Female data were taken as reference.

Table 4. Probability percentiles for sex prediction by logistic regression analysis.

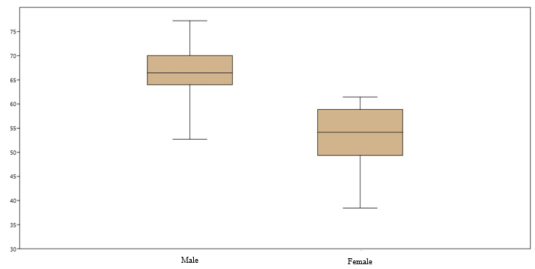
	Female %	Male %
Condyle Width	50	84,9
Maximum Coronoid Height	85,7	88,6
Condylar Height	69,9	89,5
Bicondylar Width	57,1	82,6
Bigonial Width	36,6	84,4
Mandible Body Height (M3 alignment)	57,1	85,1
Mandibular Body Height (P alignment)	51,7	81,3
D-1	50	87,8
D-2	73,1	90,2
Length Between M3	41,2	87,5



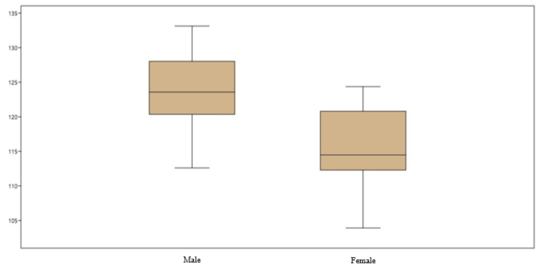
Graphic 1. Boxplot of condyle width values.



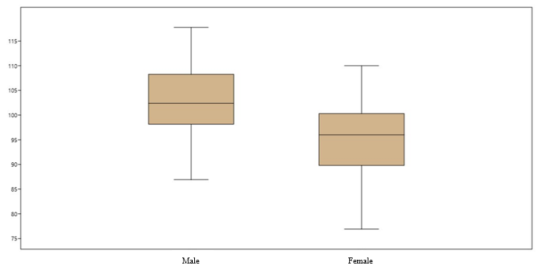
Graphic 2. Boxplot of maximum coronoid height values.



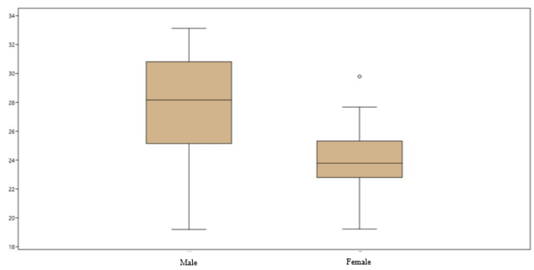
Graphic 3. Boxplot of Condylar height values.



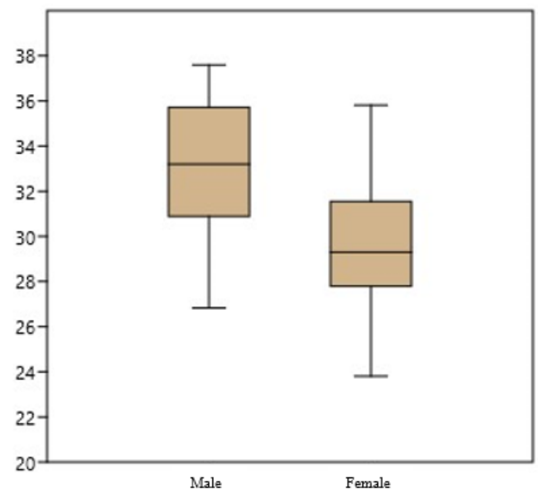
Graphic 4. Boxplot of Bicondylar width values.



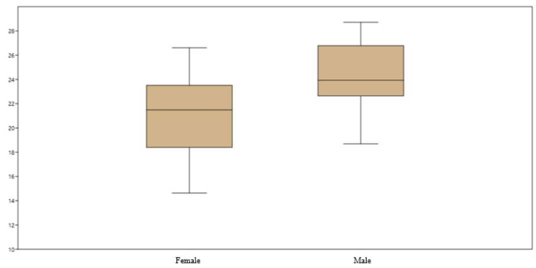
Graphic 1. Boxplot of bigonial width values.



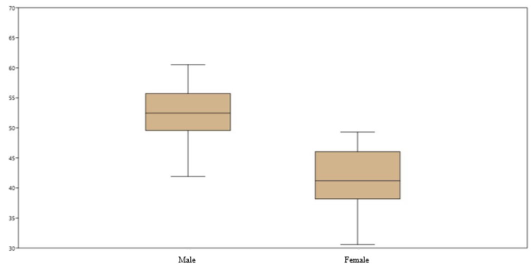
Graphic 6. Boxplot Plot of body height (M3 alignment) values.



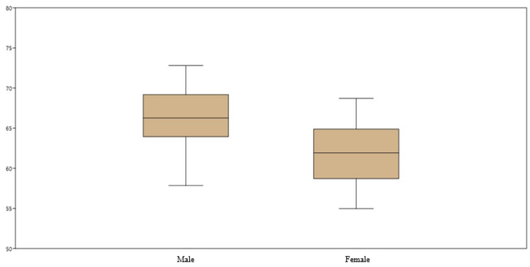
Graphic 7. Boxplot Plot of trunk height (P alignment) values.



Graphic 8. Boxplot of D1 measure values.



Graphic 9. Boxplot of D2 measure values.



Graphic 10. Boxplot of length values between M3.

In male individuals, the *Bigonial Width* ranged from 88.15 to 122.85, while in female individuals, it ranged from 76.12 to 109.88 (Graph 5).

For male individuals, Body Height (M3 alignment) ranged from 19.48 to 33.61, while for female individuals, trunk height (M3 level) ranged from 19.42 to 27.65 (Graph 6). Although the minimum values are relatively close, a substantial difference is observed in the maximum values of body height between male and female individuals

For male individuals, *Body Height* (P alignment) ranged from 27.81 to 37.86, while for female individuals, it ranged from 23.3 to 35.79 (Graph 7).

In male individuals, the *D1* values range from 18.38 to 29.48, while in female individuals, they range from 14.37 to 27.38 (Graph 8). It can be confidently stated that individuals with *D1* values below 18.38 are female.

"In male individuals, *D2* values range from 42.45 to 61.11, while in female individuals, they range from 29.79 to 49.93 (Graph 9). This measurement stands out as one of the most prominent indicators of the difference between male and female individuals, reflecting sexual dimorphism.

In male individuals, the Length between M3 ranged from 58.22 to 72.38, while in female individuals, it ranged from 56.69 to 67.32 (Graph 10). The difference between the maximum values of the length between M3 teeth in male and female individuals is statistically significant, whereas the minimum values are closely aligned.

Discussion

The mandible, which is one of the skull bones, is among the bones where sexual dimorphism is most prominent. Factors such as the developmental stage of the mandible, growth rate, and masticatory forces cause morphological differences in male and female mandibles (13). These differences in morphology are reflected in morphometry. In this study, 11 different measurements were taken on the mandible and

the differences between sexes were evaluated. In addition to this, the studies of the researchers in the literature who conducted studies on dry mandibles were analysed and compared with the data obtained.
When the studies on the *width of the condyle* are analysed, Pokhrel and Bhatnagar (14) reported that male individuals were detected with a high accuracy rate of 90.6%, while the accuracy rate of female individuals was 30.8%. Saini et al. revealed that there was a significant difference between sexes with the findings obtained from condyle width. However, Vodanovic et al. (15) reported that condyle width did not differ statistically between sexes.
A significant difference has been found between sexes in term of the *maximum coronoid height* by various researchers (8,10,16-18). Sairam et al. conducted studies from *condylar height*. Saini et al. reported that there was a statistically significant difference between sexes when the analyses of the obtained measurements were examined.
When the studies on *bicondylar width measurement* are analyzed by researchers, it is found that bicondylar width is statistically significant between sexes (2,6,9,13,16,18-23). However, Kujur et al. found that there was no statistically significant difference in bicondylar width between male and female individuals.
When various studies on *bigonial width measurement* are analyzed, it is observed that there is a statistical difference between sexes in bigonial measurements taken on dry mandibles (2,6,7,9,13,16,18,20-26).
Considering some of the studies on *mandibular body height (P alignment),* Datta et al., Sikka and Jain, Saini et al. reported that there was a statistical difference between the sexes in the mandibular body height measurement obtained from dry mandibles.
Considering the studies conducted on D-1, D2 measurements, Sairam et al. explained that there was a statistically significant difference between sexes in D-1, D2 measurements in their study on dry mandible.
When the studies on the *inter-M3 length* measurement were analyzed, Jacob et al. on dry mandibles reported that the inter-M3 length measurement was statistically significant between sexes.
Consequently, the results of the statistical analysis of the 10 parameters used in this study were compared with the studies of other researchers in the literature. The results obtained support the results obtained by many researchers. In the study, 10 parameters taken from the mandible showed significant differences between sexes and probability percentages for sex prediction were determined by logistic regression analysis (Table 4).
In the study, the feasibility of sex determination was tested using metric measurements taken from dry mandibles obtained from the Kefevi necropolis, dated to the Byzantine Period. As a result, it is observed that the maximum coronoid height among the measurements taken from the mandible has the highest percentage in terms of predicting female individuals. For male individuals, the D-2 height was found to be quite effective in predicting sex. Overall, when the measurements taken from the mandible are evaluated, it is observed that predicting male individuals is more likely. This study is important because it demonstrates that sex determination can be achieved using measurements from the mandible with osteometric methods.

Acknowledgement
We extend our sincere appreciation to the Head of the Department of Anthropology at Hitit University for granting permission to utilize the mandibles employed in this study.

Declaration of Interest
No potential conflict of interest was reported by the authors.

Author Contributions
HHE: Excavation and cleaning of materials retrieved from the excavation area, measurement of materials, data entry and evaluation, literature review, Master's Thesis Work
AS: Excavation and cleaning of materials retrieved from the excavation area, measurement of materials, data entry and evaluation, literature review, Master's Thesis Advisor

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