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Sex determination from scapular length measurements by CT scans images in a Caucasian population.

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***Abstract*— Together with race, stature and age, sex is a main component of the biological identity. Thanks to its proportional correlation with parts of the human body, sex can be evaluated form the skeleton.**

The most accurate approach to determine sex by bone size is based on os coxae or skull. After natural disaster their presence can never be guaranteed, therefore the development of methods of sex determination using other skeletal elements can result crucial. Herein, sexual dimorphism in the human scapula is used to develop a two-variable discriminant function for sex estimation.

We have enrolled 100 males and 100 females who underwent thoracic CT scan evaluation and we have estimated two scapular diameters. The estimation has been carried out by analyzing images of the scapulae of each patient after three-dimensional post-processing reconstructions. The two-variable function allows to obtain an overall accuracy of 88% on the calibration sample. Furthermore, we have employed the mentioned function on a collection of 10 individual test sample from the collection of the "*Museo di Anatomia Umana di Firenze*" of the *Università degli Studi di Firenze*; sex has been correctly predicted on 9 skeletons.

I. Introduction

After natural disaster, war crimes, terroristic attacks or any other condition with an elevated number of cadavers, one of the main challenge is victim identification. Nowadays in forensic anthropology the number of new techniques of identification is constantly increasing. In particular the DNA technologies seem to be the most reliable ones but the availability of forensic laboratories and the cost-effectiveness of these technologies have limited their diffusion on large scale. Although DNA is commonly used for disaster victim identification (DVI) or in identification of human remains found in mass graves, the use of "traditional" techniques is usually preferred than approaches more technologically expensive (e.g., DNA analysis) [1]. Traditional techniques generally consist of combining witness testimony, personal effects and anthropological data, like race, age, stature and sex [2]. Sex is one of the most important component of the biological identity that can be evaluated from the skeleton because of the marked sexual dimorphism of some bone segments (e.g., head, trunk and arms).

However, other skeletal elements have been already considered in this field, such as os coxae or skull [3, 4]. The bone studied in the present work, is a paired short bone: the scapula. The choice to focus on the scapula is motivated in the first place by its negligible morphological changes during life after the growth is complete [5]. Secondly by the scenario that frequently appears in cases of chattered bodies, act of terrorism, or disaster victim identification, where flat and short bones seem to be better preserved than long bones, which are often fragmented, scattered or mixed together.

The present study has been conducted to set a formula to determine sex on the basis of two scapular diameters. We performed our analysis in an *in vivo* population of 200 Italian subjects (100 males and 100 females) using CT scan images to estimate the abovementioned diameters. Firstly, we calculated a discriminant function based on a two-variable model, then we found a simple discrimination threshold based on only one scapular diameter, considering the possibility of a skeleton recovery with fragmented bone. The usefulness of our research is mainly related to corpses recoveries or skeletal analysis. In order to assess the accuracy of the proposed equation and threshold values in an *ex vivo* sample, we successfully tested our sex prediction on a skeletal collection.

II. Materials and Methods

A. Materials

From April 2012 to October 2012 we collected a sample of 200 healthy Italian subjects (100 males; 100 females) with a mean age of 64.2 years (SD 12.8 years) who underwent thoracic CT scan evaluation during a pulmonary screening program on heavy smokers, which has been carried out in our institution.

Our exclusion criteria were: scapular, vertebral, pelvis or lower limb fractures; vitamin deficiencies; metabolic-endocrine diseases; lactose intolerance; growth disorders; severe osteoporosis (T-score <2.5).

Low dose exams (35 mAs; 120 kV) were obtained using Somatom Sensation 64 CT scans (Siemens Medical, Erlangen, Germany). A 500 mm topogram was performed between the superior borders of the clavicles and the kidneys with the upper limbs held up beside the head; scans in spiral mode were executed in inspiratory breath-old and then

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images were reconstructed with a slice thickness of 1 mm in axial and sagittal planes.

B. Methods

After completion of sampling, we analyzed images of each patient and we measured two parameters for both scapulae:
- longitudinal scapular length (LSL): The distance between the end of the inferior angle and the superior margin of the coracoid process (Fig. 1a, b)
- transverse scapular length (TSL): The distance between the medial margin and the inferior margin of the glenoid cavity (Fig.1b, c)

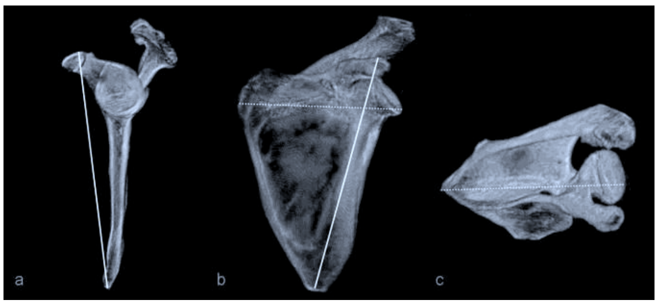

Figure 1. CT scan imaging with volume rendering reconstruction; 1a) LSL in the sagittal plane (continuous grey line); 1b) LSL (continuous grey line) and TSL (dashed grey line) in the coronal plane; 1c) TSL in the axial plane (dashed grey line).

In order to improve the measurements repeatability, we have elaborated the 2D CT scan axial images through post-processing volume rendering technique and we have obtained 3D reconstructed bones, so that virtual bones can be aligned and the maximum length of the parameter that is to be measured is in the frontal plane of the screen.

All statistical analyses were performed considering for each parameter the mean value between left and right scapula because we did not identify any significant differences between the two scapulae in each patient.

Our measurements had an uncertainty lower than 1 mm due to the procedure of length bones estimation because the 3D post-processing reconstruction of bones derives from 2D images with slice thickness of 1 mm.

III. Results

The two scapular lengths (i.e., LSL and TSL) measured in this work show statistically significant variations between females and males groups ($p<0.001$). In order to highlight the different distribution of LSL and TSL with sex, the histograms of these two bone lengths are reported in Fig. 2.

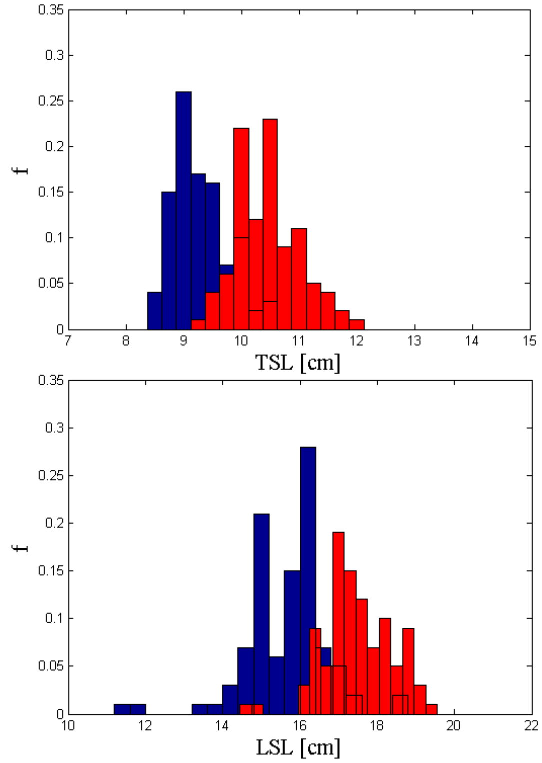

Figure 2. Histograms of TSL values and LSL values. Red bars (males), blue bars (females).

The sex determination has been performed with two methods:

1) only one scapular length has been used to estimate sex. This approach simulates the condition where only one of the two mentioned lengths is guaranteed (e.g., in fractured elements). In this case we calculated the threshold value of both TSL and LSL which maximizes the accuracy in sex estimation. The threshold values (T) and the accuracy obtained for females, males and considering the whole sample are reported in Table I.

TABLE I. Threshold values of TSL and LSL and accuracy in the sex estimation considering males, females and all the sample.

	T [cm]	Male Acc. [%]	Female Acc. [%]	All individuals Acc. [%]
LSL	16.69	84 %	84%	84%
TSL	9.97	89 %	85%	87%

For the calibration sample, this method proved accurate in 84% of cases considering LSL and in the 87% of the cases considering TSL. Fig. 3 shows the distribution of LSL and TSL values compared with the two calculated thresholds for both males and females groups.

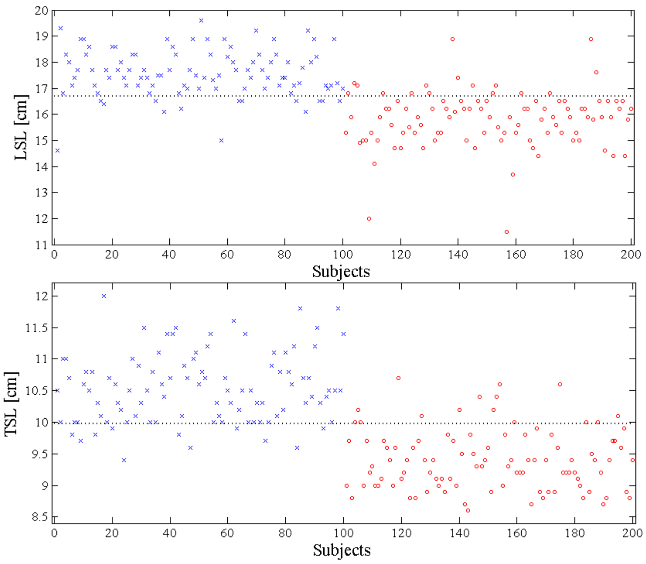

Figure 3. Distribution of LSL and TSL values in males (cross) and females (circles). The dotted lines represents the threshold values of TSL and LSL.

2) A two-variable discriminant function was developed for use in situations where both LSL and TSL values are present. The value of ''sex'' is calculated by substituting the individual values for the variable code. The demarcation point is zero, with males having sex values larger than zero, females smaller. The decision rule which maximizes sex estimation on calibration sample is the following:

$$\begin{cases} Sex = -57.9537 + 1.3274 \cdot LSL + 3.5903 \cdot LST \\ Sex > 0 \quad male; \; \text{Sex} < 0 \quad \text{female} \end{cases} \qquad (1)$$

It is worth observing that we used a linear boundary in order to prevent overfitting issues. Fig. 4 shows the distribution of LSL and TSL values for females (circles) and males (cross) groups; the line of demarcation is also reported.

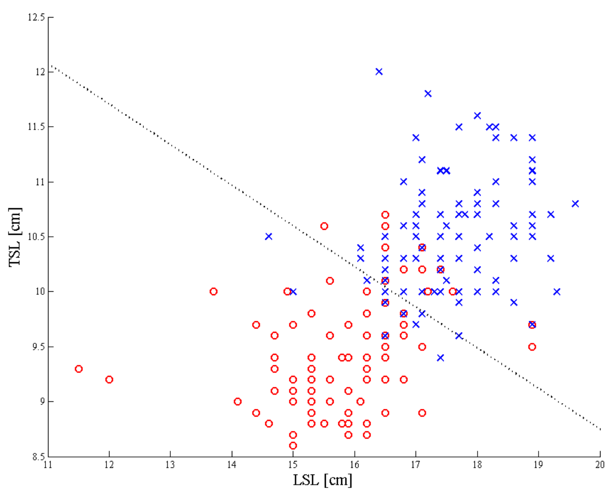

Figure 4. Distribution of LSL and TSL values for females (circles) and males (cross) groups; the line of demarcation is also shown.

For the calibration sample, this method (1) proved accurate in 88% of cases (87% for females and 89% for males).

Additionally, the two methods were used to estimate sex from the skeletal collection of the *"Museo di Anatomia Umana di Firenze" Università degli Studi di Firenze*. Their LSL and TSL values and sex are reported in Table II.

TABLE II. SEX, TSL AND LSL VALUES OF THE 10 CADAVERS.

	TSL [cm]	LSL [cm]	Sex
1	9.9	17.0	male
2	10.2	17.2	male
3	10.8	17.8	male
4	9.6	15.1	female
5	9.6	17.1	female
6	11	17.8	male
7	10.7	18.2	male
8	9.6	16.2	male
9	11.3	17.2	male
10	9.2	14.2	female

The distribution of LSL and TSL values for females and males groups of the 10 cadavers and the line of demarcation (1) are reported in Figure 5.

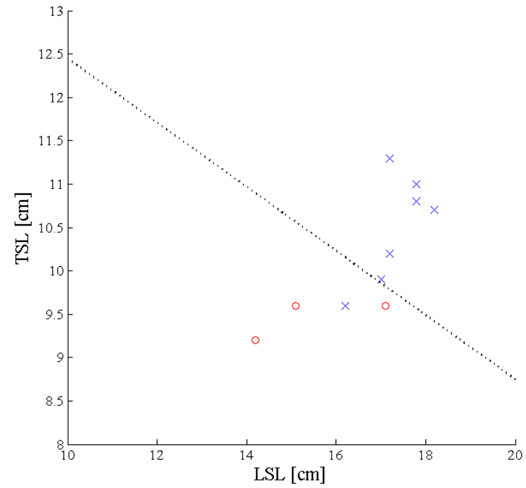

Figure 5. Distribution of LSL and TSL values for females (circles) and males (cross) skeletons; the line of demarcation is also shown.

The use of (1) allows to correctly discriminate sex on 9 skeletons (accuracy=90%); on the other hand, using only one scapular segments the accuracy decreases (80 % using either LSL or TSL lengths).

IV. DISCUSSION AND CONCLUSION

Sex determination represents a key point in forensic evaluations because it is an important component of biological identity.

An equation obtained in a certain population is not suitable for people originating from a different country because genetic and environmental factors have a strong influence on skeletal development [6]: this is why population specific sex estimation formulae are required.

In literature some authors have performed anthropometric analysis on *in vivo* populations [7] but the largest part of these studies have been carried out on cadavers [8, 9, 10] or skeleton collections.

The scapula is a paired short bone that does not undergo significant morphological changes during life after the growth is complete and so in our study we focused our attention on it.

Different authors have analyzed scapular parameters in order to predict sex from skeletal remains [8, 9, 10, 11].

In 1894 Dwight [11] noted several morphological differences between the male and the female scapula.

In 1956 Bainbridge and Tarazaga [10] published a study on the sex differences of the scapula using scapulae from archaeological population and they found that the axillary border is a useful morphological indicator of sex.

In 1994 Di Vella *et al.* [9] studied the scapulae of a modern southern Italian population in order to determine sex and they concluded that using a multivariate discriminant analysis, the maximum distance between the acromion-coracoid processes, maximum length of the coracoid, and the length of the glenoid cavity, it was possible to sex a skeleton with 95% accuracy.

Finally, Dabbs *et al*. [8] in 2010 analyzed 724 individual calibration sample from the Hamann-Todd collection and measured 23 scapular variables showing statistically significant differences between male and female groups.

To date, few authors have applied radiology in the field of anthropometry to achieve accurate standard measurements in vivo, analyzing the bones of interest with DXA [14], CT scan [5, 7], radiographs [12, 13].

Skeletal measurements based on CT scan images could be standardized because the anatomical landmarks are easy to locate.

Knowing that the main application of this kind of study is in course of identification of cadavers or skeletons recovery, we test the reproducibility of our analysis on *ex vivo* samples and we successfully applied the results provided on 10 skeletons taken from the collection of the "Museo di Anatomia Umana di Firenze".

In conclusion, our study demonstrates that scapula could be useful for sex estimation: the two variable discriminant function provide accuracy of 88 % and 90 % for the calibration sample and the skeletons, respectively.

Furthermore, in skeletal recoveries bones appear frequently fragmented and so we have assessed a method based on a single scapular parameter. This method shows a slightly lower accuracy than the approach based on two-variable approach: using only LSL the accuracy was 84% on the calibration sample and 80% on the skeletal collection, instead using only TSL the accuracy was 87% on the calibration sample and 80% on the skeletal collection.

The good accuracy obtained by applying the two variable function on a small *ex vivo* sample size encourages to carry out further investigations on larger samples. A deeper analysis could allow to assess the accuracy of the proposed equation to estimate sex from scapular dimensions on the Caucasian population, which should be a useful tool for the re-individualisation in mass graves or disaster victim identification.

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