



## Letter to the Editor

**Comment on Bidmos and Manger, “New soft tissue correction factors for stature estimation: Results from magnetic resonance imaging” [Forensic Sci. Int. 214 (2012) 212.e1–212.e7]**

Dear Editor,

We would like to comment on the recent reanalysis of anatomical stature reconstruction (the Fully [1] technique) by Bidmos and Manger [2]. These authors attempted to reproduce the traditional skeletal measurements included in the technique [1,3] – articulated talocalcaneal height, tibial and femoral lengths, heights of the S1 through C2 vertebrae, and basion–bregma height – using MRI on living subjects whose statures had been measured. They found that the difference between the sum of these elements (skeletal height) and living stature in their sample was much greater than that estimated in previous studies [1,3], and therefore proposed new “soft tissue” correction factors. Population-level anthropometric differences were mentioned as one possible explanation for their results, but they also noted more generally “it is possible that previous studies might have underestimated the magnitude of the soft tissue correction factor that is needed for accurate estimation of stature using Fully’s method” (p. 212.e6). However, we show here that for a variety of reasons, Bidmos and Manger’s MRI method appears to significantly underestimate skeletal height as it has been traditionally determined from direct measurements of skeletal elements. Therefore, their new correction factor may be only applicable to their sample, measured in a particular way, and should not generally be applied in studies based on skeletal material.

As discussed elsewhere [3], the “soft tissue” correction factor in anatomical reconstruction of stature actually incorporates a number of parameters – both additions to and subtractions from skeletal height – to account for the difference between the sum of skeletal elements included in the technique and living stature. One of the most important additions to skeletal height is the summed height of the S1–C2 intervertebral discs. Bidmos and Manger measured curved (articulated) vertebral column length from their MRI scans, and from this and the sum of vertebral heights obtained an average difference of 19.7 cm, which should represent the summed total of S1–C2 intervertebral disc heights. This is much greater than that indicated by other sources, however. Using data from the anatomical literature [4,5, also see 6,7], Raxter et al. [3] calculated a summed total of approximately 11 cm for intervertebral disc heights over this region (the actual summed height in Raxter et al.’s sample was probably closer to 10 cm when adjusted for the older average age of their sample). It is possible that the particular sample measured by Bidmos and Manger had thicker intervertebral discs than those reported in the anatomical literature. We measured vertebral body heights and vertebral column length from the authors’ Fig. 2 using ImageJ and following their described measurement techniques. We obtained a curved

column length of 61 cm and a sum of vertebral body heights of 48 cm, giving a summed S1–C2 intervertebral disc height of 13 cm. This is about 21% of the curved column length, which is consistent with figures given in the anatomical literature [4, p. 513]. The individual in their Fig. 2 may also be taller than average for their sample, based on data given in their Table 2.<sup>1</sup> Therefore, average values for intervertebral disc heights reported in the literature appear to be applicable to their sample. While this calculation is based on only one image, it suggests that Bidmos and Manger mismeasured (underestimated) vertebral heights and consequently overestimated intervertebral disc heights, possibly by as much as almost 9 cm over the entire column. Difficulties in accurate identification of boundaries between bone and intervertebral discs using MRI, due to shading artifacts, have been noted [8,9].

The talocalcaneal height measured by Bidmos and Manger from MRI images is also substantially shorter than that measured directly from articulated skeletal elements [3]. Bidmos and Manger used a coronal image through the apparent anteroposterior midpoint of the talocrural joint to take this measurement (their Fig. 4). They concede that this image does not afford “a complete visualization of the articulated talus and calcaneus” (p. 212.e6). In fact, because the calcaneal tuber is well posterior to the A–P midpoint of the talocrural joint (e.g., see Fig. 5 in [3]), it is impossible for such an image to capture the full superoinferior height of the articulated talus and calcaneus (this is actually obvious from their Fig. 4). As defined previously [1,3], this dimension should also be taken to the most superior point on the talus, i.e., the medial and lateral ridges on the trochlear surface, not the midline concavity of this surface (their Fig. 4). The sum total underestimate of true talocalcaneal height using their method is about 2 cm.

The tibial length dimension measured by Bidmos and Manger is also not the same as that traditionally included in anatomical stature reconstruction [1,3]. The traditional measurement is taken to the superior-most point on the lateral condyle, while Bidmos and Manger took it to the medial condyle (their Fig. 4). Because the tibial plateaus slope slightly inferiorly from lateral to medial, relative to the long axis of the tibia, this leads to an underestimate of the traditional measurement by several millimeters.

In sum, these under-measurements of skeletal elements using Bidmos and Manger’s technique, compared to traditional measurements, total about 11 cm, accounting for the great majority of the “soft tissue” discrepancies that they note (14.8 cm different from Raxter et al.’s [3] living stature estimate). In addition, Bidmos

<sup>1</sup> No vertebral column heights are listed in Bidmos and Manger [2], but the average skeletal height of their sample was 144.9 cm and the average tibia and femur lengths were 38.2 cm and 45.2 cm, respectively (their Table 2). This leaves 61.5 cm for all other elements (summed vertebral heights, basion bregma height, talocrural height). Apportioning about 21.5 cm for talocalcaneal + basion-bregma height (based on data used in Raxter et al. [3]) leaves an average summed vertebrae height of about 40 cm for Bidmos and Manger’s sample.

and Manger apparently did not apply Raxter et al.'s recommended age-adjusted formula for "soft tissue" correction [3,10] (using the average skeletal height of 144.9 cm given in Bidmos and Manger's Table 2, a living stature estimate of 156.0 cm is obtained using Raxter et al.'s non-age-adjusted formula, which is 14.8 cm below Bidmos and Manger's mean of 170.8 cm, the difference that they cite in their paper). Age adjustment is necessary given that the average age of Bidmos and Manger's sample (35 years) is considerably less than that of Raxter et al. (54 years). Raxter et al.'s non-age-adjusted formula has been shown to give biased results when applied to younger samples [10]. Use of the appropriate age-adjusted formula would add 8 mm on average to estimated living stature in Bidmos and Manger's sample. This further reduces the difference between their measured living stature and that estimated using Raxter et al.'s [3] technique.

Finally, it should be noted that because of the limitation of MRI (in this study) to strictly sagittal or coronal slices, there is a real chance that any of the "maximum" lengths or heights obtained by Bidmos and Manger were not always truly physical maximums. This is most obvious in the talocalcaneal height measurement, as shown above. However, any slight out-of-plane tilting of the femur or tibia – for example, slight flexion of the hip or knee – would result in a less-than-maximum length being obtained in a coronal slice. The precise positions of the most proximal and distal points on the femur and tibia are also unlikely to lie in exactly the same coronal plane in every individual. The effects of lying in a supine position for the MRI study may also affect alignment of such landmarks. Put another way, the MRI dimensions represent at most the true maximum lengths of these bones, and many cases likely less than the maximum lengths, as they would be measured three-dimensionally *ex vivo*.

In explaining the difference between their results and those of Fully [1] and Raxter et al. [3], Bidmos and Manger also noted a measured 5.4 cm distance between the proximal surface of the femoral heads and the inferior surface of the S1 vertebra (one of the "gaps" in the anatomical stature method). Raxter et al. [3] reported an average distance of 3.6 cm, which is somewhat smaller. However, again this difference in results is very likely due to the measurement technique employed by Bidmos and Manger. Because the sacrum is posteriorly angled, and because in anatomical position the femoral heads lie slightly anterior to the middle of the S1 vertebral body, an MRI coronal plane through the centers of the femoral heads will intersect S1 at some point on its anterior surface, not at its inferior border (this is also apparent in Bidmos and Manger's Fig. 7). This would account for the somewhat larger dimension obtained by Bidmos and Manger.

Maijanen [11], in a study not cited by Bidmos and Manger, tested several anatomical stature reconstruction methods (all osteometric) against both cadaveric and reported living statures in a sample of modern US white males. The Raxter et al. [3] method produced stature estimates that were virtually unbiased (mean error of .03 cm) when compared to corrected living statures. This provides more evidence that the "soft tissue" correction factor

incorporated by Raxter et al.'s formulae is appropriate, for osteological samples.

In conclusion, the technique described by Bidmos and Manger [2] appears to be applicable only to the particular sample and MRI methodology employed in their study. The dimensions measured do not match those included in traditional osteometric analyses, and in many cases appear to underestimate them. For these reasons, their derived formula cannot be recommended for general use on osteological specimens.

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