Improving anatomical stature estimation method. The relationship between living stature and intervertebral disc thickness.

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Abstract:

Anatomical stature estimation methods reconstruct stature for skeletal specimens by adding up the heights of skeletal elements contributing to stature. In addition, these estimations factor in a certain amount of soft tissue known as "soft tissue correction".

Our study focuses on the relationship between living stature and one of the major soft tissue contributors to stature: the intervertebral disc thickness/height. The purpose of this study was to clarify whether intervertebral disc thickness is greater in tall individuals and whether there is a linear correlation between stature and intervertebral disc height.

To conduct this study, we utilized a subsample of the Northern Finland Birth Cohort of 1966 (n=12,058) with known stature. We measured vertebral heights and intervertebral disc heights from low back MRI examination performed at the age of 46 years (n=200). All subjects were considered healthy with no spinal injuries or pathologies.

Our results clearly indicate that stature and intervertebral disc height have positive, statistically significant association. According to our results it is advisable to take into account the individual's skeletal height when soft tissue corrections for anatomical stature estimations are performed. Further studies utilizing full body MRI are needed to produce more accurate soft tissue corrections.

Introduction

Anatomical stature estimations and soft tissue corrections

Constructing the biological profile of an unidentified individual is an essential part of forensic medicine, physical size and stature in special being key factors behind this process (Krogman 1962, Blau & Briggs 2011). There are two different ways to estimate stature from skeletal remains, the anatomical and the mathematical method (e.g. Lundy 1985). The mathematical method is based on regression formulae applied directly to an individual bone for stature estimation, (e.g. Trotter & Glesser 1952, 1958). However, there are some limitations as the formulae cannot be used for all populations as such due to the variation of human proportions (e.g. Eveleth and Tanner, 1976; Ruff, 1994).

The Fully technique, introduced in 1956 and revised in 1960, (Fully 1956; Fully & Pineau 1960) was the first representative of the anatomical method. Depending on the estimation method, further corrections are made for example according to individuals' age (e.g. Niskanen et al. 2013).

In anatomical stature estimation dimensions of all skeletal elements directly contributing to stature are measured and added together. In addition some corrections are made to convert dry bone measurements to reflect living bone (Lanier 1939). A coefficient or addition is also factored in to take into account missing soft tissue.

The Fully technique (1956) was completely revised by Raxter and colleagues (2006). Also several corrections have been made since, for example soft tissue corrections (Raxter et al. 2007; Niskanen & Maijanen 2006; Ruff et al 2012; Bidmos & Manger 2012). As a result there are more reliable ways to estimate stature and also take into account several factors such as age (Niskanen et al. 2013) and the condition of bones (Bidmos, 2009). Bidmos & Manger (2012) tested the applicability of formulae provided by Raxter et al. (2006) on 32 indigenous South-Africans with full body MRI examination. This study also clarified the role of soft tissue correction in anatomical stature estimations, as it noted that the previous studies underestimated the living stature.

Soft tissue corrections for anatomical stature estimations are still controversial. In Fully's (1956) original technique a constant of soft tissue components is added to the sum of the heights of the skeletal components. Raxter et al. (2006) provided a linear regression based approach in their formulae (living stature=1.009 x Skeletal height – 0.0426 x age + 12.1 or if age is unknown: living stature=0.996 x Skeletal height + 11.7. Already Fully noticed that tall individuals tend to have more soft tissue compared to short ones and therefore his soft tissue corrections take stature into account: for skeletal height equal to or below 153.5 cm, the addition is 10 cm. For skeletal height between 153.6–165.4 cm, the addition is 10.5 cm. For skeletal height equal to or above 165.5 cm, the addition is 11.5 cm.

However, the information about different soft tissue components and their relationship to stature is still quite imprecise. Bidmos (2005) suggested that "soft tissue correction factors might be population specific".

In fact, the so-called soft tissue correction is rather an estimate of all other factors affecting stature apart from direct skeletal measurements such as spinal curvature. As a result, anatomical stature estimates and especially their soft tissue corrections are found unreliable for certain populations (e.g. Bidmos & Manger 2012, Ruff et al, 2012).

Intervertebral disc

Studies such as Bidmos & Manger (2012) have successfully demonstrated with full body MRI technology how soft tissue components contribute to living stature. In this study we hypothesized that intervertebral disc height must be strongly correlated with stature as according to Kunkel et al. (2011) there is a connection between vertebral height and intervertebral disc height in the thoracic spine.

Kunkel and colleagues (2011) found that intervertebral disc thickness in the thoracic spine varied from 4,5mm to 7,2mm. Thus the intervertebral discs should contribute to stature approximately 10-15cm. However as a result of curvature in the vertebral column, this figure, in reality, is much less and possibly also population specific (Bidmos 2011). We decided to perform this study to better understand the relationship between living stature and intervertebral disc thickness. We hypothesized that intervertebral disc thickness would be greater in taller individuals and thus soft tissue corrections for anatomical stature estimation techniques should be in relation to stature/skeletal height.

Materials and methods

Materials

The subjects of this study were members of The Northern Finland 1966 Birth Cohort (NFBC 1966, http://www.oulu.fi/nfbc). It is a general population study started in the 1960's including 12,058 ethnic Finns with expected date of birth in 1966 in the provinces of Oulu and Lapland. The cohort is comprised of males and females in approximately equal proportions. The mothers of the subjects were recruited to the study on the basis of the expected birth date in 1966. This unique cohort has been followed prospectively since the 24th gestational week. The course of the delivery and neonatal outcome has been confirmed from the patient records.

In this study we utilized a randomly selected subsample of 200 individuals who attended a low back MRI examination in 2012, at the age of 46 years. 1988 individuals were invited to undergo lumbar spine MRI study and of those 1540 individuals attended. The MR imaging was performed using two GE Signa 1.5T scanners (Milwaukee, WI, USA) with a GE torso array coil. Two routine lumbar spine MRI sequences were used for measuring vertebral dimensions. For measuring vertebral height dimensions (anterior, medial and posterior), a T2-weighted fast spin echo sequence (TR = 3000–4000 ms; TE = 117 ms; in-plane resolution of 0.63–0.66 mm in anteroposterior direction and 1.06–1.25 in the superoinferior direction; four averages; 4-mm slice thickness with intersection gap of 0.8–1.0 mm; echo train length of 19–28; 41.7 kHz bandwidth) in the sagittal plane was used. For measuring anteroposterior and mediolateral (maximum and minimum) dimensions, a T2-weighted fast spin echo sequence (TR = 3100–5160 ms; TE = 103–107 ms; in-plane resolution of 0.70–0.78 mm in the left-right-direction and 0.70–1.13 mm in the anteroposterior direction; four averages; 4-mm slice thickness with intersection gap of 0.8–1.0 mm; echo train length of 12–26; 31.2 kHz bandwidth) in the axial plane was used.

Measurements

In the clinical examinations at 46 years, participants' free standing height (in cm, recorded to closest 0,1cm) was measured two times in succession by using a standard and calibrated stadiometer. The mean of these two measurements was used in the analysis.

All subjects were considered healthy with no spinal injuries or pathologies detected from the MRI scans. Vertebral measurements were: maximum anterior height and maximum posterior height. Intervertebral disc heights were anterior height and posterior height from the midline of the vertebrae. Measured vertebrae were L1, L2, L3 and L4. Intervertebral discs utilized in this study were those between L1-L2, L2-L3 and L3-L4. Intervertebral disc thickness was measured at the same site as vertebral height (figure 1). All the measurements were performed by MR and RP. MRI measurements were taken using the NeaView Radiology software (Neagen Oy, Oulu, Finland) version 2.31 and recorded to the closest 0.1 mm (table 1).

The sites of the measurements were chosen according to dimensions utilized in several anatomical stature estimation techniques as anterior and posterior midline heights are normally chosen and/or they provide the maximum height of the vertebra anterior to pedicles (see figure 1). Anterior and posterior intervertebral disc height utilized in this study provide realistic information about the intervertebral disc height/stature connection.

Analyses

All analyses were performed with SPSS (IBM SPSS Statistics) version 22.0.0 (IBM, Armonk, NY, USA). P values of < 0.05 were considered statistically significant. We illustrated the correlation between intervertebral disc thickness and stature by calculating the corresponding Pearson's correlation coefficients (R). Pearson's R was calculated for men and women separately as well as for the entire sample.

Ethical approval

Approval was obtained from the Ethical Committee of Northern Ostrobothnia Hospital District. All procedures were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

Results

The mean stature in our study sample was 178,87cm for men (range 167,70-192,60cm SD 5,62) and 165,16cm for women (range 151,50-179,25, SD 5,77). Mean lumbar vertebral height for men was 28,11mm and for women 26,60mm. Individual intervertebral disc thicknesses varied from 1,9mm to 12,30mm. Anterior disc height was greater in both male (mean 7,17mm) and female (mean 6,02) compared to mean posterior disc heights that were 3,61mm for male and 3,39mm for female sample. (Table 1.)

As suggested in the previous studies, our results clearly demonstrate that taller individuals have thicker intervertebral discs. (figure.2) This association was found to be statistically significant in the overall sample ($r=0.47$, $p<0.05$). When analyses were performed separately for sex-specific samples the correlations were somewhat lower but the association was still statistically significant ($r=0.28$, $p<0.05$ for males and $r=0.38$, $p<0.05$ for females).

Vertebral height was significantly associated with stature ($r=0.68$). Statistically significant association was also detected between vertebral height and intervertebral disc thickness in overall sample ($r=0.158$, $p<0.05$). However this association was lost when male and female samples were analyzed separately.

Discussion

Our results clearly indicate that stature and intervertebral disc height in lumbar spine are positively associated in our sample of 200 adults from Northern Finland. Stature also has a strong correlation with vertebral height dimensions as expected. However we could not demonstrate a statistically significant relationship between the vertebral height and intervertebral disc height in sex specific samples and thus our results differ slightly from the work of Kunkel and colleagues (2011).

In relation to other recent stature estimation studies we utilized measurements that were taken from the midline of the vertebrae. Raxter and colleagues (2006) for example, were using maximum vertebral height described as maximum anterior to pedicles. As this method utilizes the maximum height of vertebra that sometimes is just an eminence in vertebral body, this may change and/or reduce the role of intervertebral disc height in overall stature.

Our study has several strengths. We could provide vertebral disc measurements from relatively large MRI sample at specific age (46 years) within specific population. We could thus conclude that age related changes had no effect on our results. Additionally, stature measurements and MRI studies were performed at the same time.

Our study has also some clear limitations. As we utilized low back MRI study material, we could only study a relatively small segment of the vertebral column and thus further studies, preferably full body MRI, are needed especially on cervical and thoracic spine. We could also only demonstrate the positive association between stature and intervertebral disc thickness without further applications to improve existing stature estimations.

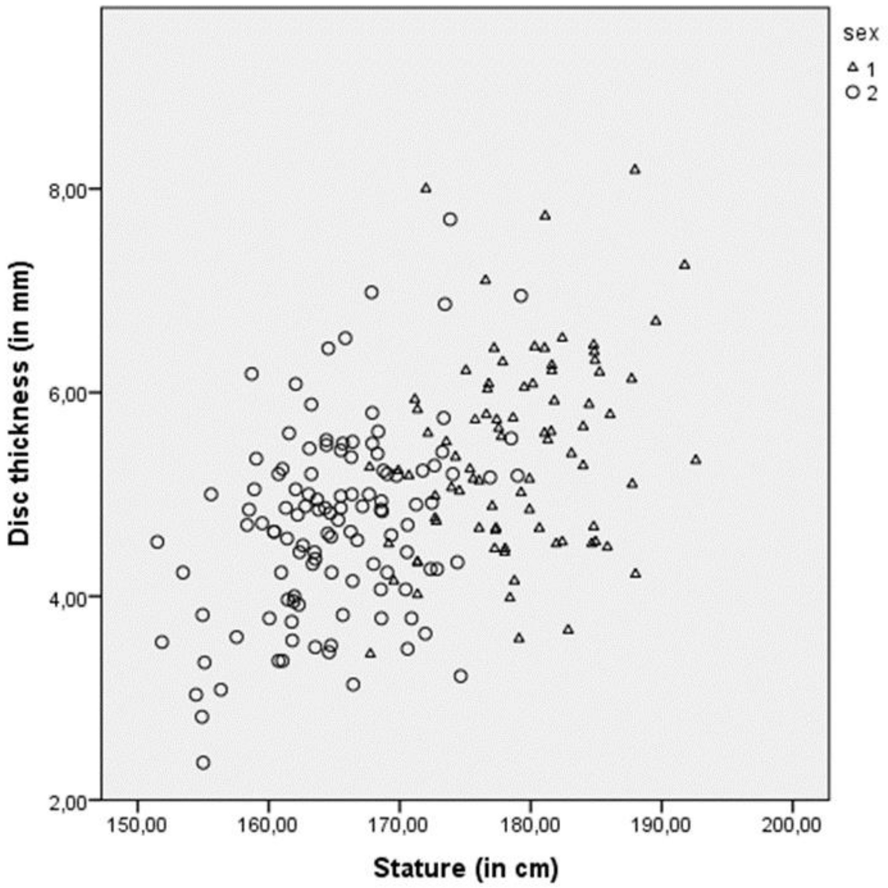
In light of our results, it seems obvious that the anatomical stature estimation method can be improved by the addition of an appropriate soft tissue correction relative to living stature. Thus it is advisable to take into account an individual's skeletal height when soft tissue corrections for anatomical stature estimations are performed. However, this study clarified only the role of individual soft tissue element on stature. In the future, further studies are needed to clarify how soft tissue is contributing to stature in different locations. Better understanding on soft tissue corrections is important when more accurate stature estimation methods for forensic and anthropological use are developed.

Table 1. Intervertebral disc heights, vertebral heights and stature.

		Anterior disc height	Posterior disc height	Anterior vertebral height	Posterior vertebral height	Stature
Male	N	85	85	85	85	85
	Mean	7,1722	3,6086	27,8124	28,4329	178,8732
	Std. Deviation	1,19221	1,00688	1,27774	1,41871	5,62087
Female	N	115	115	115	115	115
	Mean	6,0200	3,3899	26,7700	26,4300	165,1587
	Std. Deviation	1,11057	,98158	1,35810	1,48589	5,77102
Total	N	200	200	200	200	200
	Mean	6,5097	3,4828	27,2130	27,2813	170,9477
	Std. Deviation	1,27772	,99581	1,41867	1,76060	8,86183

Figure 1. Measurement protocol. Measured vertebrae were L1, L2, L3 and L4. Measured intervertebral discs were those between L1-L2, L2-L3 and L3-L4.

Figure 2. The relationship between living stature (in cm) and mean thickness of the lumbar interevertebral discs (in mm).



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