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Estimation of Stature From the Vertebral Column in Physical and Forensic Anthropology

C. Milani[1], G.L. Panattoni*[1]

[1] University of Torino, Department of Neuroscience. *E-mail: gianluigi.panattoni@unito.it

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Abstract

Stature is one of the most important parameters in personal identification for physical and forensic anthropologists. Stature can be extimated from decomposed and fully or partially skeletonized human remains. Many Authors developed anatomical methods based on measurements of the whole skeleton or mathematical methods based on measurements of single bones, from which they obtained regression formulae for calculating the stature.

In this review, we focused on the vertebral column and compared the corresponding regression formulae according to population, sex and age by a critical analysis of the literature.

Introduction

Personal identification is one of the most important issues in physical and forensic anthropology. In particular, defining attributes as sex, age, ethnicity and stature from bones may help forensic and physical anthropologists to identify decomposed and fully or partially skeletonized remains [1, 2].

In this regard, estimation of stature from isolated body parts is especially important: many researches were performed by measurements of bones of the skull, vertebral column and limbs. In particular, the main reference works for anthropologists utilized the full skeleton [3-9] or the long bones of lower limb [10,11]. However, when long bones are fragmented or missing, the measurements made on the vertebral column were considered reliable with respect to the stature estimation. The length of spine is around 30% of the total skeleton stature and it was mainly considered according to 2 different methodological approaches: either adding the length of the spine to the other bone measurements or obtaining equations that allow to calculate the stature in function of the length of the vertebral column or of one of its segments [12].

The aim of this work is to give an overview of the results, methods and populations present in literature about the stature estimation involving the vertebral column, in order to give to medical examiners and anthropologists reference parameters apt to analyse each case.

Materials and methods in literature

Measurements of the vertebral column were performed in living subjects [13-18], cadaver [3, 19-21] or skeletal remains [8, 22]. Most of the Authors utilised samples of the XX century.

According to the type of the sample, different techniques were applied: X-ray [13, 23, 24]; Nuclear Magnetic Resonance and Computer Tomography [16-18]; direct measurements on fresh material or dry bones [3, 8, 19-22]. Calipers, flexible tapes or image analysis software were employed.

The whole spine or some of its segments were taken into consideration: the lenght of each segment may include disks (i.e. half-height of the more cranial or more caudal or both of the intervetebral disks of the segment) or do not include disks (i.e. sum of the heights of vertebral bodies).

The main methods for the stature estimation are the anatomical and the mathematical one.

In the anatomical method the stature is obtained adding the measurements of skeletal elements that mainly contribute to the skeletal lenght and a "soft tissue" correction factor that varies according to Authors.

The mathematical method allowed to obtain regression formulae in order to use only certain bones to determine the living stature: the most common formulae are based on the long bones of the limbs; Trotter and Gleser [10,25] and Wilson *et al.* [11] developed the most accurate formulae. Other authors obtained regression formulae from bones of hand or foot [26-31], skull [32], scapula [33] and vertebral column [16, 17, 19, 20, 22-24, 34-36].

Body proportions vary widely between the different populations [37-41], so that it is suggested to use methods focused on populations most similar to the investigated one [41]. However, Raxter *et al.* [6] demonstrated that the anatomical method is not affected by this variability as it involves the direct measurement of the skeleton.

The main anatomical method was proposed by Fully [4], who studied 102 males from European populations.
Since some authors [18, 42] noticed that statures measured by Fully's technique were lower than cadaveric statures, Raxter *et al.* [6] tested the method and modified the soft tissue correction factors and described more attentively the measurement technique. He used men and females, blacks and whites, from the Terry Anatomical Skeletal Collection of the National Museum of Natural History (Smithsonian Institution -Washington, D.C.).
Many discrepancies among the different tecniques could be due to errors in cadaveric measurements or in measurements of bones owing to a lack of some details in the method explanation (when different authors are testing it) or to intra-observer error.
For example, the spine measurements of cadaveric length may lead to errors [43], so that, in order to obtain living stature, Trotter and Gleser [25, 44] suggested to subtract 2.5 cm from the cadaveric stature, Manouvrier [45] 2 cm and Pearson [46] 1.2 cm for males and 2 cm for females. Therefore, Raxter *et al.* [6] noticed that the maximum height of the vertebrae anterior to the pedicles and facets produced less errors than the anterior midline height.
The spine is involved in the main aging process that lead to a reduction of the stature [47]. This could be due to total or partial vertebral collapses, fractures, compression of intervertebral disks and modification of the curves [4, 6, 24]. Raxter *et al.* [6] demonstrated that the age is the only factor that could affect the stature, while ethnicity/ancestry or sex have not a significant influence on stature prediction.
The advantage of the anatomical method is that the bone modifications are intrinsically included since the bones are measured one by one. Nevertheless, Bidmos [48] affirms that, although the anatomical method is not population-specific, the Fully's method for stature estimation seems to be less accurate in black individuals.
The age-related correction factor equal to - 0.06 x (age - 30), proposed by Trotter and Gleser [44], was corrected by Raxter *et al.* [6] in a little more than 0.04 cm/year (age - 30). In his sample, this correction corresponds to no more than 1 cm loss of intervertebral disk thinkness.
Some authors [14, 15, 49, 50] affirmed that a non-linear reduction in stature starts around 30 years. In this regard, discrepancies between sexes seem to occur: in females they may be due to vertebral fractures [51].
The disks constitute between 20-30% of the vertebral column length below C2 [13, 52], which is considered the cranial extremity of the spine, because its odontoid process spatially corresponds to C1. However, Raxter *et al.* notice some gaps in the skeletal measurements of Fully [4]: the odontoid process does not reach basion and the average distance between these two points is about 7 mm [53]; the distance between the inferior edge of S1 and the acetabular roofs measures 3.6 cm [6].
According to Delmas index [54], the linear vertical height of the column averages 94-96% of its curved length [24, 55].
Since the estimated living stature, obtained by mathematical method, is population-specific, in this review we collected the regression formulae from different Authors according to ethnicity, sex and age stature loss as follows.

Regression formulae for estimated living stature (ELS) in literature

Legend: A = age (years); CL_C = curvilinear length of the cervical vertebrae; CL_T = curvilinear length of the thoracic vertebrae; CL_L = curvilinear length of the lumbar vertebrae; CL_S = curvilinear length of the sacral vertebrae; CL_{Co} = curvilinear length of the coccygeal vertebrae; LL_C = linear length of the cervical vertebrae; LL_T = linear length of the thoracic vertebrae; LL_L = linear length of the lumbar vertebrae; LL_S = linear length of the sacral vertebrae; LL_{Co} = linear length of the coccygeal vertebrae; SE = standard error; SD = standard deviation.
All the measures and correction factors of the formulae are expressed in cm.

Formulae for Black Americans:

- Jason and Taylor [19] (with disks):
Males:
$ELS = CL_{C1-C7} \times 8.92 + 62.26$ (SE = 5.94)
$ELS = CL_{T1-T12} \times 4.07 + 59.29$ (SE = 6.04)
$ELS = CL_{L1-L5} \times 4.70 + 85.72$ (SE = 6.74)
$ELS = CL_{T1-L5} \times 2.79 + 42.71$ (SE = 5.82)
$ELS = CL_{C1-L5} \times 2.42 + 29.40$ (SE = 5.09)
Females:
$ELS = CL_{C1-C7} \times 2.50 + 134.09$ (SE = 5.41)
$ELS = CL_{T1-T12} \times 3.02 + 84.20$ (SE = 3.58)
$ELS = CL_{L1-L5} \times 3.93 + 91.51$ (SE = 4.32)
$ELS = CL_{T1-L5} \times 1.98 + 75.21$ (SE = 2.60)
$ELS = CL_{C1-L5} \times 1.66 + 70.34$ (SE = 3.62)
- Giroux and Wescott [21] (sacrum):
Males:
$ELS = LL_{S1-S5} \times 3.12 + 143.77$ (SE = 7.96)
Females:
$ELS = LL_{S1-S5} \times 2.90 + 133.68$ (SE = 7.21)
- Tibbetts [23] (without disks: anterior midline height of vertebral bodies):
Males:
$ELS = CL_{T11-L4} \times 5.24 + 89.79$ (SE = 5.49)
$ELS = CL_{T12-L3} \times 7.80 + 89.23$ (SE = 5.50)
$ELS = CL_{T12-L4} \times 6.16 + 90.04$ (SE = 5.47)
$ELS = CL_{L1-L3} \times 10.05 + 90.88$ (SE = 5.51)
$ELS = CL_{L1-L4} \times 7.41 + 92.15$ (SE = 5.49)
Females:
$ELS = CL_{C2-L4} \times 2.31 + 61.78$ (SE = 5.31)
$ELS = CL_{C2-L5} \times 2.17 + 62.11$ (SE = 5.35)
$ELS = CL_{C5-L4} \times 2.58 + 65.77$ (SE = 5.34)
$ELS = CL_{C6-L4} \times 2.66 + 65.98$ (SE = 5.34)
$ELS = CL_{C7-L4} \times 2.74 + 66.37$ (SE = 5.33)
$ELS = CL_{T1-L4} \times 2.83 + 67.01$ (SE = 5.34)

Formulae for White Americans:

- Jason and Taylor [19] (with disks):
Males:
$ELS = CL_{C1-C7} \times 5.40 + 103.71$ (SE = 6.45)

$ELS = CL_{T1\text{-}T12} \times 3.60 + 69.61$ (SE = 5.91)
$ELS = CL_{L1\text{-}L5} \times 4.06 + 95.56$ (SE = 6.66)
$ELS = CL_{T1\text{-}L5} \times 2.39 + 58.61$ (SE = 6.03)
$ELS = CL_{C1\text{-}L5} \times 2.07 + 47.26$ (SE = 5.29)
Females:
$ELS = CL_{C1\text{-}C7} \times 5.19 + 101.41$ (SE = 7.11)
$ELS = CL_{T1\text{-}T12} \times 3.92 + 57.10$ (SE = 6.08)
$ELS = CL_{L1\text{-}L5} \times 4.38 + 82.37$ (SE = 6.87)
$ELS = CL_{T1\text{-}L5} \times 2.65 + 42.92$ (SE = 5.72)
$ELS = CL_{C1\text{-}L5} \times 2.33 + 29.74$ (SE = 5.32)
- Giroux and Wescott [21] (sacrum):
Males:
$ELS = LL_{S1\text{-}S5} \times 2.46 + 149.81$ (SE = 7.17)
Females:
$ELS = LL_{S1\text{-}S5} \times 0.88 + 154.00$ (SE = 7.73)

Formulae for Japanese population:

- Terazawa *et al.* [35] (with disks):
Males: $ELS = CL_L \times 3.23 + 101.7$ (SE = 6.16)
Females: $ELS = CL_L \times 2.31 + 110.8$ (SE = 4.05)

Formulae for South India population:

- Nagesh and Pradeep Kumar [20] (with disks):
Males:
$ELS = CL_{C1\text{-}C7} \times 3.66 + 121.56$ (SE = 5.65)
$ELS = CL_{T1\text{-}T12} \times 3.04 + 85.72$ (SE = 5.21)
$ELS = CL_{L1\text{-}L5} \times 4.90 + 80.78$ (SE = 5.23)
$ELS = CL_{T1\text{-}L5} \times 2.42 + 59.99$ (SE = 4.66)
$ELS = CL_{C1\text{-}T12} \times 2.22 + 80.23$ (SE = 4.80)
$ELS = CL_{C1\text{-}L5} \times 1.88 + 60.70$ (SE = 4.38)
Females:
$ELS = CL_{C1\text{-}C7} \times 1.90 + 132.98$ (SE = 4.16)
$ELS = CL_{T1\text{-}T12} \times 2.96 + 80.64$ (SE = 5.05)
$ELS = CL_{L1\text{-}L5} \times 3.29 + 99.95$ (SE = 4.61)
$ELS = CL_{T1\text{-}L5} \times 2.21 + 63.22$ (SE = 4.33)
$ELS = CL_{C1\text{-}T12} \times 2.06 + 80.54$ (SE = 4.93)
$ELS = CL_{C1\text{-}L5} \times 1.90 + 55.36$ (SE = 4.16)

Formulae for Turkish population:

- Pelin *et al.* [16] (without disks):
Males:
a) $ELS = CL_{S1} \times 7.91 - CL_{S4} \times 9.35 + CL_{S5} \times 12.56 + LL_{S1\text{-}S5} \times 1.82 + CL_{Co1\text{-}Co4} \times 3.09 + 110.89$ (SE = 5.68)
b) $ELS = CL_{S1} \times 8.42 - CL_{S4} \times 9.69 + CL_{S5} \times 14.31 + LL_{S1\text{-}S5} \times 1.56 + CL_{Co1} \times 6.41 + 111.41$ (SE = 5.67)

Correction factors according to age:

- Cline *et al.* [15]:
Males:
Loss in cm of stature $= 3.28 - 0.17 \times A + 0.02 \times A^2$
Females:
Loss in cm of stature $= 5.14 - 0.24 \times A + 0.03 \times A^2$
- Jason and Taylor [19] (with disks):
Males:
$ELS = CL_{L1\text{-}L5} \times 4.09 - A \times 0.12 + 100.25$ (SE = 6.34)
$ELS = CL_{T1\text{-}L5} \times 2.33 - A \times 0.06 + 64.43$ (SE = 5.71)
- Trotter and Gleser [44]:
Loss in cm of stature $= 0.6 \times (A - 30)$
- Galloway [14]:
Loss in cm of stature $= 0.16 \times (A - 45)$ (SD = 3.7)

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