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Estimation of sex using dimensions around the metatarsal diaphyseal nutrient foramen: Application of discriminant function analysis and logistic regression models

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A R T I C L E I N F O

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A B S T R A C T

Sex estimation equations are population-specific, and a wider use of multiple bones to generate equations will increase the accuracy of sex estimation in forensic settings. The metatarsal bones have been used previously, however the dimensions around the diaphyseal nutrient foramen have not been utilised in sex estimation. The current study aimed to determine the utility of the dimensions around the nutrient foramen of metatarsal bones in estimating sex in the South Africans of European descent (SAED). Five measurements around the nutrient foramen were taken from a total of 876 metatarsal bones (first to fifth) from 186 individual skeletons (99 males, 87 females) obtained from the Raymond A. Dart Modern Skeletal Collection. Measurements subjected to direct and stepwise discriminant function (DFA) and logistic regression (LRA) analyses included total length, distance from proximal end to nutrient foramen, circumference, and mediolateral and dorsoplantar diameters at the level of the nutrient foramen. The original classification accuracies for multivariable functions of the stepwise and direct DFA ranged from 83.1–88.3% to 85.5–88.3%, respectively. The original classification accuracies for multivariable functions of the stepwise and direct LRA ranged from 83.3%–88.7% to 86.2%–88.3%, respectively. The cross-validation classifications showed a drop of 0–2.4% for DFA and 0.2–1.1% for LRA. The width measurements were better predictors of sex than length. The dimensions around the metatarsal bone nutrient foramen exhibit sexual dimorphism in the SAED. The generated DFA and LRA functions produced high average classification accuracies which are useful in sex estimation during forensic human identification.

1. Introduction

Sex estimation from recovered human skeletons is integral to establishing the biological profile of unknown individuals in medico-legal cases [1,2]. Accurate sex estimation is pivotal in establishing the age, stature, and population affinity of skeletal specimens [1]. The development of sex estimation methods involves using metric and non-metric approaches, with metric methods being considered the most reliable due to their reproducibility and reduced reliance on the expertise of the anthropologist [2–4]. The metric method entails taking a series of reproducible measurements that can be validated using different statistical techniques and subjected to different classification analyses, like discriminant function (DFA) and logistic regression (LRA) analyses, to develop sex estimation equations applicable to a specific population group [2]. DFA and LRA are the most commonly used statistical methods for sex estimation in forensic and anthropological contexts [5–8].

Dimensions around the diaphyseal nutrient foramen (NF) of the upper and lower limb long bones have been utilised to generate sex estimation equations yielding high estimation accuracies [1,9–13]. Nutrient foramina are external openings to the nutrient canal on the bone diaphysis that convey blood vessels and nerves [14–16]. South Africa has one of the highest crime rates globally and the identification of murdered victims is challenging due to limited resources and expertise [12]. Most of these victims are found dismembered, burnt, and buried in shallow graves [17]. Positive sex estimation requires the

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Greek population whereby the dimensions from the first metatarsal bone yielded comparatively high sex estimation accuracies [22]. The stepwise LRA, on the other hand, selected the fourth metatarsal bone as the single best predictor of sex.

Previous studies utilizing the dimensions around the base, midshaft, head and length of the metatarsal bones in different populations reported classification accuracies similar to the current study [2,22–25]. In addition, studies in the SAED population using dimensions around the NF of the humerus, radius, ulnar and tibia also produced classification accuracies ranging from 84 to 88 % [1,11]. Generally, classification accuracies greater than 80 % are acceptable in forensic and archaeological settings [43] and a drop of less than 5 % between the original classification and the cross-validation accuracies indicates the validity of the generated functions [11]. In the current study, both the DFA and LRA equations on a combination of measurements produced high classification accuracies greater than 80 % with a drop of 0–2.4 % in the cross-validation.

The DFA and LRA equations in the current study also demonstrated that the combination of the diameter/circular measurements (CNF, DPNF, MLNF) performed better than length measurements (TL and NFPE), similar to that reported in previous studies [9,10,29]. Length measurements are minimally affected by lifetime activities while the diameter and circular measurements are affected by the activity-related factors in different populations. Hence, for correct sex estimation a combination of both width and length measurements is ideal since it factors in both the genetic and physical forces on the bone morphology [24]. In the current study, males were classified with the highest accuracy across all metatarsal bones using the multivariable functions, with a bias between 0.1 % and 10.8 %, similar to other studies [22,44]. Sex-specific accuracies are associated with genetic, hormonal and biomechanical factor differences [42].

It should be noted that only MT1CNF exhibited multicollinearity in most of the generated multivariable function equations that included it in both the DFA and LRA. However, when MT1CNF was removed from the multivariable function equations, the sex estimation classification accuracy rates dropped significantly (range 3.5–9.3 %). This may be due to the fact that the MT1CNF as a single variable has a high sex estimation classification accuracy rate of 79.1 % (Table 3). This finding suggests that MT1CNF is a significant predictor of sex, hence it was retained in the affected multivariable function equations throughout.

Bartholdy et al. [44] suggested that LRA is better than DFA for developing sex estimation equations. Although both methods produce comparable classification accuracies as shown in the current study and also in previous studies [2,5], DFA and LRA possess intrinsic differences that affect their suitability for generating sex estimation equations. LRA provides the probability of group membership with classification values ranging from zero to one, while DFA provides a rigid dichotomous membership classification based on sectioning points [44]. In addition, LRA is a non-parametric analysis that assumes that the multivariable data is not normally distributed, whereas DFA is a parametric analysis that assumes that the multivariable data is normally distributed [33,44]. Given the biological overlaps between sexes within a population, a flexible analysis approach is recommended to account for uncertainties associated with sex estimation equations, particularly in forensic contexts [45]. The assumption of multivariable normality was violated in the present study, suggesting that LRA equations may be more appropriate than DFA equations in the current population.

In conclusion, the dimensions related to the metatarsal bone NF show high sexual dimorphism in the SAED population. A combination of measurements around the NF from different metatarsal bones produced high sex classification rates that are applicable in both medico-legal and archaeological settings particularly for intact or fragmented metatarsal bones. Overall, the study recommends the use of LRA functions on all the non-normally distributed data.

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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Ethical approval

The current study was conducted under the ethical clearance waiver number W-CBP-220504-01 and was covered by the Human Tissue Act (No. 65 of 1983) and the National Health Act (No. 61 of 2003) on the use of human specimens for research and teaching purposes.

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