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Sex estimation by metric analysis from the sternum bone in the Havuzdere (Yalova) Medieval population‡

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Abstract

The priority in creating biological profiles is sex estimation. The use of metric measurements in sex estimation has a long history. However, in the sex estimation studies using metric measurements, bones like the sternum have been less frequently examined compared to long bones. This study examined the accuracy rate of metric measurements taken from the sternum in sex estimation. A total of 62 adult individuals (24♀/38♂) from the Medieval Havuzdere (Yalova) population were examined. 4 different measurements (maximum manubrial width, manubrial width, manubrial length, corpus sterni length) were determined on the sternum bone, and 166 measurements were taken from a total of 62 sternum in the population. The data were analyzed using SPSS 23 program, applying the *t*-test, *Wilks Lambda* test, *F*-test, and Discriminant Function Analysis. Analysis results show that reliable accuracy was achieved in sex estimation based on sternum measurements. Accordingly, the manubrial width measurement at the sternum was 92.5% (93.8%♀/91.7%♂) respectively; corpus sterni length measurement was 85.3% (100%♀/78.3%♂); the manubrial length measurement was able to differentiate correctly at a rate of 74.5% (76.2%♀/73.3%♂). The lowest discrimination rate is the maximum manubrial width measurement with 73.8% (68.8%♀/76.9%♂). The accuracy of sex estimation was higher in 3 measurements for female and in 1 for male. When the measurements of the bones taken separately were evaluated together, the rate of correct sex determination generally increased.

These findings highlight the potential of the sternum in sex estimation and contribute to forensic and bioarchaeological research.

Key Words: Sternum, Sex Estimation, Discriminant Function Analysis, Havuzdere (Yalova), Medieval

Havuzdere (Yalova) Orta Çağ popülasyonunda sternum kemiğinden metrik analizle cinsiyet tahmini

Özet

Biyolojik profillerin oluşturulmasında öncelik cinsiyet tahminidir. Cinsiyet tahmininde metrik ölçümlerin kullanılmasının uzun bir geçmişi vardır. Bununla beraber metrik ölçümler kullanılarak yapılan cinsiyet tahmini çalışmalarında sternum gibi kemikler uzun kemiklere göre daha az ele alınmıştır. Bu çalışmada sternumdan alınan metrik ölçümlerin cinsiyet tahmininde doğruluk oranı araştırılmıştır. Orta Çağ Havuzdere (Yalova) popülasyonunda toplam 62 erişkin birey (24♀/38♂) incelenmiştir. Sternum kemiğinde 4 farklı ölçüm (maksimum manubrial genişlik, manubrial genişlik, manubrial uzunluk, corpus sterni uzunluğu) belirlenmiş ve popülasyondaki toplam 62 sternumdan 166 ölçüm alınmıştır. Veriler SPSS 23 programında analiz edilmiş ve t-testi, Wilks Lambda testi, F-testi ve Discriminant Fonksiyon Analizi uygulanmıştır. Analiz sonuçları, sternum ölçümlerine dayalı cinsiyet tahmininde güvenilir doğruluk elde edildiğini göstermektedir. Buna göre, sternumda manubrial genişlik ölçümü sırasıyla %92,5 (93,8%♀/91,7%♂); corpus sterni uzunluk ölçümü %85,3 (100%♀/78,3%♂); manubrial uzunluk ölçümü %74,5 (76,2%♀/73,3%♂) oranında doğru bir şekilde ayırt edilebilmiştir. En düşük ayırım oranı %73,8 (68,8%♀/76,9%♂) ile maksimum manubrial genişlik ölçümüdür. Cinsiyet tahmininin doğruluğu kadınlar için 3 ölçümde ve erkekler için 1 ölçümde daha yüksek orandadır. Ayrı ayrı alınan kemiklerin ölçümleri birlikte değerlendirildiğinde, cinsiyetleri doğru bir şekilde ayırt etme oranı genel olarak artmıştır.

Bu bulgular sternumun cinsiyet tahminindeki potansiyelini ortaya koymakta ve adli ve biyoarkeolojik araştırmalara katkı sağlamaktadır.

Anahtar Kelimeler: *Sternum, Cinsiyet Tahmini, Diskriminant Fonksiyon Analizi, Havuzdere (Yalova), Orta Çağ*

Introduction

Correct evaluation of sex is critical when identification needs to be determined from skeletal remains. Sex classification effectively halves the number of possible matches. Moreover, when the remains belong to a female individual and a male individual is mistakenly searched, correct identification can never be made. In addition, it is essential to correctly determine the sex of the individual in order to choose the appropriate formula for other analyses such as height estimation. Therefore, sex estimation is the most important part of all skeletal analyses (Stanford et al., 2013; Steyn, 2013; White et al., 2012).

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There are two methodological approaches to determining sex from skeletal remains, morphological and metric methods. The morphological approach focuses on shape, that is, bones that are visible macroscopically and differ between male and female. However, not all skeletal components have consistent and discernible morphological evidence of sexual dimorphism. Problems arise when differences are based solely on size and no clear male or female shape, or when the remains are incomplete, and the observer has to rely on less dimorphic bones. A metric approach is followed in these cases. Applying statistical analysis to these metric approaches is an important method. Discriminant function analysis is one of these statistical approaches. Sex estimation with the help of discriminant function analysis is beneficial in mass graves, natural disasters, and forensic events, as it can be applied to each bone in the skeleton, and multiple data can be evaluated together within the possibilities (Güleç et al., 2003; Gülhan, 2018; Özer, 2014; Steyn, 2013). The investigator should be able to gather as much information as possible from any bone or fragment. For this reason, measurements of the sternum bone, which are not frequently used in the literature, were used in the article.

Material and Method

Material

The material of this study consists of the skeletons found during the excavations carried out in 2013 in the necropolis area, which dates back to the 15th century and is located within the borders of Havuzdere village, Altınova district, Yalova province (Figure 1). These well-preserved skeletons' cleaning and repair processes were carried out in the Anthropology Department Laboratory of Ankara University Faculty of Languages, History and Geography. Morphological analyses on the cranium and pelvis were mostly used in sex estimation. In the age assessment process, methods such as tooth wear, epiphyseal closure, and age-related change of the symphysis pubis were used (Özer, 1999; Ubelaker, 1978; WEA, 1980).

The material of this study consists of skeletons selected from the population whose sex predictions have been precisely determined by morphological data (epiphyseal closure completed, adult individuals over 18 years of age). Individuals with question marks, suspicious ones, most of whose bones are missing or destroyed; those showing pathological changes such as osteophytes, osteoarthritis, and enthesopathy; trauma and fracture samples were not included in the study. After the study material was determined according to these criteria, metric measurements were taken from the selected individuals. Although this leads to a decrease in the number of individuals used in the study, it increases the accuracy rate of our study and ensures its reliability (Table 1).

Figure 1. *Location of Havuzdere (Google Earth / 09.02.2024) and a grave photograph from the Havuzdere Excavation Archive.*

Table 1. *Sex and age distribution of Havuzdere adult individuals whose sternum measurements were taken*

Age Groups	Sex Distribution		
	♀	♂	♀ + ♂
18-29,9 (Young Adult)	5	4	9
30-44,9 (Middle Adult)	15	30	45
45+ (Old Adult)	4	4	8
Total	**24**	**38**	**62**

Method

Martin (1928) and Bass (1995) were used as references when taking measurements. Measurements were taken from the left side using spreading calipers. It is useful to use methods that can be compared with other studies, so the measurements used in previous studies, given in Table 2 and Figure 2, have been selected. The current literature on the sternum was comprehensively reviewed; however, certain studies were excluded from the analysis due to methodological differences (such as the use of alternative analytical approaches) or insufficient data presentation (e.g., lack

of separate reporting of analysis results for each measurement). While these studies were considered during the literature review to provide a broader context, they were ultimately excluded from the methodological evaluation to maintain consistency and comparability of the data used in this study.

Statistical analysis

The obtained data were systematically recorded on the computer and statistical analyses were performed. In this study, which aims to determine sex differences, the measurements taken were evaluated separately. First, univariate analyses were performed, and then multivariate analyses were performed. The accuracy percentages of the obtained formulas were calculated separately for both females and males and then a general percentage rate was determined for the entire population.

The data were analyzed in the SPSS 23 program. Following standard descriptive analyses, the *t*-test, Wilks Lambda test, *F*-test, and Discriminant Function Analysis were applied. Discriminant Analysis has been used to accurately distinguish classes within a group. The functions produced based on the calculated linear combinations provided the best separation between the groups and presented the linear ratio of this separation. The *t-test* was used to determine whether there was a difference in means between the two sample groups. In the Wilks Lambda Test, low lambda values indicate that the distribution between groups

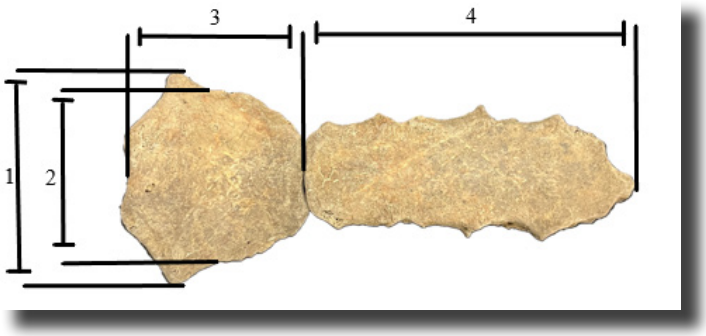

Figure 2. *Sternum bone of an individual coded B5 M65 (Female / 20-25 Years Old) in the Havuzdere population (1. MMB: Maksimum Manubrial Breadth, 2. MB: Manubrial Breadth, 3. ML: Manubrial Length, 4. LCS: Length of the Corpus Sterni)*

is large. Based on the Wilks Lambda value, it was determined how many variables could make a significant distinction between groups ($p<0.05$). The *F*-test was applied to test whether there was a significant difference between the averages of more than two groups (Kalaycı, 2014; Özer, 2014).

Results

Metric values of the sternum and statistical analyses using these values are given in Table 3. İt was observed that all measurements taken from the sternum were higher in males than in females. As a result of the applied *t*-test, all measurements are significant at the $p<0.001$ level.

According to the Wilks Lambda Test, manubrial width and corpus sterni length values at the sternum were the determining

Table 2. *Measurements used on the sternum bone*

Code	Measurement	Definition	Resources
MMB	Maksimum Manubrial Breadth	It is the largest width of the manubrium. The measuring tool is a spreading caliper.	Martin, 1928
MB	Manubrial Breadth	It is the linear distance between the centers of the first costal notches. The measuring tool is a spreading caliper	Bass, 1995
ML	Manubrial Length	It is the linear distance between the lowest point of the jugular notch and the lowest point on the lower articular surface of the manubrium. The measuring tool is a spreading caliper.	Martin, 1928
LCS	Length of the Corpus Sterni	It is the linear distance from the center of the upper joint surface (manubrial) to the center of the lower joint surface (xiphoid). The measuring tool is a spreading caliper.	Martin, 1928

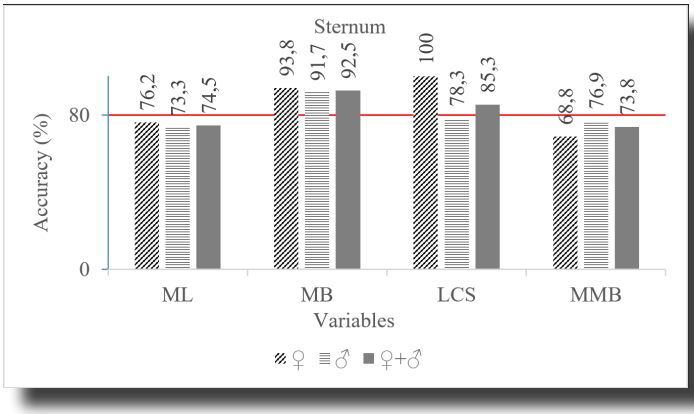

Figure 3. Accuracy rates with discriminant function analysis of sternum bone of Havuzdere individuals

of 85.3%. The lowest discrimination rate is the maximum manubrial width measure with 73.8%.

The corpus sterni length measurement was able to distinguish 100% accurately in female individuals. The lowest discrimination rate is the maximum manubrial width measure with 68.8%. The manubrial width measurement in male individuals was able to distinguish 91.7% accurately. The lowest discrimination rate is the manubrial length measure with 73.3% (Table 4, Figure 3).

Table 3. Mean, standard deviation, and statistical values of the sternum bone of Havuzdere individuals

Variables	♀ (N=24)			♂ (N=38)			Analyses (♀+♂=62)		
	N	Mean (mm)	SD	N	Mean (mm)	SD	*t-test**	Willks Lambda Test	*F*- test
Sternum									
ML	21	45,119	5,513	30	51,083	4,331	**4,323***	0,750	5,000
MB	16	48,688	3,439	24	57,104	4,170	**6,690***	**0,408**	**21,789**
LCS	11	82,591	7,127	23	103,783	12,646	**5,154***	**0,423**	**20,457**
MMB	16	53,688	6,792	26	64,712	7,494	**4,793***	0,560	11,797

*p<0,001

SD: Standard deviation

ML: Manubrial Length / MB: Manubrial Breadth / LCS: Length of the Corpus Sterni / MMB: MMB: Maksimum Manubrial Breadth

Table 4. *Discriminant function analysis of the sternum bone of Havuzdere individuals*

Variables	Coefficient	Constant	Sectioning Point	Distinction Point	Accuracy (%)		
Sternum					♀	♂	**Overall**
ML	0,206	-10,029	-0,109	48,627	76,2	73,3	74,5
MB	0,257	-13,785	-0,216	53,738	93,8	**91,7**	**92,5**
LCS	0,089	-8,641	-0,334	96,927	**100,0**	78,3	85,3
MMB	0,138	-8,359	-0,182	60,512	68,8	76,9	73,8
AV					100	80,0	88,2

AV: All Variables (only % accuracy rates used)

measurements between sexes. The measurements that most clearly reflected the sex difference in the *F*-test were the same as the values in the Wilks Lambda Test (Table 3).

Discriminant analysis results of metric data obtained from the sternum bone in the Havuzdere population are given in Table 4. Accordingly, the manubrial width measurement at the sternum succeeded in distinguishing the sexes correctly with a rate of 92.5%, and the corpus sterni length measurement with a rate

Discussion

In this section studies using univariate discriminant analysis (UDA) were examined. The total number of variables used in the studies is given in the tables. In the explanation section, the numbers and percentages of variables compatible with the current study are given. By comparing the current study with previous studies, similarities and differences were revealed. Sternum measurements were compared with studies conducted with different populations

(Table 5). In the Havuzdere population, width and length measurements in sternum measurements were decisive in sex prediction. Female measurements were classified correctly at a higher rate than male measurements.

In the study, Çırak (2004) took 6 measurements from the sternum of 315 individuals (139♀/176♂) in the Karagündüz population, whose sex was determined by morphological methods. Three measurements (manubrial length, maximum manubrial width, and corpus sterni length) are compatible with the current study. The highest value from the Karagündüz population is the corpus sterni length measure with a rate of 90.0% (88.9%♀/90.9%♂). The lowest value is the manubrial length measurement with a rate of 64.5% (71.4%♀/58.8%♂). Macaluso Jr. (2010) took 8 measurements from the sternum of 206 individuals of known sex (83♀/123♂) in the Raymond A. Dart Human Skeleton Collection and Pretoria Bone Collection. Three measurements (manubrial length, manubrial width, corpus sterni length) are compatible with the current study. Corpus sterni length has an accuracy percentage of 83.5% (84.3%♀/82.9%♂). The manubrial width measurement is 79.1% (81.9%♀/77.2%♂) and the manubrial length measurement is 68.4% (73.5%♀/65.0%♂), with values below the 80% accuracy percentage. However, in all three measurements, female measurements were classified more accurately than male measurements. In their study at the Department of Forensic Medicine, Graduate Medical Education and Research Institute, Singh and Pathak (2013) took 7 measurements from the sternum of 343 individuals (91♀/252♂) whose sex was known. Three measurements (manubrial length, maximum manubrial width, and corpus sterni length) are compatible with the current study. Corpus sterni length has an accuracy percentage of 75.5% (71.4%♀/77.0%♂). Manubrial length has an accuracy rate of 67.1% (68.1%♀/66.1%♂). All 3 measurements have values below 80% accuracy. In the study, García-Parra et al. (2014) took 8 measurements from the sternum of 105 individuals of known sex (48♀/75♂) in the skeletons unearthed from the San José Granada Cemetery. Three measurements

Table 5. Sex estimation studies performed with metric measurements from the sternum bone

Author	Population	Material	Sample (N)	NV*	UDA (↑/↓)**
Çırak, 2004	Karagündüz (Van) / Türkiye	Dry Bone / Medieval Ages	139♀/176♂	6	↑%90,0 ↓%64,5
Çırak, 2004	Kelenderis (Mersin) / Türkiye	Dry Bone / Contemporary Age (19th century)	29♀/25♂	6	↑%75,0 ↓%50,0
Macaluso Jr., 2010	South African / Black	Dry Bone / 19-20th century	83♀/123♂	8	↑%86,9 ↓%68,4
Singh and Pathak, 2013	North India	Cadaver / Current	91♀/252♂	7	↑%82,2 ↓%63,3
Chandrakanth et al., 2014	South India	Cadaver / Current	50♀/67♂	5	↑%74,4 ↓%67,5
Garcia-Parra et al., 2014	Spain	Dry Bone / 1920-2002	48♀/57♂	8	↑%87,0 ↓%70,7
Tun et al., 2015	Thailand	Cadaver / Dried Bone / Current	89♀/192♂	7	↑%85,8 ↓%56,1
Kalbouneh et al., 2021	Jordan	Living Individuals / CT	300♀/300♂	6	↑%80,8 ↓%54,8
The present study	Havuzdere (Yalova) / Türkiye	Dry Bone / Medieval Ages	24♀/38♂	4	↑%92,5 ↓%73,8

*NV: Number of Variables

**UDA (↑/↓): Univariate Discriminant Analysis (Highest '↑' and lowest '↓' accuracy rate)

(manubrial length, corpus sterni length, and manubrial width) are compatible with the current study. Corpus sterni length is the only measurement above 80% with an accuracy of 87.0% (85.3%♀/88.4%♂). Manubrial length has an accuracy rate of 76.2% (83.3%♀/69.7%♂). Manubrial width measurement percentages are not given. In both measurements, the classification percentages of male and female differed. Tun et al. (2015) took 7 measurements from the sternum of 281 individuals of known sex (89♀/192♂) in their study at the Chiang Mai University Forensic Osteology Research Center. Three measurements (manubrial length, corpus sterni length, and manubrial width) are compatible with the current study. Corpus sterni length is above 80% with an accuracy rate of 81.6% (88.0%♀/79.5%♂). Manubrial length has an accuracy rate of 65.5% (72.1%♀/62.2%♂). In all 3 measurements, female measurements were classified more accurately than male measurements. Kalbouneh et al. (2021) took 6 measurements from the sternum of 600 individuals of known sex (300♀/300♂) in their study the Radiology Department at Jordan University Hospital. Three measurements (manubrial length, corpus sterni length, and maximum manubrial breadth) are compatible with the current study. Corpus sterni length is above 80% with an accuracy rate of 80.8% (80.0%♀/81.6%♂). Maximum manubrial breadth has an accuracy rate of 67.4% (72.0%♀/62.8%♂). We see that the highest accuracy rate in these studies is the corpus sterni length measure. Macaluso Jr. (2010) and Tun et al. (2015)'s studies, the percentage of female being higher than the percentage of male is similar to the Havuzdere population. In addition, the female corpus sternum length of no community examined exceeded 90%. In the Havuzdere population, this measurement is represented at the most decisive rate of 100% in female.

In the study, Çırak (2004) took 6 measurements from the sternum of 54 individuals (29♀/25♂) in the Kelenderis population, whose sex was determined by morphological methods. Three measurements (manubrial length, maximum manubrial width, and corpus sterni length) are compatible with the current study. The UDA % of the corpus sterni length measurement from the Kelenderis population is not given. Manubrial length and width measurements have the same separation percentage, including male and female individuals, at 75.0% (100%♀/50.0%♂). In their study at the Department of Forensic Medicine, JSS Medical Faculty, Chandrakanth et al. (2014) took 5 measurements from the sternum of 117 individuals of known sex (50♀/67♂). Two measurements (manubrial length, and corpus sterni length) are compatible with the current study. Manubrial length has an accuracy percentage of 70.9% (64.0%♀/76.1%♂). Corpus sterni length has an accuracy rate of 70.1% (62.0%♀/76.1%♂). In both measurements, male measurements were classified more accurately than female measurements. All measurements have values below 80% accuracy. The study authors recommend that the use of sternal measurements in sex estimation should be limited to situations where other, more reliable bones are not available to researchers.

While the manubrial width measurement gave the highest value in determining sex in the current study, most of the studies reviewed above found the most predictive value to be the corpus sterni length measurement. The percentage of correct discrimination for both values is relatively high. Males generally have a longer and more prominent sternum and a wider manubrium structure, and corpus sterni length and manubrium width measurements are generally larger. For this reason, corpus sterni length and manubrial width measurements are considered important indicators in sex estimation studies.

Macaluso Jr. (2010) compared the study results with different populations. The author wrote that the study found that sternal measurements of South African Blacks were highly sexually dimorphic, making a good contribution to sex estimation methods. Likewise, García-Parra et al. (2014) applied the discriminant functions developed in their study to two samples taken from the Portuguese population. The authors noted that it could be applied to existing remains provided that the study populations showed similar sexual dimorphism as in their samples. When comparing the two studies conducted in Turkey, it is observed that both the general accuracy ranking and the accuracy rates of male and female individuals are differed (Çırak, 2004). These examples emphasize the need to establish population-specific standards.

Conclusion

Sternum bone was used in this study, which

was conducted on a total of 62 adult individuals (24♀/38♂) from the Havuzdere (Yalova) population dated to the Medieval Period. When the average values of male and female measurements were compared, it was seen that the male average measurement values were higher than the female average measurement values. In the applied *t-test* analysis, significant results were obtained at the $p<0.001$ level for all measurements taken from the sternum. In sex estimation made using discriminant function analysis, female reflect sexual dimorphism more, with the exception of one measurement. According to the study findings, sex and manubrial width measurement were 92.5% (93.8%♀/91.7%♂); corpus sterni length measurement was 85.3% (100%♀/78.3%♂); The manubrial length measurement was able to differentiate correctly at a rate of 74.5% (76.2%♀/73.3%♂). The lowest discrimination rate was the maximum manubrial width measurement with 73.8% (68.8%♀/76.9%♂). In the Havuzdere population, width and length measurements in sternum measurements were decisive in sex estimation. When the measurements of the bones taken separately were evaluated together, the rate of correctly distinguishing the sexes generally increased. Sex estimation can be reliably performed using the sternum bone with the help of discriminant function analysis.

The findings of this study offer a scientifically validated approach to sex estimation, suggesting a practical method for situations requiring sex estimation. The study is important as it shows that it is possible to determine sex with high reliability with a few measurements taken from the sternum. However, more comprehensive studies with different populations are needed.

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