Age estimation from dry bone measurements: evidence from a sample of soldiers exiled in two concentration camps in Bari

Mirko Leonardelli[1], Valeria Santoro[1], Alessia Leggio[1], Carmelinda Angrisani[1], Sara Sablone[1], Franceso Introna[1], Antonio De Donno[1]

[1] Department of Interdisciplinary Medicine, Section of Legal Medicine, Bari Policlinico Hospital, University of Bari, Bari, Italy;

Corresponding author:
mirkoleonardelli@gmail.com

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ABSTRACT

The mandible undergoes remodelling and morphological alterations throughout the life of an individual, and it is subjected to sex- and age-related structural changes. Personal identification from skeletal remains represents one of the most difficult challenges for a forensic anthropologist. The study of mandibular morphology is an important aid in determining the sex and age of skeletal remains. The objective of this study was to evaluate the age-related changes of three mandibular dimensions through dry bone measurements: bigonial width, ramus height and gonial angle. A total of 93 skeletal remains were included in this study, from a group of soldiers of Yugoslav origin who lived in two concentration camps in Bari (southern Italy) during World War II. These are included in the collection of the Forensic Anthropology Laboratory of the Institute of Forensic Medicine of Bari. The measurements were recorded after comprehensive examination by a forensic anthropologist and a forensic odonto-stomatologist. The data obtained were analysed statistically using a bivariate test and a multivariate linear regression model, using the Statal 13MP software. The results indicate that the bigonial width and gonial angle vary significantly according to age. In conclusion, this study confirms that the mandible is useful for age estimation in the identification of skeletal remains using these specific mandibular measurements when performed on dry bone without radiological distortion.

INTRODUCTION

A key objective of the practice of forensic anthropology is to ensure identification of recovered human remains in a medico-legal context. To determine the species, sex, age at death, stature, time since death, and estimate specific morphometric characteristics provide opportunities to identify missing people.[1] The identification of human remains may be necessary as a result of accidents and in criminal investigations or ethnic studies. In such cases, the estimation of age and sex is one of the first objectives sought by the medical examiner. The study of age and sex based on the analysis of skeletal remains can be of particular difficulty for anthropologists, especially when such studies need to be carried out on small skeletal fragments.

Evaluation of the morphological characteristics of the skull and mandible constitutes a commonly used sex-estimation approach for forensic anthropologists. In particular, analysis of the mandible can be used for sex estimation when it is not possible to assess the skull or the pelvis. The bone and tooth

tissues that can be extracted from human remains can thus be used in the age-estimation process.
The mutual dependence that is recognized between the passing of time and the morphological changes of the human body may be useful in the estimation of age at death. Such ageing patterns can be detected by both microscopic examination and macroscopic observation. Furthermore, several studies have shown that measurements made directly on bones are more likely to provide true information, which is why the methods using this technique are the most reliable in determining sex and age.[2]
Recently, studies have highlighted that the anatomy and shape of the mandible undergo changes according to both age and sex.[3-9] The morphology of the mandibular base depends on the occlusal state and the contractile strength of the masticatory muscles; i.e., the medial pterygoid and masseter muscles.[10] With age, there are modifications to the structure of the masticatory muscles that are demonstrated in reduced contractile strength. Indeed, in edentulous subjects, there is frequently a variation in mandibular shape, with reduction in the contractile strength of the masticatory muscles secondary to the loss of the teeth.[11]
Sex differences in the morphology of the mandible are a consequence of different genetic patterns, whereby in male subjects the mandible grows exponentially during puberty, unlike for females. Furthermore, the masticatory muscles are less voluminous in females than males, and this results in differences between the sexes in the shape of the mandible.[12] Several anthropological analyses have been carried out on these dimorphic characteristics. Different mandibular dimensions have been studied, such as the gonial angle, ramus length, bicondylar breadth, bigonial breadth and mandibular base length.[8]
The present study focuses on three of these mandibular dimensions as determinants of age: gonial angle, bigonial width and ramus height. Although there is some information in the literature about age- and sex-related changes of these measurements, the findings of various studies have not been consistent. Some studies have shown variations in the bigonial width and ramus height with age and sex,[9,10] while other studies have not confirmed these.[3,13] In the same way, age- and sex-related alterations in the gonial angle have been demonstrated in some studies,[14,15] while other studies highlight different results.[7,9,12]
The literature shows how these correlations have been studied through radiological investigations, such as with panoramic radiographs, computed tomography and cephalograms. To further examine skull age-related dimensional variations, the present study instead recorded the three mandibular measurements of gonial angle, bigonial width and ramus height directly from the skulls of a skeletal collection.

MATERIAL AND METHODS

To demonstrate these variations in the mandibular morphology, the sample group consisted of the skeletons of 93 soldiers from the Royal Yugoslavian Chetnik Army who were in exile in Bari in 1941 (89 men, 4 women), which form part of the skeletal collection of the Institute of Legal Medicine at the University of Bari (southern Italy). The samples were from Caucasian Mediterranean subjects who had lived in two concentration camps in the Bari area during the Second World War, and who were aged from 1 year to 75 years. All of the mandibles used were intact or not excessively fragmented, with no proportional discrepancies and no bone disease, and with clear and accessible surfaces for the measurements that were deemed suitable for this study. All distorted, incomplete, or fractured mandibles were excluded from this study. From an original population of 93 individuals (100%), 37 (39.8%) were removed from this study after application of these exclusion criteria. The remaining 56 (54 men, 2 women) were included in this analysis, and were aged between 18 years and 62 years (mean ±SD, 33.08 ±11.54 years).
A single forensic anthropologist recorded the three mandibular measurements. To ensure greater reliability and reproducibility, the measurements obtained were also reassessed by a forensic odonto-stomatologist at a later date. The mandibles underwent measurements of the bigonial width, the mandibular ramus height and the gonial angles using a goniometer and callipers. The angle formed by the intersection of the lower margin of the body of the mandible and the rear margin of the ramus was measured as the gonial angle. The bigonial width was measured as the distance between the two opposite gonial angles. The ramus height was measured as the

distance from the gonion to the upper margin of the mandibular condyle.

The descriptive statistics for each set of mandibular measurements were recorded, including the means ±standard deviation and ranges (minimum to maximum) in the males and females. The initial analyses were performed using an Excel database, and the statistical analysis was performed using the Statal 13MP software (StataCorp LLC, College Station, Texas).

Bivariate analysis was used to compare the study parameters with age. Then all of the independent variables with a p-value ≤0.25 were considered suitable for the multivariate analysis. Thus, a multivariate linear regression model was used to correlate the independent variables with age. The results of the multivariate analysis are expressed with 95% confidence intervals (CIs), with statistically significant taken as a p-value <0.05.

RESULTS

The descriptive statistics reported in Table 1 show the sex differences for the bigonial width, ramus height and gonial angle. Males have higher values for the bigonial width compared to the females. The mean ramus height and gonial angle of the male population were slightly lower than those of the female population.

Table 1. Mandibular values obtained for the whole sample analysed

Mandibular measure	Males				Females			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Bigonial width (cm)	10.13	0.72	8.9	11.9	9.7	0.2	9.5	9.9
Ramus height (cm)	6.48	0.71	4.0	8.1	6.5	0.2	6.3	6.7
Gonial angle (°)	118.72	5.76	106	132	122	6	116	128

Bivariate analysis provided an estimate of the existing associations between each single independent variable (i.e., bigonial width, ramus height, gonial angle) and the outcome of interest, as age. As shown in Table 2, all three of these parameters were considered suitable for the subsequent multivariate analysis (p-value ≤0.25).

Table 2. Summary of the significance from the bivariate analysis for the comparison of the study parameters with age

Mandibular measure	*p*
Bigonial width	0.007
Ramus height	0.19
Gonial angle	0.005

Finally, each of these variables was inserted into the multivariate linear regression model that was developed to assess the association between the variables and the dependent variable, as age. The results from the multivariate analysis are summarised in Table 3, which shows significant association between age and bigonial width and gonial angle (p-value <0.05).

Table 3. Summary of the significance from the multivariate linear regression analysis for the comparison of the study parameters with age

Mandibular measure	*p*	95% Confidence interval	
Bigonial	0.025	0.666	9.538
Ramus height	>0.05	/	/
Gonial angle	0.016	-0.423	-0.045

DISCUSSION AND CONCLUSIONS

The published literature indicates that the mandibular dimensions have been considered as one of the most useful parameters to determine sex and age in human remains as accurately as possible. From a medico-legal point of view, odontology is commonly used to identify human remains, as skulls and teeth can give accurate information about the age of an individual. This is why there are many age assessment criteria based on dental methods.[16]

Forensic odontology can have a useful role in determining the age and sex of subjects with unrecognizable body structures. There are differences in dental characteristics between the

two sexes, such as morphology, crown size, and root lengths.[17] There are also other characteristics of the teeth that are linked to changes that occur over time, and are thus also useful in determining age.

Previous morphometric analyses using panoramic radiographs have demonstrated significant results for age- and sex-related alterations to the jaw.[5] In this way, radiography has become a useful tool in studies that are designed for forensic age and sex estimation. In contrast, the present study was designed to determine age-related changes in the mandible through direct measurements from the bone, without the aid of radiographs or other imaging modalities.

The parameters assessed here were bigonial width, ramus height and gonial angle. Bigonial width and ramus height represent the horizontal and the vertical dimensions of the mandible, respectively. Furthermore, the gonial angle is formed by the intersection of an anteroposterior tangent with a vertical line. The implication of these three parameters is that they represent the mandible across all of the planes, which is important to assess mandibular shape and to demonstrate the effects of ageing in the process of modification of the mandible. Many investigations have studied age and sex alterations according to other parameters,[6] but the relation between these three parameters has been studied by very few.[3,10]

This study investigated these changes in the mandibular dimensions in adult soldiers who lived in exile in two concentration camps in Bari during World War II, with dry bone measurements included for 56 male and female individuals. The mean age of all of these subjects was 33.08 years.

In the present study, the bigonial width dimension was greater in the males, while the ramus height and gonial angle were higher in the females compared to the males. These findings are similar to those of other studies,[3,5,9,11,14] although they are also partly contrary to others.[10,18] This difference is related to the greater contractile force of the masticatory muscles of the male subjects compared to the muscles of the females.

Statistically significant differences in the bigonial width and gonial angle were noted in the present study in terms of the age of the individuals. These findings are similar to some previous studies where significant differences in these dimensions have been noted.[3,4,10] Our findings are, however, also in contrast to some other studies that found that the differences in these parameters were not statistically significant.[6,9]

The ramus height was not statistically meaningful in terms of the age variation. This finding is similar to some studies,[4] although in other studies this difference has been statistically significant.[10] These data are probably the result of a change in the mandibular shape that would have resulted in a reduction in the contractile strength with ageing.

A limit of this study is represented by the sample, because it was composed of a small number of Caucasian Mediterranean subjects with a limited age range and, in particular, few females. Future studies should include a larger study population with a wider age range, and should evaluate another population, because mandibular parameters can vary across different human populations. The greatest strength of this study, however, is the absence of geometric distortion as a result of the radiography that has been used in other studies, due to the direct measurements recorded here on the dry skull.

In conclusion, this study confirms that the mandible is important for age estimation, and our findings show significant differences in bigonial width and gonial angle measurements according to the age of these individuals from samples of Caucasian Mediterranean skeletal remains. However, the changes in the ramus height were not statistically significant according to the age variation. As indicated, the greatest strength of this study is due to the absence of geometric distortion during radiography, as has been seen in other studies. Thus, knowledge of these different patterns provides further essential information in the determination of the sex and age of human skeletal remains, whereby the morphometric analysis of these mandibular dimensions represents a helpful tool for forensic science.

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