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ESTIMATION OF STATURE FROM DIMENSIONS OF THE FOURTH LUMBAR VERTEBRA IN CONTEMPORARY MIDDLE-AGED FINNS

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HIGHLIGHTS

- We present L4-based stature estimation equations for Northern Finns
- In the pooled-sex sample, the most accurate equation yielded an error of 5.635 cm
- Among men and women, the lowest errors were 5.125 and 4.640 cm, respectively
- We suggest that L4 dimensions may be used to estimate stature relatively accurately

ABSTRACT

Background: Accurate stature estimation plays an essential role in the identification of unknown deceased individuals. For cases in which conventional methods of stature estimation are not applicable, we studied the stature estimation potential of the fourth lumbar vertebra (L4) among a large living sample of representative contemporary Finns. We also generated stature estimation equations for the middle-aged Finnish population.

Material and methods: Our study population comprised the Northern Finland Birth Cohort 1966 for which lumbar magnetic resonance imaging (MRI) scans and objective measurements of stature were available from midlife (n = 1358). After screening the MRI scans for vertebral pathologies, we measured the maximum and minimum widths, depths and heights of the L4 body with high precision and reliability. We then calculated their sums and means together with approximations of vertebral cross-sectional area and volume. By constructing simple and multiple linear regression models around the L4 parameters, we generated equations for stature prediction, and investigated their accuracy on the basis of the adjusted R squared (R^2) and standard error of the estimate (SEE) values of the models.

Results: The multiple linear regression models of the mean width, depth and height of L4 yielded the highest prediction accuracies with the lowest prediction errors (for the entire sample, R^2 = 0.621 and SEE = 5.635 cm; for men, R^2 = 0.306 and SEE = 5.125 cm; for women, R^2 = 0.367 and SEE = 4.640 cm).

Conclusion: When conventional methods for estimating stature are not applicable, the lumbar vertebrae may be utilized for this purpose. Relatively accurate stature estimates can be given on the basis of only L4 dimensions.

KEY WORDS: Stature estimation, L4, vertebral dimensions, magnetic resonance imaging, Forensic Anthropology Population Data

INTRODUCTION

The identification of unknown deceased individuals is an essential part of forensic medicine (1-4). Constructing the biological profile of an unidentified individual involves not only the estimation of sex, age and ancestry, but also the estimation of physical measures such as stature (4, 5). Once constructed, the basic biological profile can be used in conjunction with more specific traits of forensic identification to confirm an exact victim match. Although profiling is typically based on well-established skeletal parameters (such as the size and shape of the pelvis and cranium for sex (6) or dimensions of the limbs for stature (7)), in some circumstances conventional methods cannot be used. Thus, cases complicated by mutilated, poorly preserved, or completely missing skeletal material may benefit from further data describing the usability of various skeletal parameters in the profiling process.

The spine is one of the main components of stature (8). The vertebrae, in turn, are the main bony components of the spine, and their dimensions are highly intercorrelated (9). It thus seems plausible that vertebral dimensions could yield accurate stature estimates. To test this, several studies have measured the cervical, thoracic, lumbar, sacral and/or coccygeal segments (10-19) of cadaveric and living individuals of various population groups, and generated regression equations for stature in these populations. Generally, these equations have shown error margins of around 5 cm, which are somewhat higher than those produced by conventional stature estimation methods, but are still apparently useful in cases in which conventional methods are not applicable. However, previous studies have utilized rather small samples, and methodological approaches have varied considerably.

The aims of the present study were two-fold. First, we aimed to confirm previous findings regarding the stature estimation potential of the lumbar vertebrae in a considerably larger sample of a contemporary Western population (n = 1358). Second, we aimed to generate stature estimation equations for the Finnish population, in which they have been lacking. We used a large representative subsample of a Finnish birth cohort with 1) direct measurements of stature and 2) magnetic resonance imaging (MRI)-derived measurements of the body of the fourth lumbar vertebra (L4) from midlife.

MATERIAL AND METHODS

Study sample

We conducted the study using a middle-aged Finnish birth cohort sample. An MRI scanned subpopulation of the Northern Finland Birth Cohort 1966 (NFBC1966) provided the material for the study. The NFBC1966 originally included Northern Finns whose expected date of birth fell within the year 1966 (20). The subsample which we used in this study (n = 1358 male and female participants who had undergone a lumbar MRI scan and measurement of stature at a mean age of 47 and presented no vertebral pathologies) has been previously concluded as representative of the general Northern Finnish population (21). We focused on this population according to our aim of investigating the general Finnish adult population before old age when the vertebrae are more likely to be affected by osteoporosis or degeneration.

Dimensions of L4

We obtained lumbar MRI scans using a 1.5 T Signa HDxt device (General Electric, Milwaukee, Wisconsin, USA) in 2012—2014. The scanning procedure, which is described in more detail in our previous publication (22), was performed according to routine lumbar spine protocol. It included T2-weighted fast-recovery fast spin-echo images in transverse and sagittal planes, with weekly quality assurance for geometric accuracy. We have previously shown the equivalence of our MRI-based vertebral measurements to those taken directly with standard osteometric calipers (23).

The MRI scans were accessed and evaluated using NeaView Radiology software version 2.31 (Neagen Oy, Oulu, Finland). After screening the MRI scans for vertebral pathologies, one blinded researcher (P.O.) obtained six measurements from the body of L4 to an accuracy of 0.1 mm. The six dimensions, i.e., maximum and minimum widths, depths and heights of L4 were measured as the maximum and minimum mediolateral, anteroposterior and superoinferior dimensions of the L4 body, respectively. An annotated illustration of the measurements is presented in **Figure 1**. These dimensions were obtained because they are relatively easily measured and give an approximation of the overall size of the vertebral body.

We calculated the mean width, depth and height of L4 as the averages of the corresponding maximum and minimum dimensions. We also calculated the sum of the six original measurements, together with the cross-sectional area ($CSA = \pi \times (\text{mean width}/2) \times (\text{mean depth}/2)$) and volume ($V = \pi \times (\text{mean width}/2) \times (\text{mean depth}/2) \times (\text{mean height})$) of the L4 body (24). We chose L4 because 1) it was most likely to be included within the MRI scanning range, thus being most often measurable, 2) it represents the other lumbar vertebrae well (9, 22), and 3) it has been commonly used in previous studies (23, 25-30).

We randomly selected 20 individuals for a second full measurement round. The repeated measurements were taken by the original measurer in a blinded manner.

Stature

A trained study nurse measured the stature of each study subject twice in a standing position using a calibrated standard height measuring scale. The measurements were recorded to an accuracy of 0.1 cm, and their mean was used as the stature.

Statistical analysis

The data were analysed using SPSS software version 24 (IBM, Armonk, NY, USA). P values of < 0.05 were considered statistically significant. After ensuring normal distribution, we calculated the means and standard deviations (SD) of stature and L4 dimensions. We also illustrated the correlation between each L4 parameter and stature by means of scatter plots and calculated the corresponding Pearson's correlation coefficients (R). Pearson's R was calculated for men, women, and the entire sample. The sex differences in L4 parameters were analysed using Student's t-test.

We used linear regression models to generate the stature estimation equations (31). We performed both sex-stratified and pooled-sex analyses. We used both simple models (i.e., one predictor variable) and multiple models (i.e., several predictor variables), with stature as the outcome in centimetres. For each model, we collected the intercept term, the beta coefficients (β) of the predictor terms, the adjusted R squared value (R^2, coefficient of determination, i.e., the variance in the outcome that the model explains), and the standard error of the estimate (SEE, i.e., the average prediction error that the model produces with regard to the outcome) (31). The models and their characteristics are presented in the results section.

We investigated the precision and reliability of our study based on the repeated measurements (32). Precision was analysed by calculating the absolute and relative technical error of measurement (TEM) values (33), and reliability by calculating the intra-class correlation coefficient (ICC) using the two-way mixed model with the absolute agreement type for single measures (34).

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. The article does not contain any studies with animals performed by any of the authors.

The datasets generated and analysed during the study are not made publicly available. The dataset is administered by the NFBC Project Center but restrictions apply to the availability of these data due to local privacy regulations.

RESULTS

The sample consisted of 616 men and 742 women aged 46.8 (SD 0.4) years. As presented in **Table 1**, men were taller (178.7 [SD 6.2] vs. 164.8 [SD 5.8] cm) and had consistently larger L4 dimensions than women ($p < 0.001$). The precision and reliability of the vertebral measurements were high (relative TEMs ≤ 2.4%, ICCs ≥ 0.86; **Table 2**).

Figure 2 shows scatter plots illustrating the relationship between the L4 parameters and stature. When assessed individually, the width, depth, and height of L4 showed a somewhat weaker correlation with stature (e.g., Pearson's R = 0.529—0.711 for the entire population) than when they were summed or mathematically combined as vertebral CSA or volume (e.g., R = 0.745—0.781). The same trend was detected in the sex-stratified analyses.

Table 3 (simple models) and **Table 4** (multiple models) present the linear regression equations for stature. Generally, simple models with only the width, depth, or height of L4 as predictors were less accurate than the models that included their sum, CSA or volume. The highest prediction accuracies were reached by multiple regression models which included the mean width, depth, and height of L4 as predictors (e.g., $R^2 = 0.621$ and SEE = 5.635 cm for the entire population). Again, we detected analogous trends among both sexes.

DISCUSSION

In our sample of 616 men and 742 women, we used the dimensions of the L4 body to produce stature estimation equations for the general Finnish population. Multiple linear regression models of the mean width, depth and height of L4 yielded the highest prediction accuracies with the lowest prediction errors (for the entire sample, $R^2 = 0.621$ and SEE = 5.635 cm; for men, $R^2 = 0.306$ and SEE = 5.125 cm; for women, $R^2 = 0.367$ and SEE = 4.640 cm).

Several previous studies have investigated the accuracy of stature estimation on the basis of lumbar vertebrae. In a recent study of 412 Chinese living men and women, Zhang et al. (10) used computed radiography to measure the anterior, posterior and central heights of L1—L5. Their multiple regression models of L1—L5 yielded SEEs of 4.1—4.7 cm among men, and 3.0—3.8 cm among women. The L4-specific simple models were somewhat less accurate, with errors of 4.7—6.6 cm and 3.7—4.6 cm among men and women, respectively. In another recent study utilizing a sample of 42 Western male cadavers, Klein et al. (11) measured various dimensions of L2—L5 (heights, depths, facet tip distance) by means of computed tomography, and reported SEEs of 5.9—6.7 cm. Specific results for L4 were not given as they were not among the most accurate predictors of stature. A broader perspective also covers previous studies that have assessed the height of the entire lumbar block in terms of stature estimation. Studies by Terazawa et al. (12) (71 Japanese male and female cadavers; somatometric measurement from the superior endplate of L1 to the promontory of sacrum) and Nagesh et al. (13) (117 South Indian male and female cadavers; measurement from the point between T12 and L1 to the point between L5 and S1) yielded SEEs of 6.2 cm among men and 4.1 cm among women, and 5.2 cm among men and 4.6 cm among women, respectively. Our multiple linear regression models, which were based on L4 (width, depth, height) in a Finnish population, yielded SEEs of 5.1 cm and 4.6 cm among men and women, respectively. However, as discussed below, several factors complicate the comparison of our results to those of previous studies. These include 1) population groups, 2) study material (cadavers vs. living individuals), 3) choice of measurements and measurement technique (direct vs. radiologic methods), and 4) other sample demographics (sex distribution, age range, etc.).

With regard to stature estimation on the basis of only L4, our estimates had a similar error margin to those of Zhang et al., and a somewhat lower error margin than that of Klein et al. After taking into account the other lumbar segments that the other studies had also utilized, Zhang et al. reached a slightly higher overall estimation accuracy (L1—L5) than our study. However, the applicability of stature estimation formulae across population groups seems to be poor (15), which implies that the models produced by Zhang et al. in a Chinese population were not directly comparable to ours. The slightly higher error margins of our equations may stem from the use of L4 instead of L1—L5, but they may also represent the higher variation in stature or vertebral dimensions among the Finnish population. Interestingly, our estimates (L4) turned out to be more accurate than those of Klein et al. (L2—L5). Although the material that Klein et al. used was Western, which implies a better comparability with our sample, our method of measuring living individuals instead of cadavers may explain our lower SEEs. The use of cadavers instead of living individuals may be problematic in stature estimation because a difference of up to 2.5 cm has been reported in the stature of the same individual when measured alive and post-mortem (35). It is also interesting that our equations (L4) seemed to yield equally low error margins to those that utilized the length of the entire lumbar block (Terazawa et al., Nagesh et al.). Despite the methodological differences between the studies, this would suggest that L4 may produce equally accurate stature estimates to those of the entire lumbar segment. Outside the lumbar spine, previous studies which have utilized other spinal segments or their combination (13-19) have been able to produce stature estimates with SEEs ranging from 2.6 to 7.3 cm (most commonly 4—6 cm). These are comparable to the present SEEs, indicating that spinal segment does not seem to influence the estimation accuracy to a major extent.

Generally, our pooled-sex models yielded higher SEE values than sex-stratified models, and the female equations had lower SEEs than the male equations. The higher error rates of the pooled-sex models was likely to stem from the confounding effect of sex. There are considerable sex discrepancies in vertebral size (36, 37), and only the sex-stratified models were controlled for these. In a forensic setting, however, the sex of a victim or cadaver may not be known, justifying the use of the pooled-sex equations in such cases. The seemingly lower absolute SEEs of the female equations were likely to result from the naturally smaller vertebral size among women; when the mean vertebral dimensions among men and women were taken into account, the SEEs were similar across sexes.

Our most accurate models were 1) multiple regression models of the width, depth and height of L4, 2) simple regression model of the sum of the width, depth and height of L4, and 3) simple regression model of the volume of L4. These parameters consistently showed the lowest SEEs among both sexes separately, as well as when the sexes were pooled. Interestingly, our results showed that vertebral height had a weaker correlation with stature (R = 0.529) than vertebral width or depth (R = 0.703—0.711), suggesting that vertebral height may be inferior to other vertebral dimension parameters in stature prediction. As such, the overall vertebral size seems to predict stature more accurately than vertebral height. We therefore suggest that parameters which combine vertebral width, depth and height are used in stature estimation when it is performed on the basis of L4. In a wider context, however, even our most accurate estimates were less accurate than the well-established methods of using limb size and other skeletal elements for stature estimation (4, 7). Our method may thus primarily prove relevant in cases of damaged or otherwise non-accessible limbs and larger sections of the spine. While our results are in line with previous reports, confirming the relatively high potential of the lumbar vertebrae to be utilized in stature estimation among unknown individuals, previous studies have major methodological differences. This underlines the need for further research addressing the role of the lumbar vertebrae in stature estimation, especially from the living Western population's perspective.

The main strengths of our study were its large sample, its high representativeness of the general Finnish population, and its accurate measurements of stature and vertebral size. Our sample of 1358 men and women was considerably larger than that of previous studies. Importantly, we were able to investigate living individuals instead of cadavers, which likely increased the accuracy of our stature measurements and thus also the stature estimation models. Furthermore, our TEMs were relatively low (≤ 2.4%) and ICCs high (≥ 0.86), indicating precise and reliable measurements. These also contributed to the accuracy of our models. As the sample was essentially representative of the general Northern Finnish population, our results should be applicable across the population.

Our study also had limitations. We obtained the L4 dimensions using MRI, which may be less accurate than direct measurement. However, as our study concerned living individuals, direct measurements were not possible; moreover, we have previously shown the equivalence between our MRI-based measurements and those taken directly with osteometric calipers (23). We focused solely on L4 as it was most commonly located at the centre of the axial MRI scanning range and thus most often accessible using both axial and sagittal scans. Both planes were required for recording the widths, depths, and heights of the vertebra. Our study population was comprised of a birth cohort whose members had undergone MR imaging in middle-age (mean age 46.8, SD 0.4 years). This was both a strength and a limitation to our study. First, the population was coeval, minimizing the confounding effect of age-related changes in vertebral dimensions (38) on our stature estimates. However, this simultaneously prevented us from studying other age groups. While we acknowledge that this complicates the generalizability of our results, we also believe that the present results give a relatively universal view of the use of L4 as a predictor of stature. The 46-year-old sample was selected because the data were available to us and because we wanted to investigate the healthy adult vertebra before it expresses manifestations of osteoporosis or degeneration. The MRI scans were screened for pathologies in order to focus on healthy vertebrae.

In this paper we have provided simple and multiple linear regression equations for predicting stature on the basis of the dimensions of L4 in the general Finnish population. Our results confirm previous findings regarding the usability of the lumbar vertebrae in stature estimation among unknown individuals. Our results also imply that relatively accurate stature estimates can be given on the basis of only L4. As previous studies are lacking, further research in this area should investigate the living Western population in particular.

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DECLARATIONS OF INTEREST

None

COMPLIANCE WITH ETHICAL STANDARDS

Funding has been declared above. The authors declare that they have no conflict of interest.

Informed consent was obtained from all individual participants included in the study, and 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. This article does not contain any studies with animals performed by any of the authors. The datasets generated and analysed during the study are not made publicly available. The dataset is administered by the NFBC Project Center but restrictions apply to the availability of these data due to local privacy regulations. This is described in the “Ethical approval” section of the manuscript.

All authors have approved the final version of the manuscript.

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TABLES

Table 1. Characteristics of the sample (n = 1358).

	All	Male	Female	P[1]
N (%)	1358 (100)	616 (45.3)	742 (54.6)	
Age, years	46.8 ± 0.4	46.8 ± 0.4	46.8 ± 0.4	0.509
Stature, cm	171.1 ± 9.2	178.7 ± 6.2	164.8 ± 5.8	< 0.001
L4 width, mm				
Maximum	48.5 ± 4.6	51.3 ± 4.1	46.1 ± 3.4	< 0.001
Minimum	39.1 ± 3.9	41.8 ± 3.2	37.0 ± 2.9	< 0.001
Mean	43.8 ± 4.0	46.6 ± 3.3	41.5 ± 2.9	< 0.001
L4 depth, mm				
Maximum	35.4 ± 3.3	37.7 ± 2.8	33.5 ± 2.4	< 0.001
Minimum	32.6 ± 3.0	34.6 ± 2.5	31.0 ± 2.3	< 0.001
Mean	34.0 ± 3.1	36.1 ± 2.5	32.3 ± 2.3	< 0.001
L4 height, mm				
Maximum	29.6 ± 1.8	30.3 ± 1.7	29.0 ± 1.7	< 0.001
Minimum	24.8 ± 1.8	25.5 ± 1.8	24.3 ± 1.7	< 0.001
Mean	27.2 ± 1.6	27.9 ± 1.5	26.7 ± 1.5	< 0.001
Other L4 parameters				
Sum of measurements, mm	210.1 ± 14.9	221.2 ± 11.9	200.9 ± 10.2	< 0.001
CSA, cm^2	11.78 ± 2.03	13.26 ± 1.72	10.55 ± 1.32	< 0.001
Volume, cm^3	32.22 ± 6.02	37.09 ± 5.68	28.17 ± 4.11	< 0.001

Values are means ± standard deviations unless otherwise indicated. [1]P for sex difference (Student's t-test). CSA = Cross-sectional area.

Table 2. Measures of precision (technical error of measurement, TEM) and reliability (intra-class correlation, ICC) of the study (n = 20 repeated measurements).

Measurement	TEM		ICC	
	Absolute, mm	Relative, %	Coefficient	P value
Stature	0.570	0.032	1.000	< 0.001
L4 width				
Maximum	0.841	1.741	0.946	< 0.001
Minimum	0.704	1.833	0.955	< 0.001
L4 depth				
Maximum	0.699	1.959	0.965	< 0.001
Minimum	0.775	2.367	0.953	< 0.001
L4 height				
Maximum	0.679	2.324	0.864	< 0.001
Minimum	0.603	2.434	0.912	< 0.001

Table 3. Estimates for stature from simple linear regression models.

L4 parameter	Estimated equation for stature (ST), cm	Model fit	
		R^2	SEE, cm
All (n = 1358)			
Mean width (W), mm	ST = 1.622 × W + 100.025	0.494	6.513
Mean depth (D), mm	ST = 2.114 × D + 99.123	0.505	6.444
Mean height (H), mm	ST = 2.991 × H + 89.619	0.279	7.771
Sum of measurements (SM), mm	ST = 0.479 × SM + 70.427	0.610	5.717
Cross-sectional area (CSA), cm^2	ST = 3.364 × CSA + 131.436	0.555	6.107
Volume (V), cm^3	ST = 1.083 × V + 136.174	0.610	5.717
Male (n = 616)			
Mean width (W), mm	ST = 0.777 × W + 142.496	0.173	5.595
Mean depth (D), mm	ST = 1.108 × D + 138.631	0.210	5.470
Mean height (H), mm	ST = 1.572 × H + 134.797	0.147	5.683
Sum of measurements (SM), mm	ST = 0.274 × SM + 118.133	0.277	5.230
Cross-sectional area (CSA), cm^2	ST = 1.702 × CSA + 156.116	0.226	5.412
Volume (V), cm^3	ST = 0.585 × V + 156.998	0.290	5.183
Female (n = 742)			
Mean width (W), mm	ST = 0.953 × W + 125.198	0.219	5.153
Mean depth (D), mm	ST = 1.207 × D + 125.805	0.219	5.151
Mean height (H), mm	ST = 1.558 × H + 123.216	0.156	5.357
Sum of measurements (SM), mm	ST = 0.337 × SM + 96.975	0.346	4.715
Cross-sectional area (CSA), cm^2	ST = 2.314 × CSA + 140.331	0.273	4.971
Volume (V), cm^3	ST = 0.852 × V + 140.765	0.360	4.663

R^2 = Adjusted R squared, SEE = Standard error of the estimate.

Table 4. Estimates for stature from multiple linear regression models.

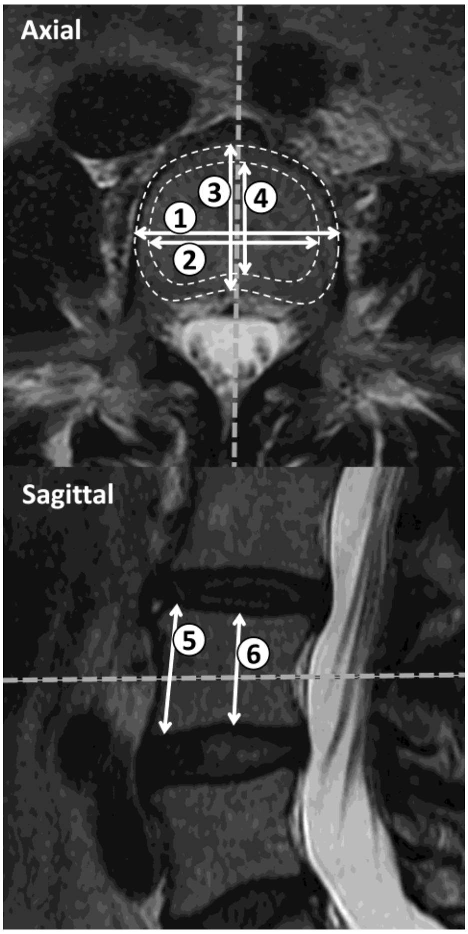
L4 parameter	Estimated equation for stature (ST), cm	Model fit	
		R^2	SEE, cm
All (n = 1358)			
W, D	$ST = 0.875 \times W + 1.232 \times D + 90.842$	0.560	6.072
W, H	$ST = 1.349 \times W + 1.659 \times H + 66.815$	0.566	6.033
D, H	$ST = 1.777 \times D + 1.764 \times H + 62.575$	0.589	5.870
W, D, H	$ST = 0.683 \times W + 1.131 \times D + 1.535 \times H + 60.853$	0.621	5.635
Male (n = 616)			
W, D	$ST = 0.367 \times W + 0.787 \times D + 133.181$	0.229	5.401
W, H	$ST = 0.635 \times W + 1.215 \times H + 115.197$	0.254	5.312
D, H	$ST = 0.960 \times D + 1.246 \times H + 109.182$	0.298	5.156
W, D, H	$ST = 0.247 \times W + 0.752 \times D + 1.178 \times H + 107.122$	0.306	5.125
Female (n = 742)			
W, D	$ST = 0.594 \times W + 0.756 \times D + 115.696$	0.273	4.970
W, H	$ST = 0.832 \times W + 1.257 \times H + 96.724$	0.316	4.820
D, H	$ST = 1.088 \times D + 1.330 \times H + 94.184$	0.331	4.769
W, D, H	$ST = 0.490 \times W + 0.725 \times D + 1.229 \times H + 88.255$	0.367	4.640

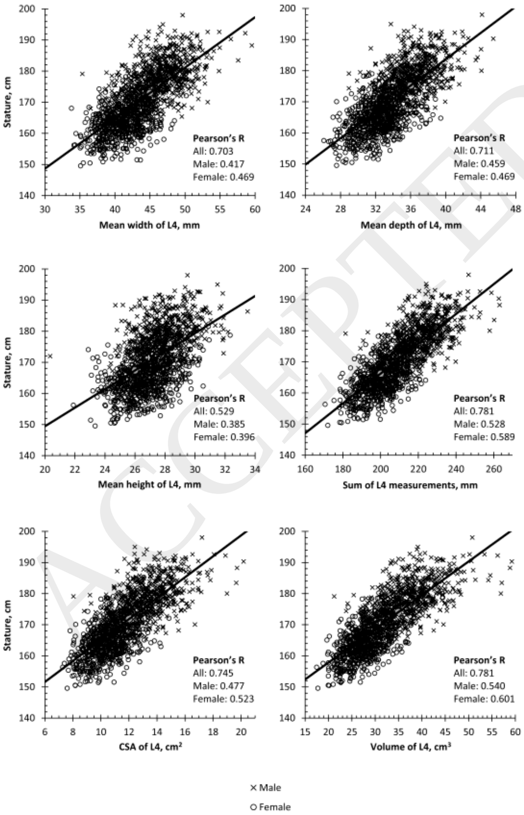
W = Mean width (mm), D = Mean depth (mm), H = Mean height (mm), R^2 = Adjusted R squared, SEE = Standard error of the estimate.

FIGURE LEGENDS

Fig. 1 Axial and sagittal MRI scans with annotated L4 measurements: Maximum width (#1), Minimum width (#2), Maximum depth (#3), Minimum depth (#4), Maximum height (#5), Minimum height (#6). Grey dashed lines mark the location of the corresponding axial and sagittal slices. Several axial slices were used when the maximum and minimum widths and depths were determined; white dashed lines demonstrate the variability of these dimensions across the slices.

Fig. 2 Scatter plots with regression lines demonstrating the correlation between stature and vertebral dimensions (n = 1358). All correlations were significant at the P < 0.001 level. CSA = Cross-sectional area.


Axial
1
2
3
4
Sagittal
5
6


Stature, cm
200
190
180
170
160
150
140
Mean width of L4, mm
30
35
40
45
50
55
60
Pearson's R
All: 0.703
Male: 0.417
Female: 0.469
Mean depth of L4, mm
24
28
32
36
40
44
48
Pearson's R
All: 0.711
Male: 0.459
Female: 0.469
Mean height of L4, mm
20
22
24
26
28
30
32
34
Pearson's R
All: 0.529
Male: 0.385
Female: 0.396
Sum of L4 measurements, mm
160
180
200
220
240
260
Pearson's R
All: 0.781
Male: 0.528
Female: 0.589
CSA of L4, cm²
6
8
10
12
14
16
18
20
Pearson's R
All: 0.745
Male: 0.477
Female: 0.523
Volume of L4, cm³
15
20
25
30
35
40
45
50
55
60
Pearson's R
All: 0.781
Male: 0.540
Female: 0.601
× Male
○ Female