Forensic Science International 222 (2012) 398.e1–398.e9

Contents lists available at SciVerse ScienceDirect

Forensic Science International

journal homepage: www.elsevier.com/locate/forsciint

Forensic Anthropology Population Data

Determination of stature from skeletal and skull measurements by CT scan evaluation

Francesco Giurazza *, Riccardo Del Vescovo, Emiliano Schena, Sofia Battisti, Roberto Luigi Cazzato, Francesco Rosario Grasso, Sergio Silvestri, Vincenzo Denaro, Bruno Beomonte Zobel

Università Campus Bio-Medico di Roma, Via Alvaro Del Portillo 200, 00100 Rome, Italy

ARTICLE INFO

Article history:
Received 11 November 2011
Received in revised form 29 April 2012
Accepted 4 June 2012
Available online 29 June 2012

Keywords:
Stature estimation
Skull
Femur
CT scan
Caucasian
Forensic Anthropology Population Data

ABSTRACT

The aim of this article is to find a correlation between height and femur/skull measurements through Computed Tomography (CT) scans and derive regression equations for total skeletal height estimation in the Caucasian population.

We selected 200 Caucasian patients from March 2010 to July 2011 who had to perform a CT scan for cancer restaging. The mean age is 64.5 years. Both sexes are represented by the same number of persons. Patients have executed a total body CT scan with contrast; once scan accomplished, we measured height through a digital scales. We analyzed CT scans of each patient, obtaining multiplanar reconstruction in sagittal and coronal planes with 1 mm of thickness, and we measured 10 diameters of skull and femur. Then we performed a single and a multiple regression analysis considering the three diameters that better correlated with height.

The skeletal diameters with the highest correlation coefficients with stature were femur lengths, length of cranial base (Ba-N), and distance from the posterior extremity of the cranial base to the inferior point of the nasal bone (Ba-NB).

Although both femur and skull are skeletal segments used for stature estimation, in our sample femur gave stronger correlation with height than skull.

$h = 35.7 + 1.48 \cdot \text{BaN} + 2.32 \cdot \text{BaNB} + 2.53 \cdot \text{FEM}$ and $h = 3.06 \cdot \text{FEM} + 72.6$ are the formulae that provided the most accurate stature assessment using multiple and single regression analysis respectively.

1. Introduction

Together with sex, age and ancestry, height is one of the biological characteristics that can be evaluated from the skeleton, even many years after death [1,2]. For this reason stature estimation represents one of the most important features in anthropometric and medical investigations.

Stature has a biological proportional correlation with other parts of the human body (head, trunk, arms); this helps the forensic scientist to establish height on the basis of skeletal remains. Since 1894 [3] several authors have performed studies with the aim of estimating stature using measurements of individual bones. In 1956 Fully predicted the total height of a skeleton by combining measurements of the skull, vertebral bodies from C2 to S1, femur, tibia and talocalcaneal joint, also in combination with a correction factor to account for soft tissues [4]. Fully's method is significant for obtaining height, but requires a complete and well preserved skeleton which is very uncommon. Because of this, it is more useful to establish stature using mathematical methods [5,6]. These are based on the correlation that some skeletal elements have with height and require processing of formulae which involve measurements of some specific diameters and subsequent regression analysis. Skull and long bones are mainly composed of hard tissues; in fact they are the skeletal elements most frequently found even after centuries. Furthermore previous studies have revealed that the length of long bones can be used to predict stature even when only parts of the human body or bone fragments are available for analysis [7].

In this field, the first complete investigation on European skeletons was led by Telkka in 1950 [8]. Trotter and Gleser conducted research on a North American skeleton sample [9,10] and realized that a formula based on data derived from a certain ethnic group is not always correct to assess a different group because of differences in the skeletal proportions [10]. Recently European studies have been carried out by De Mendonça [11] in a sample of a Portuguese population and by Radoinova et al. in a sample of a Bulgarian population [12]. Both studies were carried

* Corresponding author. Tel.: +39 3381499421; fax: +39 06225411964.
E-mail addresses: f.giurazza@unicampus.it (F. Giurazza), r.delvescovo@unicampus.it (R. Del Vescovo), e.schena@unicampus.it (E. Schena), s.battisti@unicampus.it (S. Battisti), r.cazzato@unicampus.it (R.L. Cazzato), r.grasso@unicampus.it (F.R. Grasso), s.silvestri@unicampus.it (S. Silvestri), v.denaro@unicampus.it (V. Denaro), b.zobel@unicampus.it (B.B. Zobel).

0379-0738/$ – see front matter © 2012 Elsevier Ireland Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.forsciint.2012.06.008

out on corpses and measurements were obtained from long bones immediately before or after autopsy.

Mahakkanukrauh et al. [13] analyzed a sample of 200 skeletons from a Thai population considering all six major long bones of the upper and lower limbs (humerus, radius, ulna, femur, tibia and fibula) and they concluded that lower limb bones are the most accurate estimators of stature among both males and females.

Other authors [14–16] have tried to predict height by measuring long bones on radiographs.

Even though several studies have been performed on skulls, mostly to evaluate the sex and ancestry of the skeletons, not many studies have been performed to estimate stature. In many cases, when only the cephalo-facial region is available, it is very difficult to identify the body. In these types of situations, stature prediction from cephalo-facial marks is helpful in forensic research even if it controversial: some authors [17,18] show doubts about the reliability of stature estimation based on cephalo-facial dimensions. On the other hand, several studies [19–24] have revealed a direct correlation between height and skull dimensions. Chiba and Terazawa [21] successfully managed to calculate height by measuring the skull of 124 Japanese cadavers and they then proposed regression formulae to carry out this calculation. Patil and Mody [22] carried out a similar study using *in vivo* processing of cranial X-rays of a central Indian population.

Various other skeletal segments, apart from long bones and skull, have been considered for the estimation of stature: Recently Singh et al. [25], in a post-mortem study, collected 343 subjects and measured eight sternal lengths which positively correlated with stature.

The aim of this preliminary *in vivo* study was to look for a correlation between height and femur/skull measurements using Computed Tomography (CT) scans, and to derive regression equations for the estimation of total skeletal height in a Caucasian population. In addition we compared the correlation of stature with femur and skull measurements in the same population, to identify which bone correlates best with stature.

2. Materials and methods

2.1. Materials

We collected a sample of 200 Caucasian patients (100 males; 100 females) who were enrolled for CT evaluation for restaging of oncological diseases from March 2009 to July 2011 in our Radiology Department in Rome. All the subjects were Italian with Italian ancestry and lived in Rome or in the province of Rome. Mean age was 64.5 years (SD $\pm$ 12.7); in particular females presented a mean age of 63.8 years (SD $\pm$ 13.2), males of 65.2 years (SD $\pm$ 12.2). Our exclusion criteria were non Caucasian origins; skull, vertebral, pelvis or lower limb fractures; bone tumors; vitamin deficiencies; metabolic-endocrinological diseases; milk intolerance; growth disorders and severe osteoporosis (*T*-score $<$2.5).

CT scans were obtained using Somatom Sensation 64 (Siemens Medical). First of all, a *topogram* of 1520 mm was carried out from clavicles to tibial condyles; so, scans in spiral mode were executed. Then we carried out another *topogram* for the skull and a scan in sequential mode. After image acquisition was completed, we measured the height and weight of each patient with an electronic scale (SECA model 799) using standard anthropometric instruments in millimeters; each patient stood barefoot with arms stretched out from the body, keeping the head in the Frankfurt horizontal plane [18]. Each measurement was taken twice to reduce operator errors.

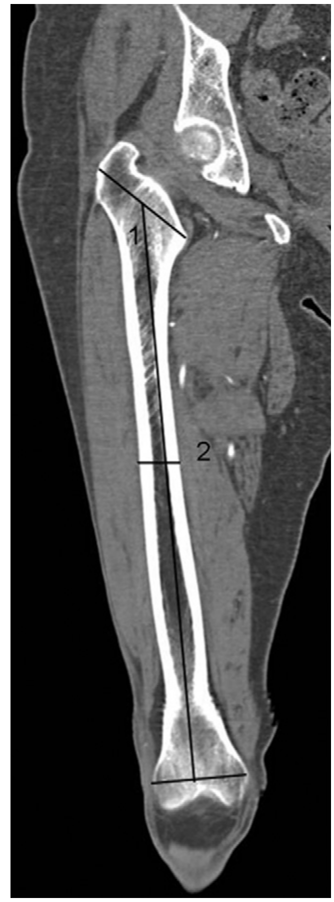

Fig. 1. CT scan of the right lower limb in the coronal plane: measurements of femoral diaphysis length (1) and width (2).

2.2. Methods

2.2.1. Skeletal measurements

After completion of sampling, we analyzed images of each patient to produce a multiplanar reconstruction (MPR) in sagittal and coronal planes with a thickness of 1mm.

We then measured the following parameters:

- Length of the left and right femoral diaphyses: The distance between an imaginary line passing through the greater and lesser trochanters and a line passing through the femoral condyles, parallel to the longer axis of the femur, in the coronal plane (Fig. 1).
- Width of the left and right femoral diaphyses: The maximum bone width at the mid-point of the dyaphyseal length, in the coronal plane (Fig. 1).
- Bimastoidal diameter: The distance between the mastoidal processes, in the coronal plane (Fig. 2A).
- Biparietal diameter: The maximum cranial width, in the coronal plane (Fig. 2A).
- Distance from Ophistocranion to Glabella (G-Op): The maximum cranial length, in the sagittal plane (Fig. 2B).
- Distance from Basion to Nasion (Ba-N): The length of the cranial base, in the sagittal plane (Fig. 2B).
- Distance from Basion to nasal bone (Ba-NB): The distance from the posterior extremity of the cranial base to the inferior point of the nasal bone, in the sagittal plane (Fig. 2B).
- Maximum length of the frontal sinus (FsHt): The frontal sinus height, in the sagittal plane (Fig. 2B).