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Forensic Anthropology Population Data

Stature estimation using measurements of the cranium for populations in the United States

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ABSTRACT

Stature estimation is an important component of the biological profile. Human crania are sometimes recovered in the absence of other skeletal material in forensic casework, and stature estimation equations using cranial measurements have not been developed for populations in the United States. Both simple and multiple regression equations for estimating stature were developed from standard cranial measurements taken from both a cranial CT dataset and the Forensic Data Bank, and the resulting equations were tested using a separate dataset. A weak to moderate correlation with stature was found for some of the measurements tested. Tests of the sex- and ancestry-specific equations and pooled sex equations produced accurate estimated stature ranges for most of the individuals in the test dataset, but large 95% confidence intervals (±14–16 cm) for these equations can produce only an imprecise estimated stature range for an unidentified individual. Pooled ancestry equations also produced accurate estimated stature ranges for many of the individuals in the test dataset, but with even larger 95% confidence intervals (±18–20 cm). The results of this study indicate that stature can be estimated using cranial measurements, but the resulting 95% confidence intervals produce stature ranges that are too broad to use in most forensic casework.

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1. Introduction

Stature estimation is an important component of developing a biological profile for an unidentified individual. The stature of an unidentified individual is often estimated by measuring the lengths of the available long bones and calculating a stature range using published sex- and ancestry-specific regression equations. Measurements from long bones that directly contribute to stature, such as the femur and tibia, typically provide narrower and more accurate stature ranges than measurements from bones that do not directly contribute to stature [1]. When complete long bone measurements are not available for an individual, stature can still be estimated using measurements from fragmentary long bones [2,3], as well as from other bones such as the metatarsals [1], the os coxae and sacrum [4], and the scapula [5]. The estimated stature ranges using these measurements are typically larger than those utilizing long bone measurements, but large estimated stature ranges can still provide general information about an unidentified individual.

Human crania are easily recognizable even to the untrained observer and are sometimes recovered in the absence of other skeletal material. The height of the cranium from points basion to bregma directly contributes to stature [6], suggesting that this measurement and other cranial measurements may correlate well with stature in most individuals and could be used to estimate stature when no other skeletal elements are present. Currently, no stature estimation equations utilizing measurements of the cranium exist for common populations within the United States, and an estimated stature range cannot be calculated for an individual in the United States whose cranium is discovered in isolation. Stature estimation equations using various cranial measurements have been developed for several regional populations in Europe [7,8], South America [9], Africa [10], and parts of Asia [11–15], but these equations are not directly applicable to populations within the United States because membership in regional groups cannot yet be reliably assessed from the skeleton

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in the United States population. These previous stature estimation studies also utilized both standard and non-standard cranial measurements for many of their equations, adding to the workload of a forensic examination.

This study examines the relationship between standard cranial measurements [16] and stature for four populations in the United States and tests the accuracy and applicability of stature estimation regression equations utilizing standard cranial measurements for populations within the United States.

2. Materials and methods

Cranial measurements for this study were obtained in part from a cranial computed tomography (CT) scan dataset. For details of the original data source and collection procedures for the CT data analyzed in this study, see Parks et al. [17]. Summarizing briefly, the CT scans were performed from 2003–2009 on 233 living adults and include self-identified Black, White, and Asian males and females and Hispanic males from the United States with an age range of 18–60 years. Either self-reported or measured stature recorded at the time of the CT scan was available for each individual. Seventeen standard cranial measurements [16] (Table 1) were collected from the CT scans by placing x-, y-, and z-coordinates of landmarks corresponding to the standard cranial measurements on a three-dimensional (3D) rendering of each cranium and automatically calculating the distance between the two specified landmarks using Mimics v.11.1 and v.12.0 (Materialise, Ann Arbor, MI). Maximum width landmarks such as left and right euryon for measurement *XCB* were estimated by adjusting the landmarks on both the 3D rendering and the orthogonal view of the CT slices. Landmark dacryon could not be visualized on the 3D rendering and was replaced with landmark maxillofrontale for the purposes of measuring *OBB*. The anonymized data were approved for use by the Institutional Review Boards of collaborating medical institutions and the FBI Laboratory.

Cranial measurements collected from CT scans using 3D reconstruction software are comparable to measurements collected directly from dry, defleshed crania [18]. To increase sample sizes, 280 individuals from the Forensic Data Bank (FDB) [19] with the same 17 cranial measurements were added to the CT dataset to form a combined dataset with 513 individuals. The FDB sample includes Black and White males and females and Hispanic males with an age range of 21–55 years. Following Ousley [20], only individuals from the FDB with antemortem stature information derived from self-reported or indirect sources (e.g., family members or a driver's license), often referred to as forensic stature, were included in the dataset. Following Spradley and Jantz [21], individuals born before 1930 were excluded from the dataset to account for secular change in stature during the late 1800s and early 1900s and create a sample representative of the age range seen in most forensic cases. All individuals in the FDB meeting these criteria were included in the combined dataset.

Correlation coefficients, both simple and multiple linear regression equations, and the standard error of the estimate (SEE) for each of the 17 cranial measurements were calculated for the combined dataset in MINITAB v.13.32 (MINITAB Inc., State College, PA) for the following groups: Black females, Black males, White females, White males, Asian females, Asian males, Hispanic males, pooled Blacks, pooled Whites, pooled Asians, pooled females, pooled males, and pooled dataset. Due to the large number of cranial measurements included in this study, the Mallows' C_p statistic [22] was used to select several of the best-performing cranial measurement combinations for each group for multiple regression equations while avoiding multicollinearity. Summary statistics for the combined dataset were calculated using Microsoft Excel 2013 (Microsoft, Inc., Redmond, WA).

The ideal method of testing the validity of regression models is by applying the regression models to an independent dataset [23]. A separate dataset consisting of 94 individuals with cranial measurements and either forensic or measured stature information from the William M. Bass skeletal collection at the University of Tennessee, Knoxville was used to test the regression equations developed from the combined dataset. These individuals were selected because they met the same inclusion criteria as the FDB samples and were not already part of the FDB dataset. This test dataset consisted of only White males and females because of a lack of available data for Black, Asian, and Hispanic individuals that had not already been included in the combined dataset. Estimated stature was calculated for each individual in the test dataset using regression equations from the following groups: White Females, White Males, Pooled Whites, Pooled Females, Pooled Males, and Pooled Dataset. Confidence intervals at the 95% level were calculated for the simple regression equations using the method developed by Giles and Klepinger [24] to produce stature ranges for each individual. Both the average differences between estimated and actual stature for simple and multiple regression for each individual and the percentage of individuals that fell within the confidence interval for the simple regression equations were calculated for the test dataset to assess method accuracy. Summary statistics for the test dataset and all tests of the regression equations were performed using Microsoft Excel 2013 (Redmond, WA).

Table 1
Cranial measurement abbreviations and definitions.

Cranial measurements	
Abbreviation	Definition
AUB	Biauricular breadth
BBH	Basion-bregma height
BNL	Cranial base length
BPL	Basion-prosthion length
FRC	Frontal chord
GOL	Maximum cranial length
MAB	Maxillo-alveolar breadth
NLB	Nasal breadth
NLH	Nasal height
OBB	Orbital breadth (left)
OBH	Orbital height (left)
OCC	Occipital chord
PAC	Parietal chord
UFHT	Upper facial height
WFB	Minimum frontal breadth
XCB	Maximum cranial breadth
ZYB	Bizygomatic breadth

3. Results

Summary statistics for the CT, FDB, combined, and test datasets are shown in Table 2. The similar mean stature values for the CT and FDB datasets support merging the two datasets to increase sample sizes. Mean stature values for the test dataset as compared to the mean values for White males and females in the combined dataset indicate that the test dataset does not deviate significantly from the combined dataset.

The correlation values, R^2 values, SEEs, and both simple and multiple regression equations for the combined dataset are shown in Tables 3–5 for the sex- and ancestry-specific, pooled ancestry, and pooled sex groups, respectively. Basion-bregma height was weakly to moderately correlated with stature (range: 0.185–0.347) for all population groups except Asian males (0.018). Weak to moderate correlations were also seen for cranial vault measurements *AUB* (range: 0.097–0.420), *BNL* (range: −0.114 to 0.451), *BPL* (range: −0.088 to 0.328), *FRC* (range: −0.049 to 0.402), *GOL* (range: