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Stature estimation from skull measurements using multidetector computed tomographic images: A Japanese forensic sample

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ABSTRACT

The aim of this study was to assess the correlation between stature and cranial measurements in a contemporary Japanese population, using three-dimensional (3D) computed tomographic (CT) images. A total of 228 cadavers (123 males, 105 females) underwent postmortem CT scanning and subsequent forensic autopsy between May 2011 and April 2015. Five cranial measurements were taken from 3D CT reconstructed images that extracted only cranial data. The correlations between stature and each of the cranial measurements were assessed with Pearson product-moment correlation coefficients. Simple and multiple regression analyses showed significant correlations between stature and cranial measurements. In conclusion, cranial measurements obtained from 3D CT images may be useful for forensic estimation of the stature of Japanese individuals, particularly in cases where better predictors, such as long bones, are not available.

1. Introduction

Identification of cadavers is crucial for forensic investigations. However, the task of identification is challenging when decomposed, dismembered, or skeletal remains are recovered [1]. Together with age, sex, and race, stature is one of the most important biological characteristics in the identification of an individual. Stature estimation helps narrow down the investigating process and provides useful clues to the investigation agency [2]. Thus, stature estimation is of immense interest to anatomists, anthropologists, and forensic experts [3]. Stature is usually estimated using mathematical methods that are based on the correlation between stature and skeletal elements [4,5]. A number of studies have demonstrated that regression equations derived from intact long bones are accurate [6–11]. However, long bones are sometimes unavailable for measurement, particularly in cases involving mass disasters, burns, or skeletal remains; hence, knowledge of the correlations between stature and other bones would be very useful [12,13].

Researchers have previously investigated the correlation between stature and various other bones such as the scapula [13–15], sternum [5,16,17], vertebrae [18–21], sacrum [22,23], pelvis [12,24], metacarpals [25], and metatarsals [26].

In cases where only head and face are available for analysis, it becomes particularly difficult for forensic investigators to identify the cadaver [27–30]. Therefore, the ability to estimate stature from measurements of the cranium would be of great value. Previous studies [2,31–38] on stature estimation from the skull have often been conducted on historical skulls because craniofacial structures are composed largely of hard tissues which are relatively indestructible and remain even when centuries have passed [36,39].

However, little is known about the correlation between cranial measurements and stature in a contemporary Japanese population. Although Chiba and Terazawa [40] performed somatometry on the diameter and circumference of the Japanese skull to investigate the possibility of estimating stature from those measurements, no study has been carried out for stature estimation based on three-dimensional (3D) multidetector computed tomographic (MDCT)

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images of the Japanese skull. It is well known that formulae based on data derived from one population group are not always useful for assessment of other groups owing to differences in skeletal proportions [7]. Thus, different stature-estimation formulae are required for different populations.

Some forensic departments and institutes have recently performed postmortem computed tomography (PMCT) using MDCT [24]. However, few authors have used computed tomographic (CT) images for anthropometric studies [14,22,24,36,41]. 3D bone images can be created immediately from the CT values, and forensic experts can assess bones from these CT images without removing tissue or cleaning the bones, even when the subject is not skeletonized. Therefore, if cranial measurements from 3D CT images could be used for stature estimation, the time and cost involved in forensic analyses would be reduced.

The purpose of this retrospective study was therefore to assess the relationship between cranial measurements and stature and to derive sex specific regression equations for stature estimation using 3D CT images.

2. Materials and methods

The study protocol was approved by the Ethics Committee of Chiba University, and the requirement for approval from the subjects' relatives was waived.

Data were reviewed for 228 subjects of known age and sex who underwent PMCT and subsequent forensic autopsy at the Department of Legal Medicine at Chiba University between September 2011 and April 2015. The study sample consisted of 123 male cadavers (mean age, 56.9 ± 16.0 years) and 105 female cadavers (mean age, 62.3 ± 17.1 years). The estimated postmortem interval for all subjects was <14 days. Subjects were excluded if they had skull fractures, burn injuries, obvious head injuries, or acquired or congenital abnormalities.

At the beginning of the autopsy, the measurements of cadaver stature was performed according to the method described in our previous study [24]. The adjusted stature (AS, cm) was then calculated by subtracting 2.0 cm from the measured stature, to compensate for postmortem changes including reduced spinal curvature.

PMCT was performed using a 16-row detector CT system (Eclos, Hitachi Medical, Tokyo, Japan). The scanning protocol from jugular notch to head was as follows: collimation, 0.625 mm; reconstruction interval, 0.625 mm; tube voltage, 120 kVp; tube current, 200 mAs; and rotation time, 1/s. A hard filter was used. Image data were processed on a workstation (Synapse Vincent, Fujifilm Medical, Tokyo, Japan) to obtain orthogonal multiplanar reconstruction images and volume-rendered images. For assessment, a 3D CT reconstructed image which extracted only bones based on CT value data was used. Five cranial measurements were performed in accordance with the previous literature [42]. The definitions of the cranial landmarks are described and illustrated in Table 1 and Fig. 1. The five measurements listed in Table 2 were taken using electronic cursors to the nearest 0.1 mm. The measurements of 20 images from randomly selected subjects were performed repeatedly by both the first author and another co-author.

The data collected were analysed on a personal computer using SPSS version 21.0 computer software (IBM, Armonk, NY, USA) and Excel software (Microsoft Office 2007, Microsoft, Redmond, WA, USA). Descriptive analyses were performed to obtain the mean, standard deviation (SD), and range for age, AS, and the five cranial measurements for all subjects as well as for males and females separately. Student's *t*-test was used to compare the mean differences between the sexes. The Shapiro–Wilk test was used to determine whether each of the five cranial measurements was distributed normally across subjects; a *p* value >0.05 indicated normal distribution of the data. To assess intra- and inter-observer errors, the relative technical error of measurement (rTEM, %) and the coefficient of reliability (*R*) were calculated. The acceptance ranges of rTEM using beginner anthropometrist levels for intra- and inter-observer errors were <1.5% and <2.0%, respectively [43]. An *R* value, a proportion of the between-subject variance that is free of measurement errors, of >0.75 was considered sufficiently precise [44,45]. The correlations between AS and each of the cranial measurements were determined by simple regression analysis with the Pearson product-moment correlation coefficient (*r*); a *p* value <0.05 was considered statistically significant. Similarly, multiple stepwise regression analyses were performed using the multiple cranial measurements. A variance inflation factor (VIF) was calculated for each measurement; a VIF score <5.00 indicated low multicollinearity. The adjusted coefficient of determination (r^2) and standard error of estimation (SEE, cm) were calculated for each formula to evaluate the significance of the regression.

Table 1
Definitions of the landmarks of the cranium (see Fig. 1 for illustration).

Landmark (abbreviation)	Definition
Frontotemporale (f)	The point where the temporal line reaches its most antero-medial position on the frontal bone
Zygion (z)	The most laterally positioned point on the zygomatic arch
Glabella (g)	The most forward projecting point in the midline of the forehead at the level of the supra-orbital ridges and above the naso-frontal suture
Opisthocranion (o)	The most posterior point on the cranium
Bregma (b)	The intersection of the coronal and sagittal sutures in the midline
Lambda (l)	The intersection of the sagittal and lambdoidal sutures in the midline
Euryon (e)	The two points on the opposite sides of the cranium that form termini of the lines of greatest cranial breadth

3. Results

The descriptive statistics for age, AS, and the five cranial measurements are shown in Table 3. Student's *t*-tests revealed that the mean values for AS and each cranial measurement were significantly greater for the male subjects than for the female subjects. The Shapiro–Wilk tests showed that all cranial measurements for all subjects, males and females were distributed normally (*p* values, 0.216–0.760). Among the cranial measurements, MCL was the longest and MFB was the shortest.

Table 4 shows rTEMs and *R* values. rTEMs for intraobserver error were <1.5% (0.336–0.554%) and those for the interobserver error were <2.0% (0.428–0.685%); the *R* values were >0.950 (0.954–0.994).

Table 5 shows the results of the simple linear regression equations derived from AS and each of the cranial measurements for all subjects, males, and females. There were significant positive correlations between AS and each of the cranial measurements for all subjects. Among males, all cranial measurements except for PC were significantly correlated with AS. However, among females, only the BZB and MCB measurements were significantly correlated with AS. The BZB measurement had the strongest correlation and the lowest SEE value for all subjects and for females, whereas the MCL measurement had the strongest correlation and lowest SEE value for males. The SEE values for all subjects were greater than those for male or female subjects.

The results of the multiple regression analysis are shown in Table 6. The VIF values ranged from 1.112 to 2.552. The *r* values obtained from the multiple regression equations using all of the five measurements were slightly greater than the *r* values obtained