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On the relationship between stature and anthropometric measurements of lumbar vertebrae

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ABSTRACT

Stature estimation is important for identifying human remains. Analysis of body parts has become an important forensic tool during global operations in the context of cases in which human remains have been dismembered, mutilated or decomposed. However, unless almost the full skeleton or at least a long bone of the lower limb is available, accuracy is still limited to approximate body height. Especially with respect to single vertebral measurements, only a rough prediction is possible. Due to their complex geometry, vertebral measurements are possible at various locations. Nine locations have been considered in this study. Regression equations for stature estimation using lumbar vertebral geometry from computed tomography scans have been evaluated to identify the measurement which gives the most reliable body height estimation. The study group comprised a representative sample of a German metropolitan male population (42 autopsied individuals). Comparing the influence of various vertebral geometry measurements with body height resulted in a coefficient of correlation (R) of 0.19–0.53 and a 95% confidence interval (CI) of ±11.6 up to ±13.1 cm.

The largest correlation with a single vertebral measurement was achieved with the central height of the vertebral body of L2 as predictor; the standard error (SE) of the estimate was 5.9 cm. Using models from CT scans appeared superior to current invasive procedures that use direct measurements of the vertebral body, in terms of reproducibility and time efficiency. For fragmented non-skeletonized human bodies, height prediction based on an all-virtual model of the vertebrae is possible. However, the regression coefficient may be similar to classic caliper measurements that prove easier if skeletonized bones are available.

1. Introduction

Apart from determining the manner and cause of death, identification of individuals is a routine task in forensic medicine — especially in cases in which human remains have been dismembered, mutilated or decomposed. Sex, age at death, and approximate body height of the deceased must be estimated based on the fragmented corpse. In practical application, those cases often prove difficult for the forensic anthropologist. Many osteological methods are not applicable if skeletons are incomplete or bones are still covered with flesh, thereby preventing geometric anthropological measurements. The increasing adoption of medical imaging technologies in postmortem diagnostics has offered new prospects [1–6]. Using the data from computed tomography (CT) scans is a reliable and practicable method for performing accurate measurements. Several studies have already proven that osteological measurements based on digital imaging data are comparable to conventional osteological measurements and can be used as supplement for classic anthropological methods [7–14].

The usage of linear conversion factors to calculate body height from single bone measurements of the long bones is well established, has commonly been used and has provided good results. Especially the long bones of the lower limb have served this purpose [15–19]. Different approaches have used regression equations to estimate the body height based on the spinal geometry [20–22]. In particular, the method established by Fully et al. [22] used vertebral heights. Raxter et al. [23] later revised this widely recognized method by clarifying the measurement procedures. They showed that measuring the maximum height of the vertebrae anterior to the pedicles and facets gives a better result than measuring the anterior midline height.

These studies utilized the full skeleton and show that dimensions of the vertebrae can be used successfully to estimate stature of humans by summing up several vertebral heights [20–23]. Few researchers intended to estimate human's stature by merely using vertebral measurements [24–27]. However, it is unclear which geometrical parameter of the vertebrae gives most reliable body height estimation. The aim of this study was to perform stature estimations based on a variety of

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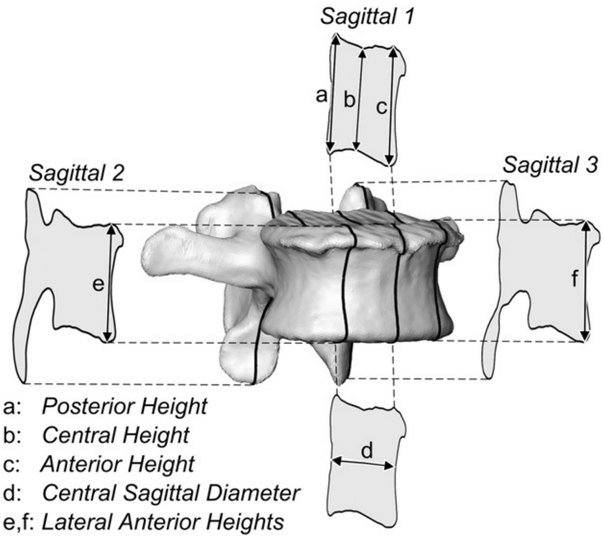

Fig. 1. Contour lines created with the sagittal cutting planes and the respective vertebral measurements. *Posterior*, *Central*, and *Anterior Heights* and the *Central Sagittal Diameter* are measured using the medial sagittal 1 plane. *Lateral Anterior Heights* are measured using the lateral cutting planes sagittal 2 and sagittal 3.

vertebral geometrical parameters from the same vertebrae and investigate which performs best. Regarding the difficulty to obtain these geometrical parameters (e.g. complete dissection of the tissue, accuracy, reproducibility) the investigation was based on computed tomography (CT) — a reliable, non-invasive method with results that might afterwards be transferred to those obtained with traditional anthropological methods.

2. Methods and materials

The measurements are extracted from a data pool containing morphological and mechanical characteristics of the human spine. The data have been collected within the framework of a mechanical in vitro study. 42 specimens from deceased Caucasian male donors between 20–64 years of age (mean age and standard deviation: 43.8 ± 11.7 years) were examined. The age range represents mature donors in the working age. Subjects were free from severe degeneration or damage at the required landmarks. Ethical approval was obtained from the competent authority.

According to standard procedure, body height of the deceased was measured after admission to the department of legal medicine. The distance between the heel base and the highest point on the head (vertex) was measured in neutral supine position with a steel sliding caliper and was included in the analysis as the true body height. No correction factors were applied because of the short time between admission and death. Four vertebrae per donor (L2–L5) were harvested during a routine autopsy representing an arbitrary subsection of the spine. The specimens were included in the study if explantation took place within 5 days of death (assuming appropriate cooling of the body) and there was no apparent severe damage. After explantation, the specimens were wrapped in saline-soaked sheets, double-packed in plastic bags, and stored at −20 °C.

It has to be mentioned that the explantation and freezing was done due to practical considerations and because of the fact that the specimens were additionally used for a mechanical in-vitro study afterwards. The following procedure can be carried out without those additional steps. Omitting them would even better represent forensic routine.

The frozen specimens were CT scanned (Mx 8000 IDT 16; Philips Healthcare DA, Best, The Netherlands). The resulting DICOM data were processed using commercial imaging software (Avizo 5.1; VSG, Merignac, France). Virtual three-dimensional (3D) surface models of the bony structures were reconstructed. The segmentation thresholds between bone and soft tissue were based on histograms of the Hounsfield Units, to avoid errors due to altered radiological densities of frozen tissues compared to fresh material. CT imaging is in favor compared to lateral x-ray imaging, since no manual orientation of the spine in the beam is needed. Furthermore the fan-shape nature of x-ray beams will not deliver true to scale 2D projections.

For each vertebra (L2–L5) nine measurements were determined. Five measurements were directly taken for analysis. Two pairs of measurements were taken bilaterally and just the mean of each pair was used for analysis. Thus seven independent parameters were available. Two additional parameters were derived from adding-up height measures for L2 to L5. All measurements were taken according to the standard anthropmetrical techniques [22,23,28].

- *Central Height*: the central vertical height of the vertebral bodies—i.e. the linear distance between the central points of the upper and lower vertebral endplates
- *Anterior Height*: the ventral vertical height of the vertebral bodies—i.e. the linear distance between the upper and lower plates in the median sagittal plane at the ventral side of the vertebral bodies
- *Posterior Height*: correspondingly, the dorsal vertical height
- *Lateral Anterior Heights*: the two maximum heights of the vertebral body, each on the sagittal plane through the cranial facet joint tips, the average of both sides was used for analysis
- *Central Sagittal Diameter*: the central diameter of the vertebral body—i.e. the linear distance between the central points of the ventral and dorsal plate in the median sagittal plane
- *Anteroposterior Distance*: the maximum linear distance between the ventral plate of the vertebral body and the dorsal process
- *Facet Tip Distances*: the maximum craniocaudal distances between the facet joint tips, the average of both sides was used for analysis
- *Summated Central Height*: the sum of the central heights of the vertebral bodies of L2 to L5
- *Summated Lateral Anterior Height*: the sum of the lateral anterior heights for L2 to L5 (digitalization of the method proposed formerly by Fully et al. [22])

Two observers independently made the measurements. The reliability of the measurement method was rated using the intra-class correlation coefficient ICC (two-way mixed model using absolute agreement definition). An ICC ≥ 0.8 was classified as good reliability. When good reliability was given for a parameter, the mean of the two observers was used for further analysis.

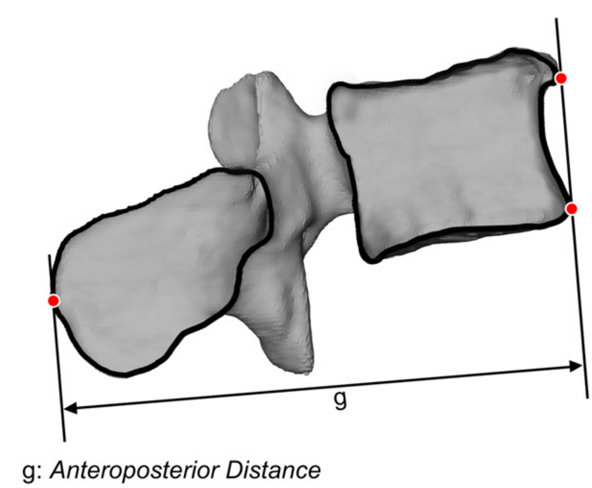

Fig. 2. *Anteroposterior Distance* determined with a semi-automatic procedure using the contour line created with the medial sagittal 1 cutting plane.