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A cross-sectional analysis of age related changes in the osteometric dimensions of long bones in modern South Africans of European and African descent

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ABSTRACT

New techniques are continuously developed to establish individualizing characteristics of unknown skeletonized remains. However, the critical evaluations of older, and seemingly standardized, methods are also necessary. Since many of the methods to determine skeletal sex are used in a medico-legal arena, the application of proper techniques to achieve accurate results is paramount. The purpose of this study was to evaluate whether the osteometric variables that are often used in discriminant function formulae to determine sex, namely the dimensions of the proximal and distal articular surfaces and the mid-shaft diameters of the long bones, increase or decrease with the advancement of age. Twenty-three standard anthropometric measurements were taken from the long bones of 404 male (n = 106 white, n = 298 black) and 189 female (n = 82 white, n = 107 black) known skeletons housed at the medical schools of the Universities of Pretoria and the Witwatersrand in South Africa. Results indicated that males and females of both ancestral groups were sexually dimorphic for the long bone measurements. The mean size of these measurements demonstrated a statistically significant increase in size from young to old groups in white females and males, with black females remaining static for their measurements and changes with age. Reasons for an increase in size are multi-faceted and may include normal degenerative changes such as bone remodeling, microfractures at articular joint surfaces, and changes in the relationship of cortical and endosteal bone as well as disease (osteoporosis). Males also increase in robusticity long after their epiphyses had closed. These changes may pose challenges to the accurate determination of sex should only metric characteristics be used.

1. Introduction

Forensic anthropology is greatly impacted by new techniques in establishing individualizing characteristics of unknown skeletonized remains. However, the critical evaluations of older, and seemingly standardized, methods are also necessary for the advancement of the field. Since many of the methods to determine skeletal sex are used in a medico-legal arena (i.e., forensic anthropology), the application of proper techniques and their calculated accuracy are paramount.

Morphological differences between males and females manifest themselves throughout both the axial and appendicular skeleton [1], and can be assessed both qualitatively (non-metrics) and quantitatively (metrics). Quantitative analysis uses skeletal measurements from a known population group to develop methods for determining sex from single or multiple skeletal elements of an unknown person presumed to be from within that group [2–5]. In order to describe differences between the sexes, the morphological and microscopic age related changes in adults need to be examined as these changes may affect the manner in which sex can be reliably determined from senescent remains.

According to Evans [6] senescent persons have been shown to exhibit less structural integrity in their bone and less bone density than those a decade or so younger. Morphological changes to the bone with age have also been observed to accompany this gradual loss in bone density. Researchers suggest that as bone density decreases in the cortical and endosteal surfaces, the width of the medullary cavity expands and causes an increase in thinning of the cortical bone [7–13].

In order to maintain strength and integrity, osteoprogenitor cells within the periosteum are stimulated to produce more bone matrix [14]. This process is known as continuing periosteal apposition (CPA) and is a well-documented age related change in which, after skeletal maturation, periosteal bone continues to be

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added to the skeletal structure as a response to endosteal bone loss [7–13,15]. This process may lead to larger measurements in the cranial and post-cranial skeleton of an older person, when compared to a younger individual. The reasons for this phenomenon are multi-faceted and may include mechanical compensation, fracture repair/mechanical response and heterochrony, or delayed maturation in *Homo sapiens* [15].

Researchers have noted an increase in osteometric dimensions of the humerus and tibiae of older persons when compared to their younger counterparts [16–18]. Interestingly enough, the greatest change has been noted among older females when compared to males. Walker [19] addressed the problem of a lost of sexual dimorphism among elder females due to problems associated with bone density loss and CPA. In a sample of poorly preserved females and males from an English cemetery, Walker noted that a large percentage of the elderly females (>50 years of age) had been misclassified as males based on their robust supra-orbital region on the cranium. Similarly Smith and Walker [20] noted an increase in the periosteum with a decrease in cortical thickness at the mid-shaft diameter of aged European females, which, in turn, increased the diameter of this area such that it was larger than the mid-shaft diameter of younger females from the same population group.

Walker [19] cautioned that overlooking morphological changes in skeletal structures that appear to be related to age could significantly affect both mortality profiles and age assessments in forensic case analysis. If morphological and metric features significantly change in shape and size due to a net loss in bone density with the progression of age, then forensic anthropologists need to be aware of these changes so that they are more capable of accurately diagnosing sex from elderly remains, especially those of females.

Following on this, the purpose of this study was to evaluate standard osteometric variables from the proximal and distal articular surfaces as well as the mid-shaft diameters of the long bones to determine whether a statistically significant change in size could be observed between younger and older adults and if present, whether these changes were of a significant enough magnitude to influence our ability to determine sex from post-cranial remains. For this purpose two samples, namely modern African and European South Africans, were used.

2. Materials and methods

While net bone loss is known to occur in the human skeleton after maturation, the rate of this decrease is dependent on numerous factors such as physical activity, synthetic hormones, nutrition, environment, and socioeconomic status and population origin [2,11,13,21–24]. Therefore, it is important to discuss the general history of the skeletal collections that were used in this study. All South African (SA) skeletal material of African and European origins originated from the Pretoria Bone Collection [25] and the Raymond Dart Collection [26]. Both collections contain modern skeletal remains (late 19th and 20th century) of known persons who had been donated either willfully or by the State (i.e., unclaimed bodies). Prior to entering the skeletal collection, the remains had been used for dissection purposes.

More than half (55%, $n = 369$) of the skeletal remains with complete post-cranials in the Pretoria Bone Collection are of African males; similar statistics were found in the Raymond A Dart Collection, in which 49% ($n = 1075$) of the collection contains middle to older aged males of African descent. African females are far less common with only 17% ($n = 115$) and 19% ($n = 408$) available for analysis in the Pretoria Bone and Raymond A. Dart collections, respectively. This trend is a consequence of a large migrant-labour work force in the country, especially in large cities such as Pretoria and Johannesburg [25]. These unclaimed persons are most likely to have been from the lower socioeconomic classes of the country, and may have experienced heavy physical labour during life as well as nutritional hardships. According to Barrier and L'Abbé [27], the cause of death among Africans (males and females) within the Pretoria Bone Collection were most commonly associated with chronic illnesses, congenital and degenerative ailments, as well as tuberculosis (8%), bronchopneumonia (15%), general cases of organ failure (12%), cancers (12%), malnutrition (3%) and HIV/AIDS (1%). The presence of tuberculosis and malnutrition indicates the possibility of poor living conditions and/or inadequate access to health care among this group of people.

Persons of European origin are the next largest group available for study in these collections. In contrast to SA blacks, young to middle aged persons of European descent are poorly represented in both collections, with the majority of individuals having had died in their 6th to 8th decade of life; this discrepancy is due to the fact that these persons wilfully donated themselves to the Department of Anatomy. Full body donors tend to be of a higher socio-economic status than unclaimed persons, with many of these people having been in the medical profession, such as doctors, nurses or researchers, during their lifetime. The most common causes of death among this group are cancer (15%, $n = 21$), heart failure (15%, $n = 21$), "natural causes" (11%, $n = 15$) and pneumonia (11%; $n = 15$).

This is a cross-sectional study and the skeletal remains used in this research project were acquired from a long time period. The effect of secular trends on the differences between skeletal structures is important to keep in mind as large secular differences could obscure the true biological results of the study.

Measurements from six long bones, namely the humerus, radius, ulna, femur, tibia and fibula, were taken. The skeletal remains of 404 males ($n = 106$ SA white, $n = 298$ SA black) and 189 females ($n = 82$ SA white, $n = 107$ SA black) were assessed.

Twenty-three standard anthropometric measurements including the maximum diameters of the proximal and distal articular ends, maximum mid-shaft diameters, and circumferences (when applicable) were taken from the above-mentioned six long bones so as to provide a comprehensive observation of metric age related changes [28]. Only the left side was used for statistical analysis.

The sample was divided into two age categories, with young to middle aged people being placed within a <50 years (<50) category, while older adults were defined as being greater than or equal to 50 years (≥50). This boundary was, for the most part, arbitrarily established; however, it is based on the fact that most women over 50 are post-menopausal, a condition which is often associated with cortical bone loss.

A one-way ANOVA comparing male and female metric data was calculated. A significance value (F-ratio) was provided by this analysis, and from this value an assessment of the variability between two groups (e.g., male and female) was made. Additionally, males and females were separated into ancestral categories and compared, e.g., SA white males to females; SA black males to females. This comparison was performed to confirm that sexually dimorphic size differences were present.

Within an ancestral group, the mean value for each variable for young (<50 years) and old (≥50 years) groups in males and females were compared. If a statistically significant increase or decrease was observed for a certain variable, this variable was then compared to the equivalent mean for the corresponding sex. For example, if the mean diameter of the head of the humerus increased significantly between younger and older SA white females, then the mean humeral head diameter for old SA white females would be compared to that of young and old SA white males to determine if overlap in metric values existed at this skeletal site.