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Sex estimation from the radiographic measurements of the humerus

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Abstract

Diagnosis of sex from skeleton or individual bones is vital to bio-archaeology and forensic anthropology. The aims of this study are to examine the applicability of the measurements taken from the humerus to assess sex, and to contribute to establishing discriminant function equations for Anatolian populations for medico legal applications. The material for this study consisted of archived x-ray films of patients who enter the clinics of emergency and elective orthopedics of Göztepe Education and Research Hospital, Istanbul. In total, 84 x-ray films (46 females and 38 males) were analyzed. The ages of the individuals vary between 20 and 79 years, with an average of 48.96 years. Five dimensions, including maximum length, vertical head diameter, head + greater tubercle diameter, right-left diameter at midshaft, and epicondylar breadth were taken and subjected to direct and stepwise discriminant function analysis. Our analyses revealed that the proximal part of the humerus have greater diagnostic accuracy than distal and middle parts. Accuracy of correct classification varies between 73.2% (right-left diameter at midshaft) and 93.2% (vertical head diameter) for univariate analyses. When the multivariate analyses were conducted, three functions were produced, with the accuracy of ranging between 90.0% and 92.7%. These findings suggested that the dimensions of the humerus, especially the measurements taken from the proximal parts, could be used successfully for sex diagnosis.

Keywords: *Forensic anthropology, forensic anthropometry, sex determination, humerus, discriminant function analysis*

Introduction

Identification of the sex of skeletonized or dismembered human bodies is the first step in bio-archaeological and forensic anthropological investigations. Biological anthropologists or forensic experts generally use "morphological" or "classical" tech-

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nique which yields 95-100% accurate results for sex assessment. In this technique, the anatomic or anthroposcopic markers on the pelvic girdle and cranium are given primary consideration, and other markers of the human body, such as Phenice (1969), WEA (1980), Loth and Henneberg (1998), Patriquin et al. (2003), Walker (2005), and Rösing et al. (2007) are given secondary consideration. However, the application of this method poses a variety of challenged. The most significant challenge with this technique is that the human skeletal remains must be obtained intact or unfragmented. It is well known that it is difficult to encounter full body parts and/or human remains in anthropological investigations or forensic cases. The second challenge is that the evaluation of anatomical or anthroposcopic markers require advanced expertise and thus it is a relatively subjective process. When the material is fragmentary or incomplete, the degree of expertise required to perform the analyses will increases (Pretorius et al., 2006).

The second technique for sex estimation is a "morphometric" or "statistical" method. In this method, in addition to pelvis and cranium examinations, other parts of the body such as the long bones of the upper and/or lower extremity can be used for sex determination (Luo, 1995; Introna et al., 1997; Wiredu et al., 1999; Mall et al., 2000, 2001; Murphy, 2002*a,b*; Patriquin et al., 2005). There are some advantages to this technique. Firstly, sex identification can be made by using fragmentary or incomplete bones. Secondly, the morphometric technique is more practical and objective than the anthroposcopic one. The disadvantage of the morphometric technique is, however, that the accuracy in sex assessment was relatively lower than the anthroposcopic one, varying between 70% and 100%. By examining specific bones and/or using multivariate analyses this disadvantage can be reduced. In this connection, the first aim of the present study is to investigate the applicability and accuracy of measuring the humerus in sex determination.

It is also well known that body dimensions, shape, and sexual dimorphism vary among human populations. Therefore, when the formulae for sex estimation are established, the variation among populations or ethnic groups should be taken into consideration (e.g., Wrobel et al., 2002). The second aim of this paper is to contribute to determination of sex from the measurements of humerus for anthropological examinations and forensic cases limited to Anatolian populations.

Material and method

This is a retrospective inquiry and the study material consists of x-ray radiographs of patients who entered the clinics of emergency and elective orthopedics of Göztepe Education and Research Hospital, Kadıköy, Istanbul, during the second half of 2008 and first half of 2009. The patients' reasons to admittance to the hospital were mainly non-serious traumas and pain. They had no disorders of bone metabolism and/or other developmental diseases. In total, 84 x-ray radiographs (46 females and 38 males) taken anteroposteriorly (AP) were compiled from the archives. The ages of the individuals vary between 20 and 79 years, with an average of 48.96 (SD = 12.64) years.

Conventional AP radiographs of the entire humerus in this study were taken at the research laboratory of above-mentioned hospital using "AXIOM Vertix MD Trauma Digital X Ray" (Siemens, Germany) machine with a 66–70 kV / 12.5–16 mAs intervals. The x-ray films was taken when the subject was standing, their elbows fully extended, hand was at supination, shoulders and elbow joints were positioned to allow the pictures to be taken from the AP direction. In addition, *tuberculum majus* was visible in lateral profile, and medial and lateral epiconyles of the humerus were visible in parallel on the radiographs.

Some studies (e.g., Akman et al., 2006) on the dimensions of the humerus indicate that there are significant differences between the right and left measurements. Therefore, while collecting x-ray films, we do not distinguish between right and left measurements; all films were collected and measured. At the end of the study, it was determined that of 71.4% (n = 60) belonged to right side and 28.6% (n = 20) belonged to the left side.

A total of 5 humeral dimensions were taken of the upper arms and shoulders using a digital caliper on x-ray films. The variables and their measurement techniques are as follows:

Maximum length: The distance between the most superior point on the head of the humerus and the most inferior point on the trochlea (Olivier, 1969; Buikstra and Ubelaker, 1994).

Vertical diameter of head: Taken from the most inferior point on the edge of the articular surface of the bone across to the opposite side on x-ray films (Bass, 1995).

Diameter of head + greater tubercle: The diameter taken from the most inferior point on the edge of the articular surface across to the most posteriorly protruding point of the greater tubercle of humerus.

Right-left diameter at midshaft: The maximum right-left diameter was found at midpoint of the shaft, as the measurements horizontal to the long axis of humerus.

Epicondylar breadth: Distance of the most laterally protruding point on the lateral condyle from the corresponding projection of the medial epicondyle (Buikstra and Ubelaker, 1994).

To ensure the reliability of measurements, each measure was taken three times and then the average was calculated. The radiographs with pathological conditions or broken bones were excluded from the study.

Data assessments were carried out by the Statistical Package for Social Sciences (SPSS 15.0). The analyses were made by both univariate and multivariate techniques. Discriminant equations were evaluated in which due consideration was given to Wilks' lambda, eigenvalue, canonical correlation, and F-statistics. Canonical correlation and eigenvalue statistics measure the ratio of the discriminant equation in relation to the total variance. The Wilks' lambda, on the other hand, is the ratio of the within-group and total sum of squares. Canonical values and eigenvalue are expected to be high while the Wilks' lambda value, low.

Results

Table 1 reveals the descriptive statistics of the males, females, and total study population. As expected, the average values pertaining to male subjects are statistically higher than those of the females ($P<0.001$). The most conspicuous difference between the sexes is in maximum height of humerus, whereas the smallest difference is in the midshaft maximum diameter.

The differences between the sexes were also examined through discriminant analysis. Table 2 indicates the equations obtained via univariate discriminant function analysis. As it can be seen in the table, the lowest Wilks' lambda values are vertical head diameter and diameter of head + greater tubercle. The values of eigenvalue and canonical correlation of these two measurements are higher than those of other variables. The highest Wilk's lambda value was found for the variable of right-left diameter at midshaft.

The correct sex allocation data derived from univariate discriminant functions were also supported in the above findings (Table 3). Our analyses showed that correct sex discrimination rate was 93.2% using vertical diameter of the head. Second and third most successful variables were vertical diameter of the head and maximum humerus length. Least successful variable for sex allocation was right-left diameter at midshaft with 73.2% correct discrimination.

Table 1: Descriptive statistics of measured variables (in mm)

	Sex	n	Mean	SD	*F*-statistic	*P*
Maximum length	Male	27	348.51	34.95		
	Female	39	307.30	15.02	42.996	0.000
	Total	66	324.16	32.21		
Vertical head diameter	Male	34	50.98	4.14		
	Female	39	45.59	2.68	83.580	0.000
	Total	73	47.03	5.04		
Diameter of head + greater tubercle	Male	36	58.93	4.30		
	Female	43	51.30	3.21	81.580	0.000
	Total	79	54.78	5.33		
Right-left diameter at midshaft	Male	37	24.45	2.35		
	Female	45	22.33	1.92	20.210	0.000
	Total	82	23.29	2.37		
Epicondylar diameter	Male	21	65.21	4.63		
	Female	26	58.03	2.99	41.412	0.000
	Total	47	61.24	5.22		

Table 2: Univariate discriminant function analysis

	Unstandardized coefficient	Constant	Wilk's lambda	Eigen-value	Group centroids	*F*-statistic
Maximum length	0.040	-12.913	0.598	0.672	M =0.970 F=-0.672	42.996*
Vertical head diameter	0.291	-13.669	0.459	1.177	M =1.146 F=-0.999	83.580*
Diameter of head + greater tubercle	0.267	-14.641	0.486	1.059	M =1.110 F=-0.930	81.550*
Right-left diameter at midshaft	0.471	-10.964	0.798	0.253	M =0.547 F=-0.450	20.210*
Epicondylar diameter	0.263	-16.076	0.521	0.920	M =1.044 F=-0.844	41.412*

* $P < 0.001$

Table 3: Percentage of correct group membership for univariate analyses

	Males		Females		Total	
	n	%	n	%	n	%
Maximum length	22	81.5	35	89.7	57	86.4
Vertical head diameter	31	91.2	37	94.9	68	93.2
Diameter of head + greater tubercle	32	88.9	39	90.7	71	88.6
Right-left diameter at midshaft	27	73.0	33	73.3	60	73.2
Epicondylar diameter	16	76.2	23	88.5	39	83.0

In addition to univariate analyses, multivariate methods were also applied. For this, three ways of techniques were applied. First, all of the variables obtained were calculated using stepwise regression analysis and than the best result was chosen, and displayed in Table 4 as Function 1. Second, the measurements of the humerus were analyzed two or three times and the most accurate equation was placed in Table 4 as Function 2. Third, all measurements were included in the analysis to construct Function 3. It can be argued that the most accurate equation is Function 3, based on the coefficients of Wilks' lambda. In this framework, the second most accurate equation is Function 1.

Table 4: Canonical discriminant function coefficient for the dimensions of the humerus

	Unstandardized coefficient	Wilk's lambda	Eigenvalue	Structure matrix[a]	Group centroids[b]
Function 1:					
Vertical head diameter	0.156	0.296	2.377	0.889	M = 1.787
Maximum length	0.049			0.739	F = –1.266
Constant	-23.008				
Function 2:					
Diameter of head + greater tubercle	0.121	0.399	1.508	0.957	M = 1.321
Epicondyler diameter	0.226			0.753	F = –1.046
Constant	–19.661				
Function 3: all variables					
Maximum length	-0.072	0.277	2.606	0.850	M = 1.871
Right-left diameter at midshaft	0.201			0.706	F = –1.327
Vertical head diameter	0.044			0.706	
Diameter of head + greater tubercle	-0.037			0.557	
Epicondyler diameter	0.090			0.290	
Constant	-24.068				

[a] Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions.
[b] M = Males; F = Females.

Using the leave-one-out method, the functions developed were compared in terms of correct allocation of sex (Table 5). In fact, there are no obvious differences among discriminant functions in sex allocation. Using the humerus dimensions, all three discriminant functions could determine sex correctly over 90%. Among them, the most successful one is the Function 3 with the accuracy of 92.7% correct allocation.

Table 5: Percentage of correct group membership for multivariate analyses

	Males (n = 38)		Females (n = 46)		Total (n = 84)	
	n	%	*n*	%	*n*	%
Function 1	22	88.0	32	91.4	54	90.0
Function 2	19	95.0	23	88.5	42	91.3
Function 3	16	91.7	23	95.8	39	92.7

Discussion

Research on sex estimation focused on skeletal material for skeletal biology and forensic cases reveals that the humerus and its measurements can be used for sex allocation (Black, 1978; Steyn and İşcan, 1999; Sakaue, 2004; İşcan et al., 2008; Kranioti et al., 2009; Kranioti and Michalodimitrakis 2009). However, the size and shape of the humerus may vary among human groups as well other body parts (e.g., Akman et al., 2006). The reason for these differences are genetic and environmental factors such as dietary patterns and occupation (Duyar and Özener, 2003; Duyar, 2008). Furthermore, secular trend may also affect the size and shape of the humerus. Although some authors (e.g., Jantz and Jantz, 1999) argued that the upper extremities and proximal body parts were less effected than lower extremities and distal body parts, secular trend can also manifest differences in the humerus' dimensions (Frutos, 2005). Thus, during the sex estimation based on morphometric measurements, these indicators should be taken consideration.

The existing literature and the sex estimation equations they propose are derived from three different contexts of skeletal remains. The first group consists of human skeletal remains obtained from archaeological excavations. The sex determination of the specimens was estimated by using morphological or visual methods, and then, based on these materials, the sex determination formulae were developed (Dittrick and Suchey, 1986). In the second group, there are the studies focused on dry skeletons, with known sex (Steyn and İşcan, 1999; Mall et al., 2001; Sakaue, 2004; İşcan et al., 2008; Kranioti and Michalodimitrakis, 2009). The third group consists of radiographic films and the measurements taken from them (Kranoiot et al., 2009). The number of this type of study based on measurements taken from radiographic images is very limited.

Among those methods mentioned above, the third one is the most reliable. In the first group, the sex of the skeletons could not be absolutely determined. In the second group, there is the risk of misplaced bones and/or records. On the other hand, authors pointed out that the reliability of the measurements taken from radiographs is fairly high (Harma and Karakas, 2007). This opinion was also supported by various studies based on the measurements taken from radiographs of computerized tomography and x-rays, such as on the cranium (Patil and Mody, 2005), the calcaneus (Riepert et al., 1996), and the femur (Kranoiot et al., 2007; Harma and Karakas, 2007). In these studies, the sex was estimated with accuracy between 92.6% and 99.0%. For these reasons, we used x-ray films to establish the equation for sex determination based on the measurements of the humerus. The findings of the study showed that the sex of a unknown person might be estimated by using humerus dimension with a rate of over 90% accuracy.

According to our search, there is only one other study addressing sex estimation from radiographic measurements of humerus (Kranioti et al., 2009). Since Kranioti and his co-workers used geometric-morphometric analysis of humerus shape in their study, we could not compare the results. Thus, the results of our study were compared with those of other studies in respect to the accuracy of stepwise discriminant functions for sex identification derived from the humerus (Table 6). The percentages of correct classification of sex vary between 89.8% and 98.5%, depending largely on the number of measurements. It can be said that among the stepwise discriminant functions, the classification accuracy is lowest for the equation derived from the material measured in China and Turkey. One reason for this is that the radiological method is limited. Indeed, it is well known that circumferential measurements cannot be taken on radiographic film, only one-dimensional measurements such as length or width can be taken. On the other hand, when circumferential measurements were included to the equations for sex assessment, the precision of the formulae were increased (Black, 1978; Dittrick and Suchey, 1986; Sakaue, 2004). Thus, it is not surprising that to develop equations with higher accuracy in studies based on osteometric material numerous measurements were necessary. For instance, in the equations derived from skeletal remains recovered from clandestine graves attributed to the recent armed conflict in Guatemala, circumferential and minimum midshaft diameter measurements were included (Frutos, 2005). Although the radiographic techniques has some limitations, it was the most advantageous to obtain the current data fort his study.

Table 6: Equations developed by various authors and their comparisons in respect of the percentage of correct classification of sex

Population and Reference	n	Function (stepwise)	Correct classification		
			Male (%)	Female (%)	Total (%)
This study	84	Vertical head diameter + maximum length	88.0	91.4	90.0
Guatemala (Frutos 2005)	118	Maximum head diameter + minimum midshaft diameter + epicondylar breadth	98.5	97.8	98.5
Greece (Kranioti and Michalodimitrakis, 2009)	178	Maximum length + vertical head diameter + minimum midshaft diameter + epicondylar breadth	92.8	92.7	92.9
Chinese (İşcan et al., 2008)	82	Maximum length + vertical head diameter + epicondylar breadth + midshaft diameter	85.4	88.6	86.8
Japanese (İşcan et al., 2008)	79	Vertical head diameter + minimum midshaft diameter + epicondylar breadth + midshaft diameter	95.5	88.6	97.0
Thais (İşcan et al., 2008)	104	Vertical head diameter + minimum midshaft diameter + epicondylar breadth	97.1	97.1	97.1
African whites (Steyn and İşcan 1999)	104	Epicondylar breadth + vertical head diameter	89.1	95.8	92.5
African blacks (Steyn and İşcan 1999)	88	Vertical head diameter + maximum lenght	95.1	91.1	93.1
Japanese (Sakaue, 2004)	64	Width distal articular surface + distal breadth + trochlear width + midshaft area + distal length + proximal lenght + sagittal diameter of the trochlea + proximal length + length	--	--	92.4
Germans (Mall et al., 2001)	143	Maximum length + vertical head diameter + epicondylar breadth	--	--	93.2

There is some controversy concerning which measurement of the humerus is the most successful indicator for sex determination. Some researchers such as Steyn and İşcan (1999), Sakaue (2004), and İşcan et al. (2008) suggested that the measurements taken from the distal humerus are more successful in sex identification. Contrarily, other researchers found that the proximal portion of the humerus is a more successful indicator than the distal part (Mall et al., 2001; Frutos, 2005; İşcan et al., 2008; Kranioti and Michalodimitrakis, 2009). The results of our study provide support for the latter opinion. Table 7 presents the best equations obtained from the literature for sex assessment from the humerus. It shows that the proximal humerus is predominant in allocating sex successfully. By considering the findings of our study and the results from the other research in the literature, it can be suggested that the proximal portion of humerus better reflects sex differences morphologically.

Table 7: The best variable for sex determination based on the measurements of humerus according to the various authors

Population and Reference	Best variable	Male (%)	Female (%)	Total (%)
This study	Vertical head diameter	91.2	94.9	93.2
	Epicondylar diameter	76.0	88.5	83.0
Guatemala (Frutos, 2005)	Maximum head diameter	93.5	97.0	95.5
Greece (Kranioti and Michalodimitrakis, 2009)	Vertical head diameter	90.5	89.3	89.9
Chinese (İşcan et al., 2008)	Vertical head diameter	79.1	82.1	80.5
Japanese (İşcan et al., 2008)	Epicondylar breadth	93.2	85.7	89.9
Thais (İşcan et al., 2008)	Epicondylar breadth	91.4	97.1	93.3
Africans whites (Steyn and İşcan, 1999)	Epicondylar breadth	83.6	95.8	94.7
Africans blacks (Steyn and İşcan, 1999)	Vertical head diameter	93.0	88.9	96.0
Japanese (Sakaue, 2004)	With distal articular surface			95.0
Germans (Mall et al., 2001)	Vertical head diameter			90.4

Finally, the capability of humerus in sex determination was compared with those of other parts of the body using the results of the classification accuracies compiled from the literature. Firstly, when the main long bones of extremities are considered, it can be concluded that their success in sex determination is quite similar, with an accuracy of 90-97% in radius (Mall et al., 2001; Purkait, 2001; Sakaue, 2004; Celbis and Agritmis, 2006), 91-95% in ulna (Mall et al., 2001; Sakaue, 2004; Celbis and Agritmis, 2006), 91-95% in femur (Šlaus et al., 2003; Purkait, 2003; Purkait and Chandra, 2004), and 94-95% in tibia (Sakaue, 2004). Secondly, the findings of studies focused on other body parts except the long bones were evaluated. It can be said that the variability in correct classification of sex was higher than those of long bones, with the accuracy of 83-90% in vertebrae (Wescott 2000; Yu et al., 2008), 74-88.6% in sternum (Wiredu et al., 1999; Koçak et al., 2003), 96% in patella (Mahfouz et al., 2007), 99% in cranium (Patil and Mody, 2007), 87.6-95.7% in talus and calcaneus (Gualdi Russo, 2007), 95-97.7% in clavicle and scapula (Murphy, 2002), and 75-94% in foot and footprints (Wunderlich et al., 2001; Atamtürk, 2010). In this study, the rate of correct classification in sex assessment from the measurements of the humerus was over 90%, with an accuracy of 93.2% for the minimum vertical head diameter of humerus. Considering all of these findings, it was concluded that the measurement of the humerus is a relatively reliable method for sex assessment in anthropological studies and forensic applications.

Bibliography

Akman ŞD, Karakaş P, Bozkır MG. (2006) The morphometric measurements of humerus segments. Turk J Med Sci 36:81-85.

Atamtürk D. (2010) Estimation of sex from the dimensions of foot, footprints, and shoe.

Anthrop Anz 68:21-29.
Bass WM. (1995) Human osteology: a laboratory and field manual of the human skeletal. Missouri Archaeological Society, Columbia.
Black TK. (1978) A new method for assessing the sex of fragmentary skeletal remains: femoral shaft circumference. Am J Phys Anthropol 48:227-232.
Buikstra JE, Ubelaker DH. (1994) Standards for data collection from human skeletal remains. Arkansas Archaeological Survey Research Series No: 44, Fayetteville.
Celbis O, Agritmis H. (2006) Estimation of stature and determination of sex from radial and ulnar bone lengths in a Turkish corpse sample. Forensic Sci Int 158:135-139.
Dittrick J, Suchey JM. (1986) Sex determination of prehistoric central California skeletal remains using discriminant analysis of the femur and humerus. Am J Phys Anthropol 70:3-9.
Duyar İ, Özener B. (2003) Çocuk işçiler: çarpık gelişen bedenler. Ankara: Utopya.
Duyar İ. (2008) Growth patterns and physical plasticity in adolescent laborers. Coll Antropol 32:403-412.
Frutos LR. (2005) Metric determination of sex from the humerus in a Guatemalan forensic sample. Forensic Sci Int 147:153-157.
Gualdi–Russo E. (2007) Sex determination from the talus and calcaneus measurements. Forensic Sci Int 171:151-156.
Gülekon ID, Turgut HB. (2003) The external occipital protuberance: can it be used as a criterion in the determination of sex? J Forensic Sci 48:1-4.
Harma A, Karakaş HM. (2007) Determination of sex from the femur in Anatolian Caucasians: a digital radiological study. J Forensic Legal Med 14:190-194.
Introna F, Velle G, Campobasso CP, Dragone M. (1997) Sex determination by discriminant analysis of calcanei measurements. J Forensic Sci 42:725-728.
İşcan MY, Loth SR, King CA, Shihai D, Yoshino M. (1998) Sexual dimorphism in the humerus: a comparative analysis of Chinese, Japanese and Thais. Forensic Sci Int 98:17-29.
Jantz LM, Jantz RL. (1999) Secular change in long bone length and proportion in the United States, 1800-1970. Am J Phys Anthropol 110:57-67.
Koçak A, Aktaş EÖ, Ertürk S, Aktaş S, Yemişçigil A. (2003) Sex determination from the sternal end of the rib by osteometric analysis. Legal Med 5:100-104.
Kranioti EF, Michalodimitrakis M. (2009) Sexual dimorphism of the humerus in contemporary Cretans − a population specific study and a review of the literature. J Forensic Sci 54:996-1000.
Kranioti EF, Bastir M, Meseguer AS, Rosas A. (2009) A geometric-morphometric study of the Cretan humerus for sex identification. Forensic Sci Int 189:111.e1-111e8.
Kranioti EF, Vorniotakis N, Galiatsou C, İşcan MY, Michalodimitrakis M. (2007). Sex identification and software development using femoral radiographs In: Balkan Academy of Forensic Sciences, 5th Meeting, p 80.
Loth SR, Henneberg M. (1998) Mandibular ramus flexure is a good indicator of sexual dimorphism. Am J Phys Anthropol 105:91-92.
Luo YC. (1995) Sex determination from the pubis by discriminant function analysis. Forensic Sci Int 74:89-98.
Mahfouz M, Badawi A, Merkl B, Fatah EEA, Pritchard E, Kesler K, Moore M, Jantz R, Jantz L. (2007) Patella sex determination by 3D statistical shape models and nonlinear classifiers. Forensic Sci Int 173:161-170.
Mall G, Graw M, Gehring KD, Hubig M. (2000) Determination of sex from femora. Forensic Sci Int 113:315-321.
Mall G, Hubig M, Büttner A, Kuznik J, Penning R, Graw M. (2001) Sex determination and estimation of stature from the long bones of stature from the long bones of the arm. Forensic Sci Int 117:23-30.
Murphy AMC. (2002*a*) The calcaneus: sex assessment of prehistoric New Zealand Polynesian skeletal remains. Forensic Sci Int 129:205-208.
Murphy AMC. (2002*b*) Articular surfaces of the pectoral girdle: sex assessment of prehistoric New Zealand Polynesian skeletal remains. Forensic Sci Int 125:134-136.
Olivier G. (1969) Practical anthropology (Translated by MacConail MA). Springfield: Charles

C Thomas.
Patil KR, Mody RN. (2007) Determination of sex by discriminant function analysis and stature by regression analysis: a lateral cephalometric study. Forensic Sci Int 147:175-180.
Patriquin ML, Loth SR, Steyn M. (2003) Sexually dimorphic pelvic morphology in South African whites and blacks. Homo 53:255-262.
Patriquin ML, Steyn M, Loth SR. (2005) Metric analysis of sex differences in South African whites and blacks. Forensic Sci Int 147:119-127.
Phenice TW. (1969) A newly developed visual method of sexing the os pubis. Am J Phys Anthropol 30:297-302.
Pretorius E, Steyn M, Scholtz Y. (2006) Investigation in to the usability of geometric morphometric analysis in assessment of sexual dimorphism. Am J Phys Anthropol 129:64-70.
Purkait R. (2001) Measurements of ulna: a new method for determination of sex. J Forensic Sci 46:924-927.
Purkait R. (2003) Sex determination from femoral head measurements: a new approach. Legal Med 5:347-350.
Purkait R, Chandra H. (2004) A study of sexual variation in Indian femur. Forensic Sci Int 146:25-33.
Riepert T, Drechsler T, Schild H, Nafe B, Mattern R. (1996) Estimation of sex on the basis of radiographs of the calcaneus. Forensic Sci Int 77:133-140.
Rösing FW, Graw M, Marré B, Ritz-Timme S, Rothschild MA, Rötzscher K, Schmeling A, Schröder I, Geserick G. (2007) Recommendations for the forensic diagnosis of sex and age from skeletons. Homo 58:75-89.
Sakaue K. (2004) Sexual determination of long bones in recent Japanese. Anthropol Sci 112:75-81.
Šlaus M, Strinović D, Škavić J, Petrovečki V. (2003) Discriminant function sexing of complete femora: standards for contemporary Croatia. J Forensic Sci 48:1-4.
Steyn M, İşcan MY. (1999) Osteometric variation in the humerus: sexual dimorphism in South Africans. Forensic Sci Int 106:77-85.
Wescott DJ. (2000) Sex variation in the second cervical vertebra. J Forensic Sci 45:462-466.
Wrobel GD, Danforth ME, Armstrong C. (2002) Estimating sex of Maya skeletons by discriminant function analysis of long bone measurements from the prehistoric Maya site of Tipu, Belize. Ancient Mesoamerica 13:255-263.
Yu SB, Lee UY, Kwak DS, Ahn YW, Jin CZ, Zhao J, Sui HJ, Han SH. (2008) Determination of sex for the 12th thoracic vertebra by morphometry of three-dimensional reconstructed vertebral models. J Forensic Sci 53:620-625.
Walker PL. (2005) Greater sciatic notch morphology: sex, age and population differences. Am J Phys Anthropol 127:385-391.
WEA (Workshop of Europen Anthropologists) (1980) Recommendations for age and sex diagnoses of skeletons. J Hum Evol 9:517-549.
Wiredu EK, Kumoji R, Seshandri R, Biritwum RB. (1999) Osteometric analysis of sexual dimorphism in sternal end of the rib in a West African population. J Forensic Sci 44:921-925.
Wunderlich RE, Cavanagh PR. (2001) Gender differences in adult foot shape: implications for shoe design. Med Sci Sports Exerc 33:605-611.