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Body height estimation from post-mortem CT femoral F1 measurements in a contemporary Swiss population

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ABSTRACT

Purpose: The present study aimed at the comparison of body height estimations from cadaver length with body height estimations according to Trotter and Gleser (1952) and Penning and Riepert (2003) on the basis of femoral F1 section measurements in post-mortem computed tomography (PMCT) images.
Methods: In a post-mortem study in a contemporary Swiss population (226 corpses: 143 males (mean age: 53 ± 17 years) and 83 females (mean age: 61 ± 20 years)) femoral F1 measurements (403 femora: 199 right and 204 left; 177 pairs) were conducted in PMCT images and F1 was used for body height estimation using the equations after Trotter and Gleser (1952, "American Whites"), and Penning and Riepert (2003).
Results: The mean observed cadaver length was 176.6 cm in males and 163.6 cm in females. Mean measured femoral length F1 was 47.5 cm (males) and 44.1 cm (females) respectively. Comparison of body height estimated from PMCT F1 measurements with body height calculated from cadaver length showed a close congruence (mean difference less than 0.95 cm in males and less than 1.99 cm in females) for equations both applied after Penning and Riepert and Trotter and Gleser.
Conclusions: Femoral F1 measurements in PMCT images are very accurate, reproducible and feasible for body height estimation of a contemporary Swiss population when using the equations after Penning and Riepert (2003) or Trotter and Gleser (1952).

1. Introduction

Over the last 10 years post-mortem CT (PMCT) scanning has become a useful tool in forensic practice [1–3]. Since CT images can depict osseous structures well, CT imaging is also applied in forensic anthropology for tasks such as determination of sex, age and body height [4–9]. Body height estimation remains one of the key parameters to identify unknown individuals [10,11]. Body height can be estimated by the 'anatomical method' or mathematically by the use of regression equations. The anatomical method provides more accurate estimates, but requires the entire skeleton by summing up measuring lines from the skull to the foot [12,13]. In forensic practice decomposed, burned or incompletely preserved corpses may be presented as the only available source to establish identity. In such cases measurement of single skeletal elements and their linear proportionality to the stature can be used for body height estimation or estimation of sex. In settings, such as mass disasters the use of PMCT imaging can be very helpful because metric bone measurements of any body part can be executed quickly, are easily to be reproduced and avoid elaborate maceration procedures [3,6,8,9,14–17]. Moreover CT data offer the advantage of population studies and enable for bone reconstruction as a means of providing metrical data of skeletal structures in victim identification. CT measurements may also be conducted for determination of sex [18,19]. Several previous studies investigated the feasibility of CT bone measurements such as pelvic measurements or radial and ulnar length measurements for body height estimation in Japanese and Chinese populations [20–23]. Other studies used the metatarsal bones in a Spanish population or the first cervical bones in a Portuguese population for body height estimation from CT measurements [18,19]. Since femur length is closely correlated with stature, metric femoral parameters can be used to determine the body height of an individual [24–31]. Hence PMCT measurements of metric femoral parameters can be used to determine body height as well [23,32]. Several

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equations for body height estimation from the femur have already been established. Only few of them have been re-evaluated since [11,13,33,34]. Trotter and Gleser [35] developed different equations for "White", "Negroid" and "Mongoloid" populations. The equations generated by Penning and Riepert [36] were established on a large southern German population sample. However, evaluation of these equations has shown regional and temporal bias [11]. The present study aimed at the comparison of body height estimations from cadaver length with body height estimations according to Trotter and Gleser [35] and Penning and Riepert [36] on the basis of measurements of the anthropologically standardized femoral F1 section in PMCT images. Furthermore, accuracy of body height estimation between the regression equations after Trotter and Gleser [35] and the regression equations after Penning and Riepert [36] for a contemporary Swiss population sample should be assessed.

2. Materials and methods

2.1. Study subjects

The study was performed retrospectively on PMCT images of 226 corpses (143 males and 83 females). Information about the living height of the individuals e.g. from passport or medical documents was not available. The sample consisted of total 403 femora (199 right and 204 left, thereof 177 pairs). Study cases were chosen by the following criteria (as stated in the autopsy reports): (1) confirmed age between 20 and 95 years, (2) skeletal system: no fractures of lower extremities, no fractures of vertebral column, no severe head fractures, (3) Caucasian origin, (4) no signs of relevant decomposition according to autopsy reports. In cases with one sided hip replacements and/or knee replacements the counterpart femur was measured. The mean age of the men was 53 ± 17 years and that of the women 61 ± 20 years. The post mortem interval between death and CT scan/autopsy ranged from one day to 10 days.

2.2. Measurement of cadaver length and estimation of body height

After PMCT scanning the cadaver length (CL) was measured in whole centimeters using a stiff yardstick. CL was defined as maximum distance between skull vertex and the sole of the heels in 90° angle to the anterior part of the lower limbs. Bodies were unclothed and in supine position on a plane metal table. According to Trotter and Gleser [35] measured cadaver length was converted into body height (BH/CL) by subtracting 2.5 cm. The mean, standard deviation and interquartile range of measured cadaver length were calculated for all subjects. Kolmogorov–Smirnov test (K–S test) for goodness of fit was used to test for normality of the distribution of cadaver length and femur length within the study population [37].

2.3. PMCT imaging and image analysis

All corpses underwent PMCT scan (6-slice Somatom Emotion 6, Siemens Medical Solution, Forchheim, Germany) prior to forensic autopsy. The interval between CT scan and forensic autopsy was maximum one day. The scan parameters for raw data acquisition were as follows: beam energy 130 kilovolt (kV); rotation time 1500 ms. Image reconstruction was performed as follows: kernel B70; slice thickness 1.25 mm; increment: 0.7 mm; the field of view was adapted to the size of the object.

Measurements in PMCT images were conducted on a Leonardo Workstation (Siemens, Forchheim, Germany) by one observer. PMCT images of the femora were examined in multi-planar mode. According to Martin [38] the metric F1 parameter (distance between the highest point of the caput femoris and the lowest point of the medial condyle on a conventional osteometric board) was measured in PMCT images (Fig. 1). The mean, standard deviation and interquartile range of measured femoral length F1 in PMCT images were calculated for all subjects. When both femora were measured in the same individual, the arithmetic mean of both measurements was used. Kolmogorov–Smirnov goodness of fit test was used to test for normality of the distribution of F1 measurements [37].

2.4. Intra-observer error

Intra-observer error of PMCT F1 measurements in corpses of the study population was estimated using randomly selected PMCT images of 20 right femora (of 10 male and 10 female bodies). After a two month period F1 was measured again in the same PMCT images by the same observer. The intra-observer error was estimated calculating the difference and the absolute difference between the two measurement series of F1. A *t*-test for paired samples was applied to test the significance of the differences [37].

2.5. Inter-observer error

Inter-observer error of PMCT F1 measurements in corpses of the study population was estimated using randomly selected PMCT images of 20 right femora (of 10 male and 10 female bodies). Two observers measured F1 of the same individuals in PMCT images. The inter-observer error was estimated calculating the difference and the absolute difference between the measurements of the two observers. A *t*-test for paired samples was applied to test the significance of the differences [37].

2.6. Accuracy of PMCT F1 measurements vs osteometric board

To test the accuracy of F1 measurements taken from PMCT, five observers independently measured F1 values at archeological femoral bones (8 femora per observer: 4 left, 4 right) with a conventional osteometric board. Afterwards the same femora were CT-scanned with their dorsal side on the plane CT examination table and F1 was measured in PMCT images by the same observers (Fig. 2). The arithmetic mean of all F1 measurements conducted

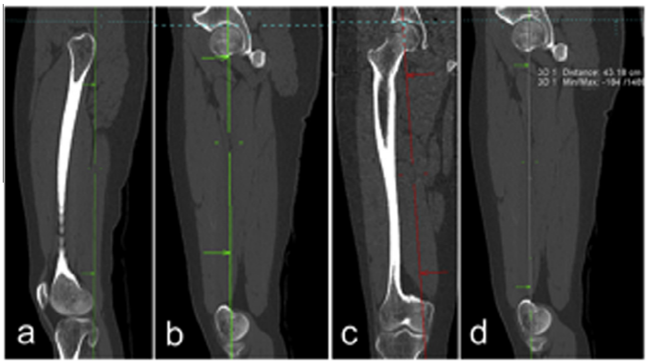

Fig. 1. F1 measurements in PMCT images: The Femur was positioned in the sagittal plane. The coronal axis (green line) was adjusted to the most dorsal points (Trochanter major and condyles) of the Femur (a). By adjusting the sagittal plane, the highest point of the Caput was determined and marked with a line (blue axial axis) (b). At the coronal plane, the sagittal axis (red line) was drawn between the lowest point of the medial condyle and the highest point of the caput femoris (c). Then, F1 was vertically measured in the sagittal oblique plane between the lowest point of the medial condyle and the highest point of the caput femoris (d). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)