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Estimation of sex from scapular measurements: use of the bone area as a criterion

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Abstract

Since the human scapula exhibits sexually dimorphic features, it has been examined in detail in recent years, especially in terms of direct anthropometric measurements. During these investigations, only very few authors have used derived variable (area of the glenoid cavity) and they reported that this measurement could be used for estimating sex. However, other areal variables of the scapula have not been studied to determine whether they contribute to predicting sex. Therefore, we aimed to clarify the question of whether derived variables, as well as direct measurements, could contribute to sex estimation. In the present study, four direct scapular measurements were taken from the magnetic resonance images (MRI) and we then calculated two derived variables from 99 male and 105 female adults' scapulae. Direct measurements are infraspinous fossa height (IFH), maximum scapular breadth (MB), glenoid cavity length (GCL), axillar bone length (ABL), and maximum spine length (MSL). Derived areal variables are MB*IFH and MSL*IFH. Univariate discriminant function analysis yielded overall sex prediction success rates ranging from 82.4% to 67.5%. As a single derived variable, MB*IFH, was the most discriminative for sexing the individuals. Multivariate discriminant analysis yielded 90.5% success in correct sex assign by using three parameters (ABL, GCL, and MSL). These results demonstrate that the analysis of scapular size provides a highly accurate tool for assigning sex.

Introduction

The determination of sex is a key part of forensic and osteological investigations as being the first essential step to biological or skeletal identification. It is indispensable for applying procedures to define sex, age at death, body height, and body weight, etc. The estimation of sex is more accurate when the complete skeleton is available, but it is nearly impossible to obtain a complete skeleton especially in forensic cases such as mass disasters and crimes. Among all human bones, pelvis, postcranial joints' size (Spradley et al., 2011), and skull have the best discriminatory indicators for the estimation of sex. In the absence of these bones, the task of the forensic practitioners becomes quite difficult, especially for the cases in which only fragmented or incomplete bones are available. Therefore, postcranial bones other than pelvis have been studied by various investigators for determining sex in recent years. Main long bones of the lower limb are the most preferred ones since they are weight-bearing elements, especially femur (Albanese, 2003; Purkait and Chandra, 2004; Albanese et al., 2008; Kranioti et al., 2009; Curate et al., 2016), and tibia (e.g., İşcan and Miller-Shaivitz, 1984; Holland, 1991; Kranioti and Apostol, 2015; Ekizoğlu et al., 2016). However, long bones of upper limb (Mall et al., 2001; Albanese, 2013) such as humerus (Frutos, 2005; Atamtürk et al., 2010), radius, and ulna (Celbis and Agritmis, 2006; Purkait, 2001) have also reliable indicators for assessing sexual dimorphism (Berrizbeitia, 1989; Mall et al., 2001). The elements other than main long bones of the limbs investigated for the capability of the sex determination are talus (Steele, 1976; Murphy, 2002*a*; Bidmos and Dayal, 2003), calcaneus (Introna et al., 1997; Bidmos and Asala, 2004; Riepert et al.,1996), metacarpals and metatarsals (Scheuer and Elkington, 1993; Lazenby, 1994; Falsetti, 1995; Robling and Ubelaker, 1997), patella (Introna et al., 1998; Bidmos et al., 2005), ribs (İşcan, 1985; Wiredu et al., 1999), sternum (Jit et al., 1980) and clavicle (Jit and Singh, 1966; McCormick et al., 1991; Murphy, 2002*b*; Frutos, 2003). Although they are not very precise, such methods can be used for sex estimation when the principal indicator mentioned above is not available.

Another postcranial bone investigated for sex determination is the scapula or shoulder blade. Morphometric analyses reveal that males have larger scapula than females, which is sexually dimorphic (e.g., Scholtz et al., 2010; Oliveira Costa et al., 2016). Therefore, a number of studies have estimated skeletal sex based on scapular dimensions in various populations (Prescher and Klümpen, 1995; Dabbs and Moore-Jansen, 2010; Tise et al., 2013; Hodson et al., 2016; Torimitsu et al., 2016). In these studies, generally direct anthropometric measurements such as length and width of the scapula have been used. Only in a few study derived variable, area of glenoid cavity, was calculated (Prescher and Klümpen, 1995; Macaluso, 2011; Bell, 2013). The results of these rare studies demonstrate that the calculated area of the glenoid cavity provides an accurate method for estimating sex. For instance, Macaluso (2011) calculated the total area of the glenoid cavity using digital photographs, but he also suggested that the area could be obtained by multiplying the height and width of the glenoid cavity. The purpose of this study is to apply these calculations suggested for glenoid cavity to apply other scapular dimensions. Thus, the utility of direct and derived variables on the scapular blade for sexing of unknown individuals will be analyzed comparatively.

Subjects and methods

All the measurements were taken on the magnetic resonance (MR) imaging scans of shoulder region of 204 patients (99 males and 105 females) at the Department of Radiology of Faculty of Medicine, Başkent University, Ankara, Turkey. The age range of the subjects was between 16 to 92 years with a mean of 51.80 years (SD = 17.23 years, median = 54.5 years). Coronary T1-weighted images were used for the anthropometric measurements.

Five direct anthropometric measurements were recorded from the MR images that were taken from the right scapulae. The direct measurements were the infraspinous (or infraspinatous) fossa height (IFH), axillar border length (ABL), maximum scapular breadth (MB), maximum spine length (MSL), and glenoid cavity length (GCL). Besides direct measurements, two derived variables reflecting “area” were also used to indicate sexual dimorphism: MB*IFH and MSL*IFH.

On the images IFH is the shortest distance between the inferior angle of the scapula and scapular spine, ABL is the distance between the inferior angle and the inferior glenoid tubercle, MB is the distance from the base of spine to the glenoid cavity, MSL is the distance from the base of spine to the *acromiale* point, GCL is the distance between the superior and inferior glenoid tubercles. The same physician took all the measurements to the nearest 0.1 mm.

In order to determine the intra-observer errors of the measurements, the above mentioned dimensions of scapula were randomly selected and re-measured on 27 MR images by the same researcher (CP).

Firstly, univariate discriminant function analysis was performed for each direct and derived variable to calculate equation for the allocation of cases. Secondly, stepwise discriminant functions were calculated to generate equation that yielded the most accurate sex discrimination.

Table 1. Statistical analyses for intra-observer error

	Intra-observer error		
Measurements	**n**	**TEM**	**Cronbach’s alpha (reliability)**
Infraspinous fossa height (IFH)	27	0.768	0.975
Maximum breadth (MB)	27	0.043	0.932
Maximum spine length (MSL)	27	2.870	0.972
Glenoid cavity length (GCL)	27	0.115	0.910
Axillar border length (ABL)	27	0.001	0.963

The generous allowance for measurement error might be over 90%. This is equivalent to a reliability value of 0.9 or more. As seen in Table 1, the inter-observer reliability values are over 0.9 for all five measurements.

To determine sex discriminant function analysis was used. Besides, Box’s M test was used for testing equality of population co-variance matrices. Co-variances were homogeneous (P = 0.137).

Results

According to Kolmogorov–Smirnov test of normality, all studied variables have a Gaussian distribution. However, Levene’s test indicated that variances of the maximum spine length (MSL) were not homogeneous. In addition to this after the application of leave one out method the Box M statistics was also verified that the covariance matrix of the MSL was not homogeneous ($P < 0.05$).

The descriptive statistics of the mean and standard error of direct and derived measurements of scapula are shown in Table 2. An independent samples t-test indicates that males have significantly higher values than females for all variables (P = 0.000).

Univariate discrimination functions for sexual dimorphism are shown in Table 3. Box M statistics indicated that covariance matrix of MSL was not homogenous ($P < 0.05$). So this measurement was not taken into consideration as a discriminative variable.

As seen in the table canonical correlation and Eigen values of axillar border length and glenoid cavity length are higher than those of the other variables. In Table 4, accuracy of discriminant functions by leave-one-out method are seen.

Table 2. Descriptive statistics and sexual dimorphism of direct and derived scapular measurements

Variable	Females (n = 105)		Males (n = 99)		P
	Mean	SEM	Mean	SEM	
Direct measurements					
Maximum breadth (MB, cm)	8.90	0.06	9.83	0.07	0.000
Maximum spine length (MSL, cm)	11.52	0.08	13.12	0.11	0.000
Infraspinous fossa height (IFH, cm)	12.27	0.11	13.37	0.10	0.000
Axillar border length (ABL, cm)	12.19	0.07	13.55	0.08	0.000
Glenoid cavity length (GCL, cm)	3.14	0.03	3.63	0.03	0.000
Derived measurements					
MB * IFH (cm^2)	109.47	1.45	131.58	1.43	0.000
MSL * IFH (cm^2)	141.62	1.87	175.61	2.09	0.000

SEM: Standard error of the mean

Table 3. Univariate discriminant functions for direct and derived measurements of the scapula

Variable	Canonical correlation	Eigen value	Wilks' lambda	Chi-square	Sig.
Direct measurements					
Maximum breadth (MB, cm)	0.576	0.497	0.668	81.357	0.000
Maximum spine length (MSL, cm)	0.637	0.546	0.594	104.860	0.000
Infraspinous fossa height (IFH, cm)	0.475	0.292	0.774	51.633	0.000
Axillar border length (ABL, cm)	0.683	0.876	0.533	126.766	0.000
Glenoid cavity length (GCL, cm)	0.671	0.820	0.549	120.693	0.000
Derived measurements					
MB * IFH (cm^2)	0.606	0.580	0.633	92.112	0.000
MSL * IFH (cm^2)	0.650	0.732	0.577	110.652	0.000

Table 4. Accuracy of discriminant functions by leave-one-out method

Variable	Correct classification rate (%)		
	Males (N = 99)	Females (n = 105)	Overall (N = 204)
Maximum breadth (MB)	77.0	79.0	76.5
Inferior fossa height (IFH)	65.0	73.0	67.6
Axillar border length (ABL)	76.0	88.0	80.4
Glenoid cavity length (GCL)	80.0	86.0	81.4
MB * IFH (cm^2)	76.0	80.0	76.5
MSL * IFH (cm^2)	81.0	87.0	82.4

Table 5. Multivariate discriminant function analysis

Function	Canonical correlation	Wilks' lambda	Chi-square	Sig.	Standardized canonical discriminant function coefficients
1	0.783	0.387	190.536	0.000	MB : 0.240 GCL : 0.614 ABL : 0.571

MB: Maximum breadth
GCL: Glenoid cavity length
ABL: Axillar border length

Looking at all measurements, MSL*IFH, a derived variable, is the most accurate variable for the discrimination of skeletal sex. This variable resulted in an overall classification rate of 82.4%. MSL*IFH approximately reflects the area of inferior scapular fossa and probably because of this it is a good indicator for the assigning of sex. Glenoid cavity length (81.4%) and axillar border length are other accurate single measurements for estimating the skeletal sex. When males and females were evaluated separately, for female subjects axillar border length was the best indicator for sex allocation (88.0%), even better than MSL*IFH (87.0%). For males the best results were obtained by MSL*IFH. Among direct measurements, GCL gave the best results (80.0%).

In Table 5 multiple discriminant analyze results by step-wise and leave-one out methods take place. When MB, GCL, ABL, and IFH were evaluated together by using step-wise regression analyze inferior fossa height was eliminated. Standardized canonical discriminant function coefficient for the three variables are seen on the table. The derived variables were also evaluated by using the above-mentioned methods together with absolute variables, but a reliable function could not be obtained.

The accurate assign the sex of multivariate discriminant function was 90.9% for males, and 88.6% for females.

Discussion

It is well known that the scapula is a sexually dimorphic bone, the male scapulae are generally larger than those of females (e.g., Scholtz et al., 2010; Papaioannou et al., 2011; Oliveira Costa et al., 2016). In the present study, all direct and derived scapular measurements of males also revealed significantly higher values than those of females. Similar conclusions were also cited by other researchers (e.g., Prescher and Klümpen, 1995; Dabbs and Moore-Jansen, 2010; Scholtz et al., 2010; Tise et al., 2013; Hudson et al., 2016; Torimitsu et al., 2016). These results suggest that the scapula is sexually dimorphic in the contemporary population living in Turkey and could potentially enable forensic experts to determine skeletal sex with a moderately high level of accuracy in the lack of pelvis and skull. Additionally, it is emphasized that single measurements have little practical value for sex estimation because of the large overlap of the ranges between sexes.

The crucial question addressed in this study is, in addition to direct scapular measurements, can derived two variables contribute to sex determination? In order to find an answer to this question, two derived variables (MSL*IFH and MB*IFH) were calculated, which were determined by multiplying the measurements taken directly. According to the findings of our study, the variable that determines with highest accuracy (82.4%) is a derived variable: MSL*IFH. This suggests that variables based on the area calculation in flat bones such as scapula will increase the sensitivity in estimating sex. However, the other derived variable, BL*IFH, yielded less accurate results in estimating skeletal sex (76%). Therefore, further research is needed to determine which derived variables play a role in predicting sex.

When the studies aimed at estimating sex from the scapular dimensions are examined in general, it is seen that the vast majority of them focused on direct anthropometric measurements, there are only few studies in which a derived variable (the area of glenoid cavity) was taken into consideration. In these studies, it was concluded that glenoid cavity area was an effective variable in predicting sex. The present study demonstrates that derived scapular variables, not only the glenoid cavity, could contribute to sex estimation.

In the field of forensic anthropology, generally, univariate or multivariate functions are established to estimate sex. As can be expected, multivariate equations are able to estimate sex at a more reliable rate than univariate ones. Torimitsu et al. (2016), for example, found the correct rate of sex to be 75.7-91.3% with functions using a single variable in the Japanese study, while this rate increased to 91.3-94.5% in multivariable functions. Di Vella et al. (1994) reported similar rates in their study conducted on 80 dry scapulae, misclassification rate decreased from 31.25-15% to 10-5%. Similarly, Dabbs and Moore-Jansen (2010) documented that the probability of accurate estimation of sex increased in parallel with the increase in the number of variables. In our study, the ratio of univariate functions to assign sex correctly ranged from 67.6% to 82.4%, whereas in the equation where multiple variables were used, the ratio increased up to 90.9% for males, and 88.6% for females. Although multivariable functions yield more successful results, the fact that the findings are often incomplete or damaged leads to a limited use of multivariate functions.

As a conclusion, our findings suggest strongly that derived scapular measurements may be used to estimate biological sex in the absence of the pelvis and skull. In this sense, it can be said that MSL*IFH showing the area under the spina of the scapula is the most successful variable in the correct classification of sex. Our study also showed that multivariate functions are more successful in classifying sex correctly. However, the fact that derived variables studied are not included in multivariate functions reveals the need for further investigation.

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