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Sex estimation of upper long bones by selected measurements in a Radom (Poland) population from the 18th and 19th centuries AD

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ABSTRACT: Several studies have shown that sex estimation methods based on measurements of the skeleton are specific to populations. Metric traits of the upper long bones have been reported as reliable indicators of sex. This study was designed to determine whether the four long bones can be used for the sex estimation of an historical skeletal population from Radom (Poland). The material used consists of the bones of 169 adult individuals (including 103 males and 66 females) from the 18th and 19th centuries. Twelve measurements were recovered from clavicle, humerus, radius and ulna. The initial comparison of males and females indicated significant differences in all measurements ($p < 0.0001$). The accuracy of sex estimation ranged from 68% to 84%. The best predictor for sex estimation of all the measurements in Radom's population was the maximum length of the radius (84%), and the ulna (83%), and the vertical diameter of the humeral head (83%). The Generalized Linear Model (GLM) detected the strongest significant relationship between referential sex and the vertical diameter of the humeral head ($p < 0.0001$), followed by the maximal length of the ulna ($p = 0.0117$). In other measurements of the upper long bones, GLM did not detect statistically significant differences.

KEY WORDS: bioarchaeology, sex estimation, upper extremities long bones

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Introduction

Sex estimation is an important first step in the development of a biological profile in human osteology and is used in both bioarchaeological studies (González et al. 2007; Bašić et al. 2013) and forensic anthropological analysis (Kamdi et al. 2014; Peckmann et al. 2015). In these fields, it is important to recognize the sex of the skeleton, regardless of the state of preservation. Today, significant accuracy in sex determination is possible through the DNA analysis from bones. Unfortunately, these methods require sophisticated equipment, and can fail in cases of dry or seriously damaged bone samples (Faerman et al. 1998; Santos et al. 1998; Rösing et al. 2007). Moreover, aDNA extraction is also an invasive technique, and it cannot be often used in the case of valuable historical bone collections. Therefore, if the skeleton is reasonably complete and a reliable morphological diagnosis is possible, there is no need to apply molecular methods. In such cases, sex estimation can generally be detected by two different approaches: observation of morphological trials and/or measurement of different bones (Asala et al. 2004; Cowal and Pastor 2008; Robinson and Bidmos 2011; Spradley and Jantz 2011; Albanese 2013; Bašić et al. 2013).

It is widely accepted that the pelvic girdle is the most accurate area by which to estimate sex and methods using these elements tend to make successful predictions in 90% to 95% of individuals (Ferembach et al. 1980; Volk and Ubelaker 2002). Comparative studies show varying degrees of the accuracy assessment of sex depending on the area of the pelvic region (sacroiliac segment, ischio-pubic segment and acetabular segment) (Bruzek and Murail 2006; González et al. 2007). The skull is somewhat less reliable for use in estimating sex, ranging from 77% to 92% (Krogman and Iscan 1986; Byers 2002; Bass 2005; Bruzek and Murail 2006). Such a large divergence in dimorphism assessment can be the result of the diversity of populations (Howells 1996; Bass 2005; Dayal et al. 2008; Spradley and Jantz 2011).

Sex estimation when the pelvic girdle and the skull are absent or destroyed is problematic. Therefore, sex estimation based on other bones is an important complement to widely used methods. Long bones have demonstrated their usefulness in sex assessment studies (e.g., Ruff and Hayes 1988; Liu 1989; González-Reimers et al. 2000). However, it is not just the morphologic data for long bones which is studied, but also the measurements for scapula (Spradley and Jantz 2011), ribs (Kubicka and Piontek 2016), carpal bones (Mastrangelo et al. 2011), calcaneus (Peckmann et al. 2015), talus (Otong et al. 2016), and even the internal auditory canal located on the temporal bone (Gonçalves et al. 2015).

Dimensions from the upper long bones (humerus, radius, ulna, and clavicle) have been used to successfully distinguish between the sexes in several European (Cowal and Pastor 2008; Bašić et al. 2013; Kranioti and Tzanakis 2015), Asian (Sakaue 2004; Lee et al. 2014) and African populations (Steyn and Işcan 1999; Barrier and Abbé 2008). In mentioned studies, different measurements have been shown to be good indicators of sex dimorphism. The ability to estimate the sex of each of these bones equips anthropologists with more options when dealing with cases in which the recovered remains are incomplete or destroyed.

The aim of this study is to estimate the degree of sex dimorphism in the 18th and 19th century population of Radom (Poland) and to develop metric standards for the estimation of sex. The upper long bones will be examined for this purpose (clavicle, humerus, ulna, and radius). In particular, the objective is to collect metric data that will generate formulae suitable for Radom's group. These formulae will probably produce the highest levels of accuracy possible for estimating sex in skeletal remains from this geographic region.

Materials and methods

The samples were selected from the Radom Cemetery collection curated at the Department of Biological Anthropology at Cardinal Stefan Wyszynski University (Warsaw, Poland). The present work utilized material obtained during the excavation seasons 2010 to 2013.

Radom is a medium-sized city located in east-central Poland, about 100 km south of Poland's capital, Warsaw.

Although the city of Radom has a long history dating back to the early Middle Ages, our study focused on individuals from the 18th and 19th centuries (Fuglewicz 2011). According to historical information, we know that the first urban municipal cemetery was founded in 1791, but due to the lack of space, a new cemetery was established in 1811 at another location, while the municipal cemetery at the citadel has been abandoned and forgotten (Piątkowski 2000; Zapłata 2011). This means that all the examined human remains come from the turn of the century, and they were buried within a span of 20 years.

Anthropological analysis of the skeletal remains was conducted at the Department of Biological Anthropology of the Cardinal Stefan Wyszynski University in Warsaw.

During the archaeological excavations, a total of 275 burials were uncovered. However, in the present study, the analyses were narrowed to the adult individuals, whose state of bone preservation allowed further examination. Only the bones with complete ossification were included in the present study. Bones showing any deformity or degeneration were excluded from further analyses. According to the above criteria only 180 individuals were chosen. But the final analyses were narrowed only to those individuals whose assessment of sex, conducted by two independent investigators, were identical (JT, WO). Above criteria have been met by 169 individuals (103 male and 66 female), who were selected to the further studies.

The age of the individual was estimated on the basis of changes in the morphology of the pubic symphysis, using the Brooks and Suchey (1990) system and standards for changes in the topography of the auricular surface (Buikstra and Ubelaker 1994; White and Folkens 2000). The referential sex of the individuals was estimated by the Phenice (1969) method. It includes visual assessments of pelvic traits, such as the greater sciatic notch, ischiopubic ramus, subpubic concavity and ventral arc. Although cranial non-metric traits are not as accurate as pelvic traits for sex estimation, they can provide successful estimates, so they cannot be ignored in the analyses. Cranial features, such as the supra-orbital ridges, nuchal area, mastoids, and chin, were used in sex estimation (Buikstra and Ubelaker 1994; Konigsberg and Hens 1998; Walker 2008).

All measurements were made according to Martin (1957): i) clavicle: maximum length (M1), superior (vertical-inferior) diameter at midshaft (M4), anterior (sagittal-posterior) diameter at midshaft (M5); ii) humerus: maximum length (M1), transverse diameter of head (M9), vertical diameter of head (M10); iii) radius: maximum length (M1), medial-lateral diameter at midshaft (M4), anterior-posterior diameter (M5); iv) ulna: maximum length (M1), anterior-posterior diameter (M11), medial-lateral diameter (M12).

Measurements were taken with a Vernier caliper calibrated to 0.1 mm and an osteometric board. Wherever possible, the left side was used. Selected measurements (superior-inferior diameter of the clavicle, transverse diameter of the humeral head and medio-lateral diameter of the ulna) were dubbed twice by the same investigator (JT). The results of the measurements of these observations were compared with the referential sex as estimated from the skull and pelvis.

Statistical analyses were undertaken as follows. First, reproducibility of the selected measurements, made by this same investigator, was assessed by calculating Spearman's correlation coefficient. Second, the Cohen's Kappa coefficient was used to compare observations between investigators. Then, the one-sample Kolmogorov-Smirnov test was conducted for all variables in either sex in order to test for any deviations from a normal distribution. The F-test of equality of variance between sexes was used. Differences in mean values between the sexes were examined by the t-student test or the Welch's test. The t-student test is more reliable when the two-sample has equal variances, while the Welch's test is better when variance is unequal.

In our analysis we consider 'n' objects, among them nF belonging to class "F" (females), and nM belonging to class "M" (males). For each of the objects we also have the numeric values of some measurements. We wanted to find a measurement which the best discriminates between "F" and "M". For a given measurement we chose a cut-point C, and computed the following indicators:

TF = number of "F" among those objects which have the measurement $< = C$

TM = number of "M" among those objects which have the measurement $> C$

$$ACC = (TF+TM)/n$$

ACC (accuracy of classification) is the fraction of correctly recognized objects.

Finally, the Generalized Linear Model (GLM) was used to assess which measurement was the most reliable method for assessing the sex of skeletons in the study population of Radom. Statistical analyses were performed using the R Project for Statistical Computing (2013). Differences showing $p \leq 0.05$ were considered statistically significant.

Results

Assessment of sex was done by two independent investigators. The first investigator identified 109 males and 71 females from 180 individuals, while the second investigator recognized 106 males and 77 females from 180 individuals. It means that eleven individuals were classified differently by two investigators, and those individuals were excluded from further studies. The value for Kappa is 0.8961 indicating a very good level of agreement. Such a result verifies the high repeatability of the observations

Table 1. Results of statistical analyses in both sexes

Measurement		Kolmogorov-Smirnov test		
		Total	Males	Females
Clavicle	Maximal length	0.274	0.277	0.281
	Antero-posterior diameter	0.274	0.276	0.280
	Superior-inferior diameter	0.274	0.276	0.280
Humerus	Maximal length	0.274	0.277	0.281
	Vertical diameter of head	0.274	0.276	0.280
	Transverse diameter of head	0.274	0.277	0.282
Radius	Maximal length	0.274	0.277	0.281
	Antero-posterior diameter	0.274	0.276	0.279
	Medio-lateral diameter	0.274	0.276	0.279
Ulna	Maximal length	0.275	0.277	0.283
	Antero-posterior diameter	0.274	0.276	0.279
	Maximal length	0.274	0.276	0.279

and it allowed us to estimate the referential sex. For intra examiner reproducibility the Spearman correlation values for the transverse diameter of the humeral head was 0.97, superior-inferior diameter of the clavicle was 0.96, and for the medio-lateral diameter of the ulna was 0.95. Such results suggest that all the measurements have high reproducibility.

The distribution of all variables of each sex was detected by the Kolmogorov-Smirnov test. This test did not detect any deviations from the normal distribution at the statistically significant level (Table 1).

Lack of equality of variance was detected by the F-test in three cases: the transverse diameter of the humeral head ($F= 0.5402$, $p= 0.0265$), and the antero-posterior ($F= 5.7712$, $p= 0.0001$) and medio-lateral ($F= 1.7339$, $p= 0.0195$) diameter of the radius (Table 2). In these cases, the Welch's test was used to calculate statistical significance between the mean of measurements.

Table 2. *F* test to compare two variances between sexes

Measurement		F	p
Clavicle	Maximal length	0.82	0.483
	Antero-posterior diameter	0.86	0.573
	Superior-inferior diameter	0.83	0.467
Humerus	Maximal length	0.02	0.071
	Vertical diameter of head	0.79	0.365
	Transverse diameter of head	0.54	0.026*
Radius	Maximal length	0.88	0.666
	Antero-posterior diameter	5.77	0.0001*
	Medio-lateral diameter	1.73	0.0195*
Ulna	Maximal length	0.96	0.908
	Antero-posterior diameter	1.79	0.737
	Maximal length	1.35	0.207

Table 3. Maximum, minimum, average and standard deviations of the measurements

Measurement		Sex	Min	Max	Mean	CI (95%) Lower bound	CI (95%) Upper bound	SD	p
Clavicle	Maximal length	M	109	172	142.5	140.1	143.7	10.6	0.0001
		F	109	163	134	132.2	137.7	9.7	
	Antero-posterior diameter	M	7	18	12.4	11.7	12.3	1.8	0.0001
		F	7	15	10.6	10.2	11.3	1.7	
	Superior-inferior diameter	M	7	16	10.8	10.6	11.4	1.9	0.0001
		F	7	15	9.3	8.5	9.4	1.8	
Humerus	Maximal length	M	270	366	325.1	323.0	330.9	24.6	0.0001
		F	231	360	303.9	293.9	305.0	19.3	
	Vertical diameter of head	M	37	52	45.7	45.3	46.6	3.1	0.0001
		F	32	47	41.3	40.8	42.1	2.7	
	Transverse diameter of head	M	32	48	42	41.2	42.7	3.2	0.0001*
		F	32	43	37.5	36.3	37.7	2.3	
Radius	Maximal length	M	215	280	242.7	238.6	245.3	14.3	0.0001
		F	185	252	218	216.5	223.4	13.5	
	Antero-posterior diameter	M	9	14	12.7	11.8	12.2	1.0	0.0009*
		F	8	23	11	9.7	10.2	2.4	
	Medio-lateral diameter	M	12	19.6	16.2	16.2	16.9	1.5	0.0001*
		F	9.6	20	14.4	14.2	15.4	1.9	
Ulna	Maximal length	M	225	300	260.4	256.6	263.4	14.5	0.0001
		F	200	273	237	232.7	241.2	14.9	
	Antero-posterior diameter	M	10	20	13.8	13.0	13.7	1.7	0.0001
		F	8	19	12	11.5	12.4	1.8	
	Medio-lateral diameter	M	12	21	16.5	16.5	17.4	1.9	0.0001
		F	8	20.1	14.7	14.5	15.4	2.2	

*Welch test sample.

All variables of measurements are shown in Table 3. Generally, all of the values were larger for males than for females, and these differences were statistically significant. The greatest differences between sexes in mean values were detected in the measurement of length: radial maximal length (males: 242 mm, females: 218 mm), ulnar maximal length (males: 260 mm, females: 237 mm), humeral maximal length (males: 325 mm, females: 303 mm), and clavicle maximal length (males: 142 mm, females: 134 mm). The differences between sexes in mean values of transverse measurements were at a similar level.

The accuracy of sex estimation for the upper long bones size is represented in Table 4.

The accuracy in estimation of sex using different measurements ranged from 68% to 84%. In general, the values for the antero-posterior diameter and maximal length of clavicle were better predictors than the superior-inferior diameter. However, these received values against other analyzed bones, are very small. The measured values showed that vertical diameter of the humeral head was a better

Table 4. Results for classification of accuracy and demarking point

	Measurement	Sex	Accuracy (%)		Demarking point (mm)
Clavicle	Maximal length	M	60.5	73.3	F<140<M
		F	83.3		
	Antero-posterior diameter	M	69.8	73.5	F<11<M
		F	75.8		
	Superior-inferior diameter	M	55.1	68.5	F<10<M
		F	79.2		
Humerus	Maximal length	M	74.3	83.3	F<316<M
		F	82.0		
	Vertical diameter of head	M	80.4	78.5	F<43<M
		F	85.4		
	Transverse diameter of head	M	78.4	84.5	F<39<M
		F	78.8		
Radius	Maximal length	M	84.2	84.5	F<228<M
		F	85.1		
	Antero-posterior diameter	M	78.8	82.4	F<11.2<M
		F	84.4		
	Medio-lateral diameter	M	70.0	72.3	F<15.5<M
		F	74.1		
Ulna	Maximal length	M	83.0	83.2	F<248<M
		F	83.5		
	Antero-posterior diameter	M	64.4	76.0	F<12.5<M
		F	79.1		
	Medio-lateral diameter	M	57.1	68.4	F<16.2<M
		F	87.2		

predictor than the transverse diameter of the head or the maximal length. The values for the maximal length of both the radius and the ulna were better predictors than the transverse diameter (antero-posterior and medio-lateral).

The best predictor for sex estimation of all the measurements in Radom's population is the maximum length of radius (84.5%) and ulna (83.2%), and the vertical diameter of the humeral head (83.3%). The worst predictive values were the superior-inferior diameter of the clavicle (68.5%) and the medio-lateral diameter of the ulna (68.4%) (Fig. 1).

The discriminate function coefficient of the upper long bones dimension for Radom's population is presented in Table 4. The functions are displayed based on a single variable. Females are indicated when the discriminate score is lower than the demarcation points and males are indicated when the discriminate score is higher. For example, a maximal length of clavicle size of 143 mm would be identified as a male because the diameter is greater than the 140 mm function coefficient.

In the final step, the GLM was used to examine the relationship between the following measurements, with the referential sex estimation from the skull and the pelvis. GLM, which ignores inter-individual variability, detected a weak sta-

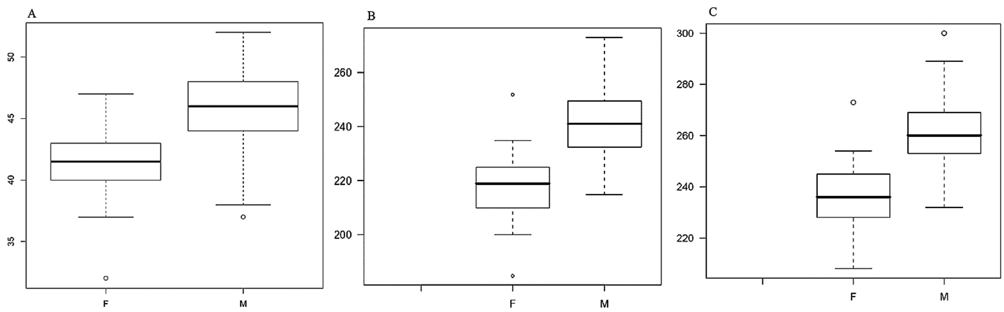

Fig. 1. Boxplots with the main measurements (A – vertical diameter of humeral head, B – maximum length of radius, C – maximal length of ulna)

tistically significant correlation between the referential sex and maximal length of the ulna (p = 0.0117), while a stronger significant relationship was found between the referential sex and the vertical diameter of humeral head (p<0.0001). In other measurements of the upper long bones, GLM did not detect any statistically significant differences.

Discussion

The skeleton plays a significant role in various sciences, such as forensic science, medicine and anthropology. The estimation of sex using metric methods has been explored by many researchers of both contemporary (Barrier and L'Abbé 2008; Celbis and Agritmis 2006) and historical populations (Bergmann et al. 1962; Cowal and Pastor 2008; Bašić et al. 2013). The humerus or clavicle have been studied intensively and standards have been obtained for several populations, from the Adriatic coast (Bašić et al. 2013), the southern India region (Patil et al. 2011), Iran (Akhlaghi et al. 2012), and even prehistoric New Zealand populations (Murphy 1994). Also, the ulna and radius have been the subject of many osteometric studies from different world regions, such as Crete (Kranioti and Michalodimitrakis 2009), Turkey (Celbis and Agritmis 2006) and South Africa (Barrier and L'Abbé 2008). Although many Polish populations have been described through metric characteristics (Piontek 1969; Ćwirko-Godycki and Swedborg 1977; Psonak and Kwiatkowska 2011), unfortunately there are few studies of sex estimation using the measurement of the upper long bones (Bergmann et al. 1961; 1962).

It should be noted that all these studies have shown that populations have different metric manifestations in both sexes. These variations are related to body size and consequently to metric differences in the dimensions of individual skeletal elements. Observed differences can be attributed to genetic factors (Holden and Mace 1999; Nyati et al. 2006; Gustafsson et al. 2007), physical activity (Ruff 1987; 2003; Carlson et al. 2007; Cowgill and Hager 2007; Patil et al. 2011), and environmental and/or social conditions (Stini 1969; Stinson 1985; Celbis and Agritmis 2006). In this context, there is evidence that populations that have either a very low or very high protein intake demonstrate the least amount of sex dimorphic variation (Gray and Wolfe 1980). The multitude of combinations among these factors may partly explain why it is so difficult to draw unambiguous conclusions on the etiology of the differences observed between the two sexes. Despite the above limitations, many studies, including our data, indicate that metric differences in the upper long bones are quite a good indicator of sex and they can be used in the diagnosis of the sex of individuals. The results have revealed that the mean values of the male measurements were significantly higher than those of females.

The clavicles of Radom's population show that the mean length and both transverse dimensions (antero-posterior and superior-inferior) of males were statistically significantly larger than the females' clavicles ($p < 0.0001$). However, in the literature, the measurement at the maximum/minimum mid-shaft diameters of the clavicles (Ray 1959; Shirley 2009) or the mid-shaft circumference is preferred over the sagittal-vertical diameters at mid-shaft (Akhlagi et al. 2012; Murphy 1994). This fact may be the result of the anatomical structure of this part of the clavicle, and the measurement technique in this anatomical region, which can be "twisted", so all the transverse measurements can be disrupted. Finding the maximum and minimum diameters is easier than approximating the sagittal-vertical diameters, because the latter require a rough estimation of the bone's anatomical orientation. Nevertheless, using our team transverse dimensions (antero-posterior and superior-inferior) also demonstrated that variation between the sexes is visible.

Three measurements (maximum length, vertical and transverse diameter of the head) were taken from each humerus of Radom's population. They show that the mean values of males were statistically significantly higher than those of the females ($p< 0.0001$). This observation is consistent with the results noted by other researchers who conducted studies both on contemporary (Patil et al. 2011; Thakur et al. 2015) and historical populations (Bergmann et al. 1961; 1962; Piontek 1969; Bašić et al. 2013).

For the ulnar and radial dimensions the sex difference between maximal length was also statistically significant. The mean for males was 260 mm and for females 237 mm in the ulna length measurement, and 242 mm for male and 218 mm for females in the radius length measurement. Sex dissimilarities in these bones were observed not only in the European populations (Piontek 1969; Celbis and Agritmis 2006), but also in Asian (Sakaue 2004; Lee at al. 2014) and African (Barrier and L'Abbé 2008) populations. However, it is worth emphasizing that both sexes are characterized by similar differences between medio-lateral and antero-posterior diameters in the bones of the forearm. Similar results, a small difference between the measurements for both sexes, were obtained for contemporary populations from Africa (Barrier and L'Abbé 2008). Results from the Early Medieval population from Ostrów Lednicki (Poland) reported increased values for both measurements. Moreover, in this population from the Early Medieval period, the medio-lateral dimension of the males' ulna was clearly bigger than the females' ulna (23.7 mm and 15.3 mm, respectively) (Ćwirko-Godycki and Swedborg 1977). That may indicate the different types of physical activity between males and females living in Ostrów Lednicki. The similar dimensions between males and females from 18th and 19th century Radom in this anatomical region suggest similar or identical types of physical activity in the upper limb in both sexes.

General studies prove that the maximum length of the humerus, the vertical diameter of the head, or the humeral midshaft circumference are the most significant of all the measurements of the humerus in estimating sex (Bergmann et al. 1962; Loth and İşcan 2000; Thakur et al. 2015). Dimensions such as maximum ulnar length, or mid-shaft circumference, as well as radial length and circumference of the radial head are shown to be good indicators of sex differences, of all the measurements of forearm bones (Mall et al. 2001; Barrier and L'Abbé 2008). According to our studies, the maximal length of the radius and the vertical diameter of the humeral head are the most discerning for the upper limb measurements (84.5% and 83.3%, respectively), followed by ulnar length (83.2%). The medio-lateral diameter of the ulna and the superior-inferior diameter of the clavicle (68.4% and 68.5%, respectively) are less useful for sex estimation of all the analyzed measurements. A comparison of the results of the present study with those from other studies of skeletal long bones demonstrates that these same measurements are especially valuable. The vertical diameter of the humeral head, and the maximum length of radius and ulna are important sex indicators in many other populations (Kranioti and Michalodimitrakis 2009; Bašić et al. 2013; Lee et al. 2014). However, these same measurements can have a different value in the assessment of sex in the studies of populations. For the vertical diameter of the head, a contemporary population from Korea had 87% accuracy, while our study achieved 83% accuracy (Lee et al. 2014). In the maximal length of the radius, modern Cretans had 91% accuracy, while the population from Radom achieved only 84% accuracy (Kranioti and Michalodimitrakis 2009). In the maximal length of the humerus, a German population had 80% accuracy, while the analysis of Radom's population achieved 77% accuracy (Mall et al. 2001).

In the analysed sample, the females were classified better than the males for all variables. The maximum length of the radius was considered a useful measurement for distinguishing sex, with a classification accuracy of 84% for males and 85% for females. The vertical diameter of the humeral head was characterized by an accuracy of 80.4% for males and 85.4% for females. The maximum length of the ulna was considered to have a classification accuracy of 83% for males and 83.5% for females. A similar phenomenon was also observed by some authors (Cowal and Pastor 2008; Barrier and L'Abbé 2008). The explanation of this fact can be a less pronounced robustness in the male group, which would have increased their chances of being classified as females. However, we cannot exclude the reason that males and females may differ in size variability within their own group.

The demarcation points of Radom's population were larger than those determined by other studies, such as from the Eastern Adriatic regions (Bašić et al. 2013), Korea (Lee et al. 2014), Crete (Kranioti and Michalodimitrakis 2009), and an Early Medieval population from Poland (the city of Strzelno) (Piontek 1969). The demarcation points of Radom's sample from the 18th and 19th centuries were smaller in comparison with the Early Medieval Polish population from Ostrow Lednicki (Bergmann et al. 1962; Ćwirko-Godycki and Swedborg 1979). It means that it is extremely difficult, or even impossible, to propose general standards for differences between the sexes that would be applicable to all populations.

GLM was used to examine the relationship between measurements with the referential sex estimated from the skull and the pelvis. The results of the GLM analysis indicated that the vertical diameter of the humeral head is the most valuable for sex diagnosis in this population, followed by maximal length of the ulna. The rest of the measurements were not statistically significant according to this model. Overall, the data generated by the present investigation suggest that this metric dimension for the determination of sex in the skeletons of the Radom population can be very useful. However, the application of this dimension is not recommended for geographically remote populations or archeological samples before further studies can confirm their suitability.

Conclusion

Where pelvis or skull bones are not available, long bones can be useful in determining sex. In this context, metric measurements are preferred due to their high levels of accuracy. For the purpose of the present study, the clavicle, humerus, radius, and ulna were selected to determine which measurements of these bones were the most useful for the determination of sex in a population from Radom. Our studies proved that the maximal length of the radius, the vertical diameter of the humeral head and the maximal length of the ulna are the most useful of the upper limb measurements.

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Authors' contributions

JT designed the research interpreted the results, wrote the paper; JND gave support and conceptual advice, collected the articles, commented the initial draft of the manuscript; WO collected the data; MZ and WN performed statistical analyses. The final version of paper was prepared by JT and approved by all authors.

Conflict of interest

The authors declare that there is no conflict of interests regarding publication of this paper.

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