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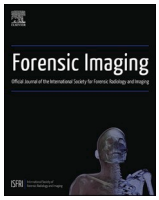



Cranial measurements obtained by three-dimensional computed tomography technique in the estimation of sex of contemporary Black South Africans

Oriasotie M Ujaddughe [a,b], Jenny Haberfeld [c], Mubarak A Bidmos [d,*], Oladiran I Olateju [a]

[a] School of Anatomical Sciences, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa
[b] Anatomy Department, Ambrose Alli University, Ekpoma, Nigeria
[c] Radiology Department, Charlotte Maxeke Johannesburg Academic Hospital, Johannesburg, South Africa
[d] College of Medicine, QU Health, Qatar University, Doha, Qatar

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ABSTRACT

Human identification forms an integral part of forensic and biological anthropology. For proper identification, a biological profile made up of biodata such as age, sex, ancestry, antemortem stature, and factors of individualization, is obtained and stored for use by anthropologists. A correct sex estimation can help unravel other anthropological parameters. South Africa has a multi-dimensionally high crime rate and its largest distinct population group (Black South Africans) is most affected by such crimes. Several authors have in the past used cranial measurements to carry out sex discrimination among South Africans, such attempts have largely been done using direct assessment of post-mortem specimens and on subjects of European Descent. This study, therefore, attempted to overcome these drawbacks by using a non-invasive method, the three-dimensional computed tomography (3DCT) to obtain population-specific data from a contemporary Black South African population group. It obtained measurements from cranial CT records of 350 Black South Africans (50 % sex ratio) housed in the Radiology Department of Charlotte Maxeke Johannesburg Academic Hospital. The Xiris and IntelliSpace software were used to reconstruct the images into three-dimensional forms from which measurements were taken. Evaluation of previously derived equations using data from the current study yielded low average classification accuracies which necessitated the formulation of new equations. Discriminant function analysis yielded acceptably high average classification accuracies for sex estimation which ranged from 78.3 % to 82.9 %.

Introduction

Human identification from remains (decomposed, dismembered, or mutilated beyond recognition) is a legal imperative and a humanitarian need as it is essential to track human activities relating to crime, criminalities, and its control [1]. Human biodata such as age, sex, ancestry, antemortem stature, and other factors of individualization are useful to biological anthropologists for the identification of individuals from their skeletonized remains [2,3]. Likewise, sex estimation is a major guide to other anthropological parameters like age at death, stature, and the ancestral origin of the individual [1,4]. A correct sex estimation of an individual narrows the identification possibilities of a subject by 50 % due to the reduction of potential matching identities [5–7]. It also increases the accuracy of estimating other biological attributes such as sex-specific age and stature estimation standards [8,3].

Non-metric (or morphological) and metric methods are commonly used for the estimation of sex from skeletal remains. While the non-metric method provides a speedy preliminary assessment by relying on the visual evaluation of sexually dimorphic traits, it is inefficient and highly subjective in the case of a badly decomposed body or incomplete specimens because of missing vital morphological information ([1,9]. In addition, it requires the combination of several sexually dimorphic parameters which may not be beneficial for the sex differentiation of bones (e.g. skull) at pre-puberty age [10,11]. Metric methods, on the other hand, involve taking measurements between fixed landmarks on a bone and are used for the estimation of sex. It is reliable, reproducible, and relevant for building the biological profile of unidentified human remains which is an important step in identification [9–12]. The metric

* Corresponding author: College of Medicine, QU Health, Qatar University, Doha, Qatar.
E-mail address: mbidmos@qu.edu.qa (M.A. Bidmos).

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method works on the basic principle of morphometric variations in females and males which utilizes the derivation of models or equations that are reliable for sex estimation [1,11,12].

Previous studies on sex estimation in South African population groups utilized osteometric data obtained directly from dried bones [4,11,13–20]. Although the models formulated in the aforementioned studies yielded average accuracies ranging from 75 % to 97.5 % which were considered good identification accuracies at the time the studies were conducted, however, the osteological collections from which the data used in those studies were obtained may no longer be considered a good representation of the populations from which they have been derived due to over–representation of individuals from the lower socio–economic class and the elderly [21]. In addition, the bones in these collections including the Raymond Dart Collection of Human Skeletons – University of the Witwatersrand [22], the Pretoria Bone Collection – University of Pretoria [21], and the UCT Human Skeletal Repository – University of Cape Town [23] are the remains of individuals that have lived several years earlier. It is thus logical to assume that the existing functions and equations for sex estimation that were derived from direct measurements of bones from these collections may be unreliable, non–sensitive, and not applicable to the contemporary population group.

To obtain measurements from living populations, a non-invasive approach using radiological materials such as X–ray images [24] and Magnetic Resonance Imaging [25] has proven effective. Computerized tomography (CT) images are however the most commonly used non–invasive technique due to their high sensitivity to bone imaging and the ease of recreating volumetric 3-dimensional versions of the CT (3-DCT) images [26–28] and they have proven to be reliable in obtaining dimensional information from the skull following fractures [29]. In addition, measurements using 3-DCT images are accurate and reliable [30,31], and produce results that are slightly different from the measurements done directly on dried bones [32,33]. The CT images are often diagnostic records of patients (i.e. living population) who visit the hospital for various medical reasons [28]. This means that the CT records are continuously populated, thereby providing a better representation (and sampling) of the different population groups. More importantly, it allows access and accurate measurement of bony features that are hidden and more difficult to access on a bone or on a plain radiograph [1] as revealed in a study on the greater sciatic notch of Japanese [34].

The cranium is known to be sexually dimorphic from studies on direct skull measurements [1,14,35–38] or CT images such as the foramen magnum of a Bulgarian [39] or a Swiss [40] population group. Similarly, the multi-detector CT has been used for sex estimation on skull measurements in a contemporary Chinese population in which derived discriminant function analyses provided an average sex classification accuracy rate of 89.3 % [41]. It has also been used to obtain data from the fragmentary or complete skulls of Jordanians [42], Kurds in Iraq [43], Saudi Arabians [44], Indians [45,46], Europeans in Hamburg [47], Americans of mixed ancestry [28], a combined Czech and Greek population [36], Turks [48], and Kashmiris [49].

Although, there have been previous attempts to utilize direct skull measurements in the establishment of standards for sex estimation in South Africa [50,19,51], however, there is no known study on sex estimation using CT cranial images of any contemporary South African population group. The Black South African population group was selected for this study because it is the most predominant and most affected by violent crime. The predominant crimes (assault, murder, sexual offences, and home robbery) in South Africa increased in 2022 compared to the preceding year and these crimes were more prevalent in the rural areas where the majority of Black South Africans reside [52]. With the increasing rate of violent crimes in South Africa, it is estimated that over two million crimes are committed annually of which about 33 % are violent which result in deaths [53–55]. In some cases, the bodies of victims of crime are dismembered by criminals in order to conceal the identity of the victims. In addition, the human body is considered to be very powerful and consequently used by "traditional medicine" practitioners for medicinal purposes [56]. As a result, it is not uncommon for law enforcement agents to recover the heads (skulls) of murdered victims [56,57]. Therefore, it is important to assess the reliability of existing cranial equations by using data obtained from contemporary or living Black South Africans and then derive new equations if the existing equations are no longer applicable for the sex estimation of living or contemporary black South Africans.

Materials and methods

An Ethics approval (Human Ethics number: M220108) by the Human Research Ethics Committee (HREC), University of the Witwatersrand, Johannesburg was granted before the commencement of this study. Complete CT records of the head of 350 South African Blacks (50 % sex ratio) between 18 and 60 years old that were collected from January 2016 to December 2022 and housed in the Radiology Department, Charlotte Maxeke Johannesburg Academic Hospital, Johannesburg, South Africa were assessed. This hospital which is located in the Gauteng Province of South Africa, offers tertiary health care services to the inhabitants of the province. It also serves as a referral centre for the health facilities around its locality and as a training institution for the Medical School of the University of the Witwatersrand, Johannesburg. These CT records were obtained with Phillip (SOMATOM Definition AS) and saved in Digital Imaging and Communications in Medicine (DICOM) format. With the use of the Xiris and IntelliSpace PACS Radiology (version 4.4.516.21), the images were reconstructed into two-dimensional (2-D) and three-dimensional (3D) formats. The 3-D format was essential because circumferential dimensions like the maximum frontal breadth (CRA_12) could not be effectively taken in 2-D format. Persons over the age of 60 years were excluded from the study because they could be prone to osteoporosis and loss of bone density [58,59]. Eight different variables as described in Table 1 and Fig. 1 were measured on each reconstructed 2-D and 3–D format of the image of the skull:

All measurements were taken by a specialist radiologist and the values were recorded in millimetres (mm). To ascertain the reliability of the measurement techniques, intra-observer reliability was assessed from repeated measurements from the first 20 subjects randomly selected from the sample. Absolute and relative technical error of measurement (TEM and rTEM) were calculated to demonstrate the extent of measurement error as compared to the size of the measurement and the overall margin of error for each measurement ([60]). The data obtained were analysed using IBM SPSS Statistics version 28.01.1. The normality test was assessed using the Kolmogorov-Smirnov and Shapiro-Wilk's test methods, the skewness values against the standard errors, the Q-Q plots, and histograms which showed that the data were normally distributed. Comparison of means was done using the one-way ANOVA and all inferences were based on a 95 % confidence interval (p-value <0.05 was taken as significant).

To test the validity of selected equations earlier formulated by Steyn and İşcan [19], Franklin et al. [61], and Dayal et al., [15] (Table 4), data from independent samples drawn from the Black South Africans in the present study were analysed using the existing functions. Thereafter, univariate and multivariate direct discriminant function analyses (DFA) were performed on the cranial measurements. By using the stepwise procedure, the best-performing sets of measurement were used to obtain coefficients and constants by which new DFA equations for sex estimation were derived. Accuracies based on correct classifications using sectioning points were used to discriminate between the two sexes. In the SPSS, a 'leave-one-out' classification process was used to test the validity of the derived function equations. The original accuracy obtained was then cross-validated. The obtained function equations were then applied to an independent sample of 25 male and 25 female cranial measurements obtained by the same method and from the same population of CT scan images.

Table 8
Comparison of dimensions of the cranium from previous studies and the current study.

Variable	Current study		Steyn & Işcan, [19]		Franklin et al. [61]		Dayal et al. [15]	
Sex	Female	Male	Female	Male	Female	Male	Female	Male
CRA_01	184.7±6.0	189.5±7.6	179.0±5.9	187.7±5.5	178.5±5.5	185.5±6.7	181.6±6.1	188.5±5.6
CRA_05	131.3±4.7	136.3±6.1	130.5±5.3	136.8±4.1	132.4±5.7	126.9±5.2	128.5±5.2	133.1±6.0
CRA_06	95.6±4.5	100.4±5.01					97.6±3.56	101.6±3.8
CRA_04	128.1±5.5	135.4±5.6	121.9±3.5	128.9±4.4	115.7±4.5	122.6±5.4	124.0±5.0	130.6±4.7
CRA_14	47.6±3.6	50.8±3.1	49.8±2.2	53.7±3.5			46.1±2.4	48.3±3.5
CRA_15	28.2±2.3	28.9±2.62	22.9±2.06	24.8±2.2			27.1±1.9	27.9±1.9
CRA_12	116.5±4.4	120.3±5.8	93.6±4.8	97.8±3.9				
CRA_11	67.2±4.5	71.3±4.5	66.0±5.1	71.3±3.9				

([19], Dayal et al., 2008; Franklin et al., 2005).

bi-zygomatic breadth was also the best-performing equation in the study by Ogawa et al., [37]. However, no explanation was given for their observations. The poor classification accuracies that were observed when equations by previous authors [19,22,61] were applied to the independent samples in the present study showed that the previously derived equations may still relevant but they have proven not very useful for the contemporary Black South African population.

Conclusion

Population-specific measurements from black South Africans can be useful in the estimation of the sex of skeletonized and unidentified individuals because of the high average identification accuracies depicting high sexual dimorphism. The use of non-invasive techniques has however proven more useful in obtaining such measurements from recent and living populations. It also provides the practitioner with the advantage of obtaining accurate and easily reproducible sets of measurements and with greater reliability. This certainly makes such data more relevant for forensic applications. The bizygomatic breadth is the most discriminatory individual measurement. The average accuracy in the correct sex classification from this study ranges between 76.9 and 82.9 are high compared to other study outcomes. Information from this study will be beneficial for forensic science practitioners like the Victim Identification Centre (VIC) of the South African Police Service (SAPS). This study acknowledges the possible impact of variations in measurements amongst individuals from different sub–population groups of Black South Africans but unfortunately delineating these sub-population groups was not possible from the CT scan records assessed in the present study, also the subjects included in the study were from a single hospital. It will be in the interest of forensic practitioners who will be involved similar studies in the future to consider a prospective study that will enable the research to focus on the sub–population groups especially the Black South Africans due to its diverse ethnic groups and also carry out a multi-centre study.

Disclosure statement

The authors declare no conflict of interest.

CRediT authorship contribution statement

Oriasotie M Ujaddughe: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Jenny Haberfeld:** Writing – review & editing, Validation, Software, Resources, Methodology, Investigation. **Mubarak A Bidmos:** Writing – review & editing, Writing – original draft, Supervision, Investigation, Formal analysis, Conceptualization. **Oladiran I Olateju:** Writing – review & editing, Writing – original draft, Supervision, Software, Resources, Project administration, Funding acquisition, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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