TITLE PAGE

TITLE: BODY MASS ESTIMATION FROM DIMENSIONS OF THE FOURTH LUMBAR VERTEBRA IN MIDDLE-AGED FINNS

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DECLARATIONS OF INTEREST

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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.

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HIGHLIGHTS

- We studied the fourth lumbar vertebra (L4) in body mass estimation among Finns.
- Equations for body mass were generated for the full sample and for normal-weight individuals.
- In our data, body mass was clearly associated with all the L4 parameters.
- Vertebral cross-sectional area had the highest predictive value in body mass estimation.
- L4 dimensions are potentially useful in body mass estimation.

BODY MASS ESTIMATION FROM DIMENSIONS OF THE FOURTH LUMBAR VERTEBRA IN MIDDLE-AGED FINNS

ABSTRACT

Although body mass is not a stable trait over the lifespan, information regarding body size assists the forensic identification of unknown individuals. In this study, we aimed to study the potential of using the fourth lumbar vertebra (L4) for body mass estimation among contemporary Finns. Our sample comprised 1158 individuals from the Northern Finland Birth Cohort 1966 who had undergone measurements of body mass at age 31 and 46 and lumbar magnetic resonance imaging (MRI) at age 46. MRI scans were used to measure the maximum and minimum widths, depths, and heights of the L4 body. Their means and sum were calculated together with vertebral cross-sectional area (CSA) and volume. Ordinary least squares (OLS) and reduced major axis (RMA) regression was used to produce equations for body mass among the full sample (n=1158) and among normal-weight individuals (n=420). In our data, body mass was associated with all the L4 size parameters (R=0.093—0.582, p≤0.019 among the full sample; R=0.243—0.696, p≤0.002 among the normal-weight sample). RMA regression models seemed to fit the data better than OLS, with vertebral CSA having the highest predictive value in body mass estimation. In the full sample, the lowest standard errors were 6.1% (95% prediction interval ±9.6kg) and 7.1% (±9.1kg) among men and women, respectively. In the normal-weight sample, the lowest errors were 4.9% (±6.9kg) and 4.7% (±5.7kg) among men and women, respectively. Our results indicate that L4 dimensions are potentially useful in body mass estimation, especially in cases with only the axial skeleton available.

KEY WORDS: Body mass estimation; L4; vertebral dimensions; magnetic resonance imaging; forensic anthropology; population data

ABBREVIATIONS: BMI = Body mass index, CSA = Cross-sectional area, ICC = Intra-class correlation, L1—L5 = The lumbar vertebrae, MRI = Magnetic resonance imaging, NFBC1966 = Northern Finland Birth Cohort 1966, OLS = Ordinary least squares regression, PI = Prediction interval, R = Pearson's correlation coefficient, RMA = Reduced major axis regression, SD = Standard deviation, SEE = Standard error of the estimate, TEM = Technical error of measurement

CONFLICT OF INTEREST STATEMENT

Funding has been disclosed in a separate section of the manuscript. The authors declare that they have no other conflicts of interest.

1. INTRODUCTION

Accurate estimations of living body mass help in the forensic identification of unknown individuals [1]. Body mass has an influence on bone mass and geometry [2,3], which indicates that estimates of body mass may be generated on the basis of skeletal elements, especially in cases in which its direct assessment is not possible due to, for example, poorly preserved remains. Previous studies have used a number of postcranial elements, mostly from weight-bearing skeletal sites, to generate and evaluate regression equations for living body mass [1,4-16]. These include the pelvis [4,8,10,11], femur [8,9,13,14,16], tibia [14], knee [1,12], humerus [14], and metatarsals [5]. Articular and periarticular dimensions at weight-bearing sites have also been used [17]. Body mass estimates are most commonly obtained using the femoral head breadth or the combination of bi-iliac breadth and stature [14]. These estimates typically have relatively wide error margins, depending on the population and equation used [12,17].

Unlike the other major components of a forensic profile, i.e., sex, ancestry, and stature [18,19], which remain relatively constant over time, body mass may fluctuate significantly across the lifespan [17]. This is problematic in body mass estimations, because most skeletal components are already developed by the third to fourth decade of life when peak bone mass is reached, and have a limited adaptation capability thereafter [3,20]. Interestingly, vertebrae are known to increase in size well beyond peak bone mass [20,21], suggesting that they may be more flexible in adapting to changes in body mass over the life course than most other bones. The lumbar vertebrae also have substantial weight-bearing properties [22] and their dimensions have indeed been associated with body mass [23,24]. Yet data describing the usability of vertebral dimensions as predictors of body mass are scarce.

In our study, we aimed to investigate the body mass prediction potential of the corpus of the fourth lumbar vertebra (L4) in a large representative middle-aged sample of Northern Finns. We utilized body masses that were objectively measured at two time points (31 and 46 years of age), and the width, depth, and height of L4, which were measured in lumbar magnetic resonance imaging (MRI) scans at the age of 46. This approach enabled us to study how midlife vertebral dimensions reflect body mass 1) in early adulthood when skeletal maturity and peak bone mass are reached, and 2) in midlife, when the vertebral dimensions were measured. We also generated equations for estimating the body mass of the Finnish population at these two time points. As previous studies [11,25] have indicated that body mass estimations seem to reach highest accuracy among individuals within the normal body mass index (BMI, kg/m^2) range (18.5 ≤ BMI < 25 according to the WHO classification [26]), we decided to utilize 1) our entire sample and 2) a subsample that included only individuals with normal BMI at both time points. Our purpose was to investigate how sample selection affects body mass estimation.

2. MATERIALS AND METHODS

2.1 Study sample

The study was conducted using a sample from the Northern Finland Birth Cohort 1966 (NFBC1966) [27]. Briefly, the NFBC1966 is a population-based prospective cohort which originally comprised Northern Finnish mothers and their children born in 1966 (coverage of up to 96% of births, n = 12 231). The cohort has been followed closely over the life course of the members, and measurements of body mass and stature have been taken at the ages of 31 and 46. A representative subsample of the cohort [28] also underwent lumbar MRI scanning at the age of 46 (n = 1540). From these, we excluded individuals with vertebral pathologies visible in MRI (n = 177) or missing anthropometric data (n = 205). The final sample of the study thus comprised of 1158 individuals.

2.2 Dimensions of L4

We obtained the dimensions of L4 using lumbar MRI scans. These scans were performed in 2012–2014 using a 1.5 T Signa HDxt machine (General Electric, Milwaukee, Wisconsin, USA), according to a standard lumbar spine protocol including transverse and sagittal T2-weighted fast-recovery fast spin-echo images. Checks for geometric accuracy were conducted on a weekly basis. The imaging parameters are more closely described in our previous publication [29]. The use of MRI-derived vertebral measurements has been previously validated against direct measurements with osteometric calipers [30]. L4 was selected because it is an accurate indicator of overall vertebral size [29,31], has been a common choice in previous studies [32-34], and was most often accessible in the MRI scans.

One researcher evaluated the MRI scans using NeaView Radiology software version 2.31 (Neagen Oy, Oulu, Finland). First the scans were screened for underlying pathologies, and then the maximum and minimum widths, depths, and heights of the L4 body were measured and recorded to an accuracy of 0.1 mm (**Figure 1**). These dimensions were considered to give a comprehensive three-dimensional view of the size of L4. We have previously assessed the precision and reliability of our vertebral measurements by means of technical error of measurement (TEM) and intra-class correlation (ICC), and concluded that they are precise (relative TEMs ≤ 2.4%) and reliable (ICCs ≥ 0.86) [34]. The mean width, depth, and height of L4 was calculated by averaging the maximum and minimum measurements. We also calculated the sum of all measurements, the cross-sectional area of L4 (CSA = π x (mean width/2) x (mean depth/2)), and the volume of L4 (V = π x (mean width/2) x (mean depth/2) x (mean height)) according to previously published formulae [35].

2.3 Body mass and stature

At the ages of 31 and 46, the NFBC1966 members underwent clinical examinations which included objective measurements of body mass and stature. These measurements were systematically taken by a research nurse using standard calibrated scales to an accuracy of 0.1 kg (body mass) and 0.1 cm (stature). BMI was calculated as weight (kg)/height squared (m^2).

2.4 Statistical analysis

Descriptive statistics were calculated as means and standard deviations (SD), as the data were fairly normally distributed. Pearson's correlation coefficients (R) were used to demonstrate the relationship between the vertebral parameters and body mass.

The formulae for body mass estimates were generated using ordinary least squares (OLS) and reduced major axis (RMA) regression modelling in accordance with the methodology described in the previous literature [36-40]. Presenting results from both OLS and RMA is a common choice in studies of body mass estimation, because OLS typically underestimates individuals at the higher end and overestimates those at the lower end of the population [37,39]. The models were separately constructed for estimating body mass in kilograms at the ages of 31 and 46 years (outcomes) on the basis of the vertebral parameters (predictors). The following parameters were documented from each regression model: regression formulae, 95% confidence intervals (CI) and the P values of the slope (i.e., statistical significance of the association between the predictor and outcome), standard errors of the estimate (SEE, i.e., the average error that the model produces with regard to the outcome), relative SEEs (%SEE, i.e., SEE/population mean x 100%), and 95% prediction intervals (PI, i.e., measure of uncertainty around the predicted value).

The regression modelling was first performed for the full sample because a general population approach with maximal representativeness at the population level was considered beneficial in this forensic context; publishing formulae for body mass estimates derived from an unselected population may be potentially valuable for future forensic practice. However, as previous studies have suggested that equations derived from normal-weight individuals are more accurate than those derived from under/overweight individuals [11,25], we re-ran the analysis among normal-weight individuals only ($18.5 \leq BMI < 25$ according to the WHO classification [26]).

The data were administered and analysed in SPSS version 24 (IBM, Armonk, NY, USA) except for RMA regression, which we performed using the R software version 3.5.0 [41] and the LMODEL2 function. The level of statistical significance was set as $P = 0.05$.

2.5 Ethical approval

The study was approved by the Ethical Committee of the Northern Ostrobothnia Hospital District, Oulu, Finland. 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.

3. RESULTS

The full study sample consisted of 1158 individuals who had undergone lumbar MRI at the mean age of 46.8 years. On average, the body mass of the sample increased from 71.6 to 78.0 kg between the ages of 31 and 46. Of the full sample, 420 individuals remained within the normal BMI range at both time points. **Table 1** presents the detailed characteristics of the full sample, the normal-weight sample, and the source population (NFBC1966).

Regarding the full sample, scatter plots demonstrating the relationship between the L4 parameters and body mass at the ages of 31 and 46 are shown in **Figure 2** and **Figure 3**, and the corresponding regression formulae are presented in **Table 2** and **Table 3**. The correlation coefficients between the L4 parameters and body mass ranged from 0.093 to 0.582, being somewhat higher for body mass at the age of 31 (than age 46) and among men (than among women). The L4 parameters that combined several one-dimensional measurements (i.e., sum of measurements, CSA, and volume) showed stronger correlations with body mass than the one-dimensional L4 parameters. RMA regression models tended to fit the data better and produced lower %SEEs than the corresponding OLS models. However, the %SEEs were rather high, ranging from 12.8 to 19.8% in the OLS models, and from 6.2 to 19.8% in the RMA models. The 95% PIs were also fairly high, ranging from ± 20.1 to 28.8 in the OLS models and from ± 9.1 to 25.8 kg in the RMA models.

The regression formulae for body mass in the normal-weight sample are presented in **Table 4** and **Table 5**. The correlation coefficients were slightly higher than those of the full sample, ranging from 0.243 to 0.696. The %SEEs were lower, ranging from 8.1 to 11.8% in the OLS models and from 13.5 to 4.7% in the RMA models. The 95% PIs were also lower, ranging from ± 9.9 to 15.0 kg in the OLS models and ± 5.7 to 18.8 kg in the RMA models.

4. DISCUSSION

Body mass is a feature known to be highly variable throughout an individual's lifetime, unlike other forensic profile elements (e.g. sex and stature) [17]. Therefore, it is typically harder to predict than other major forensic parameters. Yet, as body mass is an indicator of overall body size, it is a useful tool in forensic science. In this study, we used a sample of 513 men and 645 women to create body mass estimation equations from dimensions of the L4 vertebral body for the Northern Finnish population.

Among our full pooled-sex sample, the correlations between the L4 parameters and body mass ranged from 0.312 to 0.582 at the age of 31, and from 0.289 to 0.527 at the age of 46. RMA regression models seemed to fit the data better than OLS, presenting the lowest %SEE of 6.8% at the age of 31, and 7.0% at the age of 46 for the pooled-sex sample. The lowest 95% PI in the RMA was ± 9.5 kg at the age of 31 and ± 10.7 kg at the age of 46. In addition, we used a subsample of 146 men and 274 women with normal BMI to test how using the overall population affects the accuracy of the formulas. Estimation formulas of the normal-weight sample had a slightly higher correlation with the L4 parameters, ranging from 0.243 to 0.696. They also presented smaller %SEEs of 5.0 (age 31) and 4.8 (age 46), and narrower 95% PIs of ± 6.2 kg (age 31) and ± 5.7 kg (age 46) than those of the full sample. As it became evident that the RMA models showed higher prediction accuracies in the full sample and in the normal-weight sample than the OLS models, we discuss mainly the RMA results here.

Few previous studies have investigated the usefulness of vertebral dimensions in body mass estimation. McHenry [42] was able to find a correlation coefficient of 0.690 between the average cross-sectional area of L5 and body mass. Porter also found a strong correlation (0.9) for L1, and 0.70—0.76 for L2, L3, and L4 (in [43]). However, it should be noted that both studies were based on rather small sample sizes (> 50 individuals). The present results showed only a moderate connection between L4 parameters and body mass. The study also included body masses from two separate time points (ages 31 and 46). The correlations with the L4 parameters were higher for body mass at the age of 31. The strongest correlation between body mass and the sum of the vertebral measurements was found among the pooled-sex sample (R = 0.582). Otherwise, correlation coefficients ranged between 0.093 and 0.536 (at the age of 31). In the normal-weight sample, the correlations were stronger overall. We found stronger correlations between L4 and body mass at the age of 46 for the pooled-sex sample and women but at the age of 31 for men. The strongest correlation was found between body mass and volume in the pooled-sex sample (R = 0.696), otherwise the correlations ranged from 0.243 to 0.687.

The majority of body mass estimation equations are either based on other postcranial bones that are directly related to weight support or clearly contribute to body size and shape, reconstructing body mass through height and breadth of the body (e.g. stature and bi-iliac breadth method) [44]. These studies are mainly for anthropological research rather than forensic purposes.

For femoral head diameter, Grine et al. [45] reported a correlation of 0.92, using a sample of 10 sex-specific means for larger-bodied modern humans. Their estimation formula yielded a SEE of 4.3 kg. Although our correlations were not as strong, the SEEs were relatively close, with lowest SEE 4.9 kg, and even smaller for the normal-weight group (SEE 3.2 kg). The %SEEs were 6.8 and 4.8, respectively. We obtained the most accurate body mass estimates with vertebral CSA, utilizing RMA regression equations for the pooled sample (for men, SEE = 4.9 and %SEE = 6.1; for women, SEE = 4.6 and %SEE = 7.1; for normal-weight men SEE = 3.5 kg and %SEE = 4.9; for normal-weight women SEE = 2.9 kg and %SEE 4.7).

Otherwise, the full sample's RMA regression SEEs ranged from 4.6 to 13.2 kg, and %SEEs from 6.1 to 18.4, which is closer to the results of Squyres and Ruff [12]. Similar to Grine et al., Squyres and Ruff also found stronger correlations between body mass and three knee breadth measurements (R = 0.72–0.20 for their sample of 100 individuals) but their SEEs ranged from 7 to 8.5 kg, and %SEEs from 9.94 to 13.16. However, they used normal-weight individuals, and compared to our normal-weight sample (whose SEEs ranged from 2.9 kg to 9.6 kg and %SEEs from 4.7 to 13.5), the results are relatively similar.

In morphometric studies, using 56 sex/population-specific sample means, Ruff [46] created a cylindrical model that yielded correlation coefficients of 0.898 and 0.816 from men and women, respectively. His SEEs were 3.6 kg and 4.1 kg, and %SEEs 6.0 and 7.7. However, although population means are representative of worldwide variation, this excludes a great deal of individual variation and typically results in strong correlations. Schaffer [11] utilized a larger sample of normal-weight individuals and created formulas for three American ethnic groups. He observed correlation coefficients varying between 0.549—0.774 and his SEEs ranged from 5.16 kg to 8.03 kg, which were closer to our results especially in the normal-weight sample. However, although it is important to acknowledge that comparison between formulas created using whole body size and individual bones may be challenging, our results do seem to hold up compared to these, and interestingly our 95% PIs for CSA were slightly higher than Schaffer's [11], ranging from ± 9.1 to 9.6 kg (overall range of all formulas was ± 9.1 to 25.8). His PIs ranged from ± 10.0 to 13.2 kg.

Despite the similar accuracy of the body mass estimation equations, it seems that the present correlations between bone dimensions and body mass were somewhat weaker than those published previously. Although correlation is an important indicator of the connection between size and vertebral size parameters, it may be affected by sample size, specifically the increase in the level of variation that comes with using larger samples. Importantly, we utilized a distinctly larger sample than most previous studies. While most studies have relied on sample sizes of 100 individuals or less, ours was 1158 individuals, consisting of 513 men and 645 women. Only Schaffer [11] came closer with his sample of men ranging between 494–527 and women 234–470. Notably, Schaffer's [11] correlations are also lower than those of Ruff [46], although they use the same morphometric method, indicating that a larger reference sample increases variance and therefore decreases the strength of correlations.

Although it is clear that using a sample with normal BMI seems to provide better body mass estimation formulae, we would still argue that using a more variable sample that includes both under- and overweight individuals, as in the general population, could be more beneficial in forensic use. Although this inevitably decreases the accuracy of our models, it contributes to our aim of generating generally applicable body mass estimation equations for recent industrial people, including those who are outside the normal weight range.

Numerous studies have tested the accuracy of previously created formulae (e.g. [8,10,15,25,44]), and reported varying accuracies, depending on the sample. It seems evident that most body mass estimation formulae can estimate the body mass of the majority of individuals within a 20% range of their actual weight. It has been noted that estimation formulae tend to work best with normal-sized individuals. This makes sense, as despite the slight adjustments that bones can make when adapting to body mass changes [3,47], the skeletal frame is overall designed to carry 'normal' weight. This is also reflected in our results. It became evident that using normal-weight individuals as the reference sample created more accurate formulae.

The majority of the previously referenced studies (e.g. [8,10,15,25,44]) have also raised concerns about the use of body mass estimation formulae to estimate individual body masses, especially if used in forensic science. However, considering that the difference between the estimated and known body masses mainly remained under 10 kg for the normal-weight individuals in these studies, and that even inside the normal BMI range body mass can vary over 15 kg, this does not seem to be a major problem. While we emphasize that the estimates should not be taken as exact body masses, we also suggest that they may contribute considerably to the assessment of a cadaver's body size in a relatively sedentary industrial Northern European population.

Our most accurate models were produced by RMA regression. They were 1) CSA of L4, 2) mean height of L4, and 3) mean depth of L4 in both samples. These dimensions showed the lowest SEEs, %SEEs and 95% PIs among both sexes separately, as well as when sexes were pooled. Thus, if the cadaver's sex is known, we recommend using sex-specific formulae, since men in particular seemed to perform better with their own formula. According to the SEEs and %SEEs of the present models, our formulae seem to be almost as accurate as those based on weight-bearing elements and the morphometric method. However, due to the fluctuating nature of body mass, our estimates should be regarded as directional and as representing the normal weight or weight that an individual's skeletal frame is designed to carry. However, they can be especially relevant in cases in which limbs and larger sections of the spine are missing. Although the present results indicate that the lumbar vertebrae may prove useful in body mass estimations, further investigations are needed in other populations.

The main strengths of our study were the large sample, the high representativeness of the general Finnish population, and accurate vertebral size measurements. The sample size of 1158 individuals was greater than that of previous studies investigating weight-bearing bones and stature or body mass. Our study sample also consisted of living individuals rather than cadavers, which increased the accuracy of our study. Outside the forensic context, our results may also be interesting from the physical anthropological and medical perspective, as they introduce a new understanding of how L4 dimensions are related to body mass.

The use of living subjects can be also seen as a limitation of our study. The fact that the L4 dimensions were obtained using MRI and were not directly measured could have influenced the accuracy of the measurements. However, we have previously shown that our MRI-based measurements were equivalent to those taken by osteometric calipers [30]. We focused on L4 because it is most commonly located at the centre of the axial MRI scanning range and is therefore most often visible in both axial and sagittal scans. Both planes were needed to record the widths, depths and heights of the vertebrae. Our study sample being comprised of a birth cohort whose members had undergone MR imaging in middle-age (mean age 46.8, standard deviation 0.4 years) was both a strength and limitation. The sample was coeval, which minimized the confounding effect of age-related changes in vertebral dimensions, but simultaneously prevented us from studying other age groups. We acknowledge that this could complicate the generalization of our results, but we also believe that the present results provide a universal view of the use of L4 as a predictor of body mass. This sample was elected because the data were available to us and because we wanted to study healthy adult vertebrae before manifestations of osteoporosis or degeneration. The MRI scans were screened for pathologies in order to focus on healthy vertebrae. As we were measuring living subjects, some correction is needed when utilizing these formulas for dry bone [48]. However, this shrinkage is evidently still very small, around 2.5%, and could be compensated by multiplying the dry bone measurements by 1.025.

In this study, we presented OLS and RMA regression formulae for estimating body mass from the L4 dimensions of the Northern Finnish population. Overall, our results support the usability of vertebral dimensions, especially CSA, in body mass estimation. Due to the lack of previous studies on the use of lumbar dimensions in body mass estimation, further research should be conducted in different populations.

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Table 1. Main characteristics of the present samples and the full NFBC1966 population.

Characteristic	Full sample			Normal-weight sample			Full NFBC1966 population*		
	All	Men	Women	All	Men	Women	All	Men	Women
N (%)	1158 (100)	513 (44.3)	645 (55.7)	420 (100)	146 (34.8)	274 (65.2)	12165 (100)	6232 (51.2)	5933 (48.8)
Body mass, kg									
At age 31	71.6 (13.8)	79.9 (11.2)	65.0 (12.0)	63.3 (8.2)	70.8 (6.6)	59.2 (5.7)	72.6 (14.9)	80.2 (12.7)	65.5 (13.2)
At age 46	78.0 (15.3)	86.1 (12.5)	71.5 (14.3)	66.3 (8.5)	74.3 (6.8)	62.0 (5.7)	78.7 (16.7)	87.2 (14.9)	72.0 (14.9)
Stature, cm									
At age 31	170.9 (9.1)	178.7 (6.2)	164.8 (5.8)	170.4 (8.5)	178.8 (6.0)	166.0 (5.8)	171.1 (9.3)	178.2 (6.4)	164.6 (6.2)
At age 46	170.9 (9.2)	178.7 (6.2)	164.7 (5.8)	170.3 (8.5)	178.6 (6.1)	165.9 (5.8)	170.8 (9.1)	178.5 (6.3)	164.8 (6.0)
Body mass index, kg/m^2									
At age 31	24.4 (3.9)	25.0 (3.2)	24.0 (4.3)	21.7 (1.6)	22.1 (1.5)	21.5 (1.6)	24.7 (4.2)	25.2 (3.6)	24.2 (4.7)
At age 46	26.7 (4.6)	27.0 (3.7)	26.4 (5.2)	22.8 (1.5)	23.3 (1.4)	22.5 (1.5)	26.9 (4.9)	27.3 (4.3)	26.5 (5.3)
L4 dimensions at age 46									
Width, mm									
Maximum	48.4 (4.6)	51.3 (4.1)	46.0 (3.4)	47.5 (4.3)	50.5 (4.1)	45.9 (3.3)	48.5 (4.6)	51.3 (4.1)	46.1 (3.4)
Minimum	39.1 (3.9)	41.8 (3.2)	36.9 (2.9)	38.4 (3.7)	41.4 (3.3)	36.8 (2.8)	39.1 (3.9)	41.8 (3.2)	37.0 (2.9)
Mean	43.7 (4.0)	46.5 (3.4)	41.4 (2.9)	42.9 (3.8)	46.0 (3.5)	41.3 (2.8)	43.1 (4.0)	46.5 (3.3)	41.5 (2.9)
Depth, mm									
Maximum	35.4 (3.3)	37.7 (2.8)	33.5 (2.4)	34.7 (2.9)	37.0 (2.4)	33.4 (2.4)	35.4 (3.3)	37.7 (2.8)	33.6 (2.4)
Minimum	32.6 (3.0)	34.6 (2.5)	31.0 (2.3)	32.0 (2.7)	34.1 (2.3)	30.9 (2.2)	32.6 (3.0)	34.6 (2.5)	31.0 (2.3)
Mean	34.0 (3.1)	36.2 (2.5)	32.3 (2.3)	33.4 (2.7)	35.5 (2.3)	32.2 (2.2)	34.0 (3.1)	36.1 (2.5)	32.3 (2.3)
Height, mm									
Maximum	29.6 (1.8)	30.3 (1.7)	29.0 (1.7)	29.6 (1.9)	30.3 (1.7)	29.2 (1.9)	29.6 (1.8)	30.3 (1.7)	29.0 (1.7)
Minimum	24.8 (1.8)	25.5 (1.8)	24.3 (1.7)	24.8 (1.8)	25.6 (1.8)	24.3 (1.6)	24.8 (1.8)	25.5 (1.8)	24.3 (1.7)
Mean	27.2 (1.6)	27.9 (1.5)	26.7 (1.5)	27.1 (1.6)	27.9 (1.5)	26.8 (1.5)	27.2 (1.6)	27.9 (1.5)	26.7 (1.5)
Combined									
Sum of measurements, mm	209.8 (15.0)	221.2 (12.0)	200.7 (10.1)	206.9 (13.8)	218.9 (11.8)	200.5 (10.1)	210.1 (14.9)	221.2 (11.9)	200.9 (10.2)
Cross-sectional area, cm^2	11.7 (2.0)	13.3 (1.7)	10.5 (1.3)	11.3 (1.8)	12.9 (1.6)	10.5 (1.3)	11.8 (2.0)	13.3 (1.7)	10.6 (1.3)
Volume, cm^3	32.1 (6.6)	37.1 (5.7)	28.1 (4.1)	30.8 (6.0)	36.0 (5.5)	28.1 (4.1)	32.2 (6.6)	37.1 (5.7)	28.2 (4.1)
Age at MRI scan, years	46.8 (0.4)	46.8 (0.4)	46.8 (0.4)	46.8 (0.4)	46.8 (0.4)	46.8 (0.4)	46.8 (0.4)	46.8 (0.4)	46.8 (0.4)

Values are presented as mean (standard deviation) unless otherwise indicated. MRI = Magnetic resonance imaging, NFBC1966 = Northern Finland Birth Cohort 1966.

*N varies due to missing data.

Table 2. Regression formulae for body mass at age 31 (BM_{31}, in kilograms) from linear regression models among the full sample.

L4 parameter	Correlation		OLS regression						RMA regression					
	R	P	Regression formula	95% CI for slope	P for slope	SEE for model	%SEE for model	95% PI for model	Regression formula	95% CI for slope	P for slope*	SEE for model	%SEE for model	95% PI for model
All (n = 1158)														
Mean width (W), mm	0.536	< 0.001	$BM_{31} = 1.849 \times W - 9.190$	1.681; 2.017	< 0.001	11.6	16.3	± 22.8	$BM_{31} = 3.450 \times W - 79.152$	3.286; 3.622	-	7.2	10.0	± 14.0
Mean depth (D), mm	0.559	< 0.001	$BM_{31} = 2.508 \times D - 13.609$	2.293; 2.723	< 0.001	11.4	16.0	± 22.4	$BM_{31} = 4.488 \times D - 80.891$	4.278; 4.708	-	6.1	8.5	± 12.0
Mean height (H), mm	0.312	< 0.001	$BM_{31} = 2.669 \times H - 1.004$	2.200; 3.138	< 0.001	13.1	18.3	± 25.7	$BM_{31} = 8.553 \times H - 161.097$	8.097; 9.034	-	5.5	7.7	± 10.8
Sum of measurements (S), mm	0.582	< 0.001	$BM_{31} = 0.535 \times S - 40.689$	0.492; 0.578	< 0.001	11.2	15.7	± 22.0	$BM_{31} = 0.920 \times S - 121.350$	0.878; 0.964	-	13.2	18.4	± 25.8
Cross-sectional area (A), cm^2	0.577	< 0.001	$BM_{31} = 3.913 \times A + 25.675$	3.594; 4.233	< 0.001	11.3	15.7	± 22.1	$BM_{31} = 6.779 \times A - 7.978$	6.467; 7.106	-	4.9	6.8	± 9.5
Volume (V), cm^3	0.578	< 0.001	$BM_{31} = 1.206 \times V + 32.913$	1.108; 1.305	< 0.001	11.3	15.7	± 22.1	$BM_{31} = 2.087 \times V + 4.671$	1.991; 2.187	-	8.8	12.3	± 17.2
Male (n = 513)														
Mean width (W), mm	0.325	< 0.001	$BM_{31} = 1.077 \times W + 29.754$	0.805; 1.349	< 0.001	10.6	13.2	± 20.7	$BM_{31} = 3.314 \times W - 74.372$	3.053; 3.598	-	7.1	8.9	± 14.0
Mean depth (D), mm	0.380	< 0.001	$BM_{31} = 1.680 \times D + 19.130$	1.325; 2.035	< 0.001	10.3	12.9	± 20.2	$BM_{31} = 4.416 \times D - 79.795$	4.076; 4.786	-	5.9	7.4	± 11.6
Mean height (H), mm	0.191	< 0.001	$BM_{31} = 1.419 \times H + 40.283$	0.784; 2.055	< 0.001	11.0	13.7	± 21.5	$BM_{31} = 7.448 \times H - 127.976$	6.839; 8.110	-	5.2	6.5	± 10.2
Sum of measurements (S), mm	0.391	< 0.001	$BM_{31} = 0.363 \times S - 0.525$	0.289; 0.438	< 0.001	10.3	12.9	± 20.2	$BM_{31} = 0.931 \times S - 126.013$	0.859; 1.008	-	12.8	16.0	± 25.1
Cross-sectional area (A), cm^2	0.385	< 0.001	$BM_{31} = 2.477 \times A + 47.032$	1.962; 2.994	< 0.001	10.3	12.9	± 20.2	$BM_{31} = 6.432 \times A - 5.424$	5.937; 6.968	-	4.9	6.1	± 9.6
Volume (V), cm^3	0.396	< 0.001	$BM_{31} = 0.775 \times V + 51.157$	0.619; 0.931	< 0.001	10.3	12.8	± 20.1	$BM_{31} = 1.956 \times V + 7.336$	1.806; 2.119	-	8.8	11.0	± 17.2
Female (n = 645)														
Mean width (W), mm	0.284	< 0.001	$BM_{31} = 1.196 \times W + 15.456$	0.883; 1.509	< 0.001	11.5	17.8	± 22.6	$BM_{31} = 4.216 \times W - 109.683$	3.914; 4.540	-	7.0	10.8	± 13.8
Mean depth (D), mm	0.304	< 0.001	$BM_{31} = 1.616 \times D + 12.920$	1.224; 2.008	< 0.001	11.5	17.6	± 22.5	$BM_{31} = 5.315 \times D - 106.377$	4.937; 5.721	-	6.2	9.5	± 12.1
Mean height (H), mm	0.093	0.019	$BM_{31} = 0.753 \times H + 44.954$	0.126; 1.381	0.019	12.0	18.4	± 23.5	$BM_{31} = 8.140 \times H - 151.916$	7.536; 8.792	-	5.7	8.7	± 11.1
Sum of measurements (S), mm	0.323	< 0.001	$BM_{31} = 0.383 \times S - 11.928$	0.296; 0.471	< 0.001	11.4	17.5	± 22.3	$BM_{31} = 1.188 \times S - 173.366$	1.104; 1.278	-	12.9	19.8	± 25.2
Cross-sectional area (A), cm^2	0.325	< 0.001	$BM_{31} = 2.982 \times A + 33.639$	2.310; 3.654	< 0.001	11.4	17.5	± 22.3	$BM_{31} = 9.170 \times A - 31.521$	8.523; 9.866	-	4.6	7.1	± 9.1
Volume (V), cm^3	0.312	< 0.001	$BM_{31} = 0.918 \times V + 39.237$	0.701; 1.135	< 0.001	11.4	17.6	± 22.4	$BM_{31} = 2.942 \times V - 17.640$	2.734; 3.167	-	8.2	12.7	± 16.1

CI = Confidence interval, OLS = Ordinary least squares regression, P = P value, PI = Prediction interval (in kilograms), R = Pearson's correlation coefficient, RMA = Reduced major axis regression, SEE = Standard error of the estimate (in kilograms).
*RMA slope estimates cannot be tested for significance.

Table 3. Regression formulae for body mass at age 46 (BM_{46}, in kilograms) from linear regression models among the full sample.

L4 parameter	Correlation		OLS regression						RMA regression					
	R	P	Regression formula	95% CI for slope	P for slope	SEE for model	%SEE for model	95% PI for model	Regression formula	95% CI for slope	P for slope*	SEE for model	%SEE for model	95% PI for model
All (n = 1158)														
Mean width (W), mm	0.481	< 0.001	$BM_{46} = 1.846 \times W – 2.708$	1.652; 2.040	< 0.001	13.5	17.3	± 26.4	$BM_{46} = 3.839 \times W – 89.794$	3.649; 4.038	-	8.0	10.2	± 15.6
Mean depth (D), mm	0.508	< 0.001	$BM_{46} = 2.538 \times D – 8.273$	2.290; 2.787	< 0.001	13.2	17.0	± 25.9	$BM_{46} = 4.994 \times D – 91.729$	4.752; 5.249	-	6.8	8.7	± 13.4
Mean height (H), mm	0.289	< 0.001	$BM_{46} = 2.750 \times H + 3.153$	2.224; 3.276	< 0.001	14.7	18.8	± 28.8	$BM_{46} = 9.518 \times H – 180.985$	9.006; 10.058	-	7.1	9.1	± 13.9
Sum of measurements (S), mm	0.527	< 0.001	$BM_{46} = 0.539 \times S – 35.173$	0.489; 0.590	< 0.001	13.0	16.7	± 25.6	$BM_{46} = 1.024 \times S – 136.753$	0.975; 1.075	-	14.8	18.9	± 28.9
Cross-sectional area (A), cm^2	0.520	< 0.001	$BM_{46} = 3.926 \times A + 31.886$	3.555; 4.298	< 0.001	13.1	16.8	± 25.7	$BM_{46} = 7.544 \times A – 10.589$	7.181; 7.924	-	5.5	7.0	± 10.7
Volume (V), cm^3	0.522	< 0.001	$BM_{46} = 1.213 \times V + 39.085$	1.098; 1.327	< 0.001	13.1	16.8	± 25.7	$BM_{46} = 2.322 \times V + 3.486$	2.211; 2.439	-	9.8	12.6	± 19.3
Male (n = 513)														
Mean width (W), mm	0.272	< 0.001	$BM_{46} = 1.011 \times W + 39.054$	0.700; 1.323	< 0.001	12.1	14.0	± 23.7	$BM_{46} = 3.724 \times W – 87.212$	3.425; 4.048	-	7.9	9.1	± 15.4
Mean depth (D), mm	0.354	< 0.001	$BM_{46} = 1.757 \times D + 22.614$	1.353; 2.160	< 0.001	11.7	13.6	± 23.0	$BM_{46} = 4.963 \times D – 93.306$	4.576; 5.382	-	6.4	7.4	± 12.6
Mean height (H), mm	0.153	< 0.001	$BM_{46} = 1.282 \times H + 50.347$	0.563; 2.001	< 0.001	12.4	14.4	± 24.3	$BM_{46} = 8.369 \times H – 147.446$	7.681; 9.118	-	5.6	6.6	± 11.1
Sum of measurements (S), mm	0.340	< 0.001	$BM_{46} = 0.356 \times S + 7.460$	0.270; 0.441	< 0.001	11.8	13.7	± 23.1	$BM_{46} = 1.046 \times S – 145.240$	0.964; 1.135	-	14.1	16.4	± 27.6
Cross-sectional area (A), cm^2	0.338	< 0.001	$BM_{46} = 2.443 \times A + 53.717$	1.853; 3.036	< 0.001	11.8	13.7	± 23.2	$BM_{46} = 7.227 \times A – 9.737$	6.660; 7.842	-	5.4	6.2	± 10.5
Volume (V), cm^3	0.340	< 0.001	$BM_{46} = 0.748 \times V + 58.371$	0.569; 0.928	< 0.001	11.8	13.7	± 23.1	$BM_{46} = 2.198 \times V + 4.601$	2.026; 2.385	-	9.7	11.3	± 19.1
Female (n = 645)														
Mean width (W), mm	0.265	< 0.001	$BM_{46} = 1.325 \times W + 16.577$	0.952; 1.698	< 0.001	13.8	19.2	± 27.0	$BM_{46} = 4.996 \times W – 135.541$	4.637; 5.383	-	7.7	10.8	± 15.2
Mean depth (D), mm	0.273	< 0.001	$BM_{46} = 1.721 \times D + 16.014$	1.251; 2.190	< 0.001	13.7	19.2	± 26.9	$BM_{46} = 6.298 \times D – 131.624$	5.846; 6.785	-	6.9	9.6	± 13.4
Mean height (H), mm	0.114	0.004	$BM_{46} = 1.099 \times H + 42.205$	0.357; 1.842	0.004	14.2	19.8	± 27.8	$BM_{46} = 9.646 \times H – 185.590$	8.933; 10.417	-	6.1	8.6	± 12.0
Sum of measurements (S), mm	0.305	< 0.001	$BM_{46} = 0.429 \times S – 14.630$	0.325; 0.533	< 0.001	13.6	19.0	± 26.6	$BM_{46} = 1.408 \times S – 211.010$	1.308; 1.515	-	14.2	19.8	± 27.8
Cross-sectional area (A), cm^2	0.299	< 0.001	$BM_{46} = 3.253 \times A + 37.260$	2.449; 4.055	< 0.001	13.6	19.0	± 26.7	$BM_{46} = 10.867 \times A – 42.915$	10.094; 11.699	-	5.1	7.2	± 10.0
Volume (V), cm^3	0.299	< 0.001	$BM_{46} = 1.044 \times V + 42.178$	0.786; 1.301	< 0.001	13.6	19.0	± 26.7	$BM_{46} = 3.487 \times V – 26.466$	3.239; 3.754	-	9.0	12.6	± 17.7

CI = Confidence interval, OLS = Ordinary least squares regression, P = P value, PI = Prediction interval (in kilograms), R = Pearson's correlation coefficient, RMA = Reduced major axis regression, SEE = Standard error of the estimate (in kilograms).
*RMA slope estimates cannot be tested for significance.

Table 4. Regression formulae for body mass at age 31 (BM_{31}, in kilograms) from linear regression models among individuals with normal body mass index (18.5—24.9 kg/m^2).

L4 parameter	Correlation		OLS regression						RMA regression					
	R	P	Regression formula	95% CI for slope	P for slope	SEE for model	%SEE for model	95% PI for model	Regression formula	95% CI for slope	P for slope*	SEE for model	%SEE for model	95% PI for model
All (n = 420)														
Mean width (W), mm	0.635	< 0.001	BM_{31} = 1.388 × W + 3.662	1.226; 1.550	< 0.001	6.3	10.0	± 12.4	BM_{31} = 2.184 × W – 30.519	2.028; 2.352	-	4.7	7.5	± 9.3
Mean depth (D), mm	0.622	< 0.001	BM_{31} = 1.855 × D + 1.368	1.631; 2.080	< 0.001	6.4	10.1	± 12.6	BM_{31} = 2.981 × D – 36.194	2.765; 3.214	-	4.1	6.5	± 8.1
Mean height (H), mm	0.406	< 0.001	BM_{31} = 2.054 × H + 7.429	1.610; 2.499	< 0.001	7.5	11.8	± 14.7	BM_{31} = 5.055 × H – 74.103	4.630; 5.519	-	4.0	6.3	± 7.8
Sum of measurements (S), mm	0.687	< 0.001	BM_{31} = 0.407 × S – 21.016	0.366; 0.449	< 0.001	6.0	9.4	± 11.7	BM_{31} = 0.592 × S – 59.343	0.553; 0.635	-	8.4	13.3	± 16.5
Cross-sectional area (A), cm^2	0.670	< 0.001	BM_{31} = 3.010 × A + 29.211	2.689; 3.331	< 0.001	6.1	9.6	± 11.9	BM_{31} = 4.493 × A + 12.430	4.184; 4.825	-	3.1	5.0	± 6.2
Volume (V), cm^3	0.686	< 0.001	BM_{31} = 0.938 × V + 34.318	0.842; 1.034	< 0.001	6.0	9.4	± 11.7	BM_{31} = 1.367 × V + 21.069	1.275; 1.466	-	5.6	8.8	± 10.9
Male (n = 146)														
Mean width (W), mm	0.400	< 0.001	BM_{31} = 0.766 × W + 35.606	0.477; 1.055	< 0.001	6.1	8.6	± 11.9	BM_{31} = 1.914 × W – 17.158	1.647; 2.224	-	5.3	7.4	± 10.3
Mean depth (D), mm	0.409	< 0.001	BM_{31} = 1.201 × D + 28.148	0.759; 1.642	< 0.001	6.1	8.6	± 11.9	BM_{31} = 2.936 × D – 33.516	2.527; 3.410	-	4.2	5.9	± 8.3
Mean height (H), mm	0.260	0.002	BM_{31} = 1.130 × H + 39.253	0.440; 1.820	0.002	6.4	9.0	± 12.6	BM_{31} = 4.342 × H – 50.480	3.706; 5.087	-	3.9	5.5	± 7.6
Sum of measurements (S), mm	0.459	< 0.001	BM_{31} = 0.258 × S + 14.455	0.175; 0.340	< 0.001	5.9	8.3	± 11.6	BM_{31} = 0.561 × S – 52.084	0.485; 0.650	-	9.2	13.0	± 18.1
Cross-sectional area (A), cm^2	0.440	< 0.001	BM_{31} = 1.770 × A + 48.034	1.175; 2.366	< 0.001	6.0	8.4	± 11.7	BM_{31} = 4.026 × A + 18.981	3.475; 4.666	-	3.5	4.9	± 6.9
Volume (V), cm^3	0.462	< 0.001	BM_{31} = 0.559 × V + 50.659	0.383; 0.736	< 0.001	5.9	8.3	± 11.5	BM_{31} = 1.210 × V + 27.222	1.046; 1.399	-	6.3	8.8	± 12.3
Female (n = 274)														
Mean width (W), mm	0.395	< 0.001	BM_{31} = 0.815 × W + 25.556	0.589; 1.041	< 0.001	5.3	8.9	± 10.3	BM_{31} = 2.061 × W – 25.964	1.848; 2.300	-	4.4	7.4	± 8.6
Mean depth (D), mm	0.367	< 0.001	BM_{31} = 0.943 × D + 28.872	0.658; 1.228	< 0.001	5.3	9.0	± 10.5	BM_{31} = 2.567 × D – 23.430	2.298; 2.868	-	4.0	6.8	± 7.9
Mean height (H), mm	0.243	< 0.001	BM_{31} = 0.913 × H + 34.783	0.477; 1.349	< 0.001	5.6	9.4	± 10.9	BM_{31} = 3.764 × H – 41.517	3.353; 4.225	-	3.6	6.1	± 7.1
Sum of measurements (S), mm	0.452	< 0.001	BM_{31} = 0.256 × S + 7.842	0.196; 0.316	< 0.001	5.1	8.6	± 10.0	BM_{31} = 0.566 × S – 54.491	0.509; 0.630	-	8.0	13.5	± 15.6
Cross-sectional area (A), cm^2	0.421	< 0.001	BM_{31} = 1.868 × A + 39.643	1.388; 2.349	< 0.001	5.2	8.8	± 10.2	BM_{31} = 4.441 × A + 12.693	3.986; 4.947	-	2.9	5.0	± 5.7
Volume (V), cm^3	0.445	< 0.001	BM_{31} = 0.616 × V + 41.907	0.468; 0.765	< 0.001	5.1	8.7	± 10.1	BM_{31} = 1.385 × V + 20.323	1.245; 1.541	-	5.1	8.7	± 10.1

CI = Confidence interval, OLS = Ordinary least squares regression, P = P value, PI = Prediction interval (in kilograms), R = Pearson's correlation coefficient, RMA = Reduced major axis regression, SEE = Standard error of the estimate (in kilograms).

*RMA slope estimates cannot be tested for significance.

Table 5. Regression formulae for body mass at age 46 (BM_{46}, in kilograms) from linear regression models among individuals with normal body mass index (18.5—24.9 kg/m^2).

L4 parameter	Correlation		OLS regression						RMA regression					
	R	P	Regression formula	95% CI for slope	P for slope	SEE for model	%SEE for model	95% PI for model	Regression formula	95% CI for slope	P for slope*	SEE for model	%SEE for model	95% PI for model
All (n = 420)														
Mean width (W), mm	0.621	< 0.001	$BM_{46} = 1.403 \times W + 6.024$	1.233; 1.574	< 0.001	6.7	10.0	± 13.1	$BM_{46} = 2.261 \times W - 30.809$	2.097; 2.438	-	4.9	7.4	± 9.6
Mean depth (D), mm	0.639	< 0.001	$BM_{46} = 1.973 \times D + 0.452$	1.745; 2.201	< 0.001	6.5	9.9	± 12.8	$BM_{46} = 3.087 \times D - 36.685$	2.867; 3.323	-	4.1	6.2	± 8.0
Mean height (H), mm	0.433	< 0.001	$BM_{46} = 2.264 \times H + 4.756$	1.810; 2.718	< 0.001	7.7	11.6	± 15.0	$BM_{46} = 5.234 \times H - 75.931$	4.800; 5.707	-	4.0	6.0	± 7.8
Sum of measurements (S), mm	0.692	< 0.001	$BM_{46} = 0.425 \times S - 21.582$	0.382; 0.467	< 0.001	6.1	9.2	± 12.0	$BM_{46} = 0.613 \times S - 60.650$	0.572; 0.657	-	8.5	12.8	± 16.7
Cross-sectional area (A), cm^2	0.670	< 0.001	$BM_{46} = 3.117 \times A + 31.019$	2.784; 3.449	< 0.001	6.3	9.5	± 12.4	$BM_{46} = 4.652 \times A + 13.655$	4.332; 4.996	-	3.2	4.8	± 6.3
Volume (V), cm^3	0.696	< 0.001	$BM_{46} = 0.985 \times V + 35.891$	0.887; 1.083	< 0.001	6.1	9.2	± 12.0	$BM_{46} = 1.416 \times V + 22.599$	1.321; 1.517	-	5.6	8.4	± 10.9
Male (n = 146)														
Mean width (W), mm	0.344	< 0.001	$BM_{46} = 0.679 \times W + 43.057$	0.374; 0.985	< 0.001	6.4	8.7	± 12.6	$BM_{46} = 1.976 \times W - 16.541$	1.694; 2.305	-	5.6	7.5	± 10.9
Mean depth (D), mm	0.398	< 0.001	$BM_{46} = 1.208 \times D + 31.364$	0.750; 1.666	< 0.001	6.3	8.5	± 12.3	$BM_{46} = 3.031 \times D - 33.429$	2.607; 3.523	-	4.3	5.8	± 8.5
Mean height (H), mm	0.293	< 0.001	$BM_{46} = 1.313 \times H + 37.608$	0.607; 2.019	< 0.001	6.5	8.8	± 12.8	$BM_{46} = 4.482 \times H - 50.943$	3.832; 5.243	-	3.8	5.2	± 7.5
Sum of measurements (S), mm	0.430	< 0.001	$BM_{46} = 0.249 \times S + 19.735$	0.163; 0.335	< 0.001	6.2	8.3	± 12.1	$BM_{46} = 0.580 \times S - 52.598$	0.499; 0.672	-	9.6	12.9	± 18.8
Cross-sectional area (A), cm^2	0.399	< 0.001	$BM_{46} = 1.657 \times A + 52.953$	1.030; 2.286	< 0.001	6.3	8.5	± 12.3	$BM_{46} = 4.157 \times A + 20.768$	3.576; 4.832	-	3.7	5.0	± 7.2
Volume (V), cm^3	0.440	< 0.001	$BM_{46} = 0.748 \times V + 58.371$	0.365; 0.735	< 0.001	6.1	8.3	± 12.1	$BM_{46} = 1.249 \times V + 29.275$	1.078; 1.447	-	6.5	8.7	± 12.7
Female (n = 274)														
Mean width (W), mm	0.380	< 0.001	$BM_{46} = 0.785 \times W + 29.567$	0.557; 1.013	< 0.001	5.3	8.6	± 10.4	$BM_{46} = 2.067 \times W - 23.406$	1.851; 2.308	-	4.5	7.2	± 8.7
Mean depth (D), mm	0.409	< 0.001	$BM_{46} = 1.053 \times D + 28.102$	0.773; 1.333	< 0.001	5.3	8.5	± 10.3	$BM_{46} = 2.574 \times D - 20.865$	2.309; 2.870	-	3.9	6.3	± 7.6
Mean height (H), mm	0.281	< 0.001	$BM_{46} = 1.059 \times H + 33.657$	0.627; 1.491	< 0.001	5.5	8.9	± 10.8	$BM_{46} = 3.774 \times H - 38.999$	3.366; 4.231	-	3.6	5.7	± 7.0
Sum of measurements (S), mm	0.474	< 0.001	$BM_{46} = 0.269 \times S + 8.043$	0.209; 0.329	< 0.001	5.1	8.2	± 9.9	$BM_{46} = 0.568 \times S - 51.907$	0.511; 0.631	-	7.8	12.6	± 15.4
Cross-sectional area (A), cm^2	0.438	< 0.001	$BM_{46} = 1.950 \times A + 41.570$	1.472; 2.427	< 0.001	5.2	8.3	± 10.1	$BM_{46} = 4.452 \times A + 15.352$	4.000; 4.956	-	2.9	4.7	± 5.7
Volume (V), cm^3	0.479	< 0.001	$BM_{46} = 0.665 \times V + 43.323$	0.520; 0.811	< 0.001	5.1	8.1	± 9.9	$BM_{46} = 1.389 \times V + 23.002$	1.251; 1.542	-	5.0	8.0	± 9.8

CI = Confidence interval, OLS = Ordinary least squares regression, P = P value, PI = Prediction interval (in kilograms), R = Pearson's correlation coefficient, RMA = Reduced major axis regression, SEE = Standard error of the estimate (in kilograms).

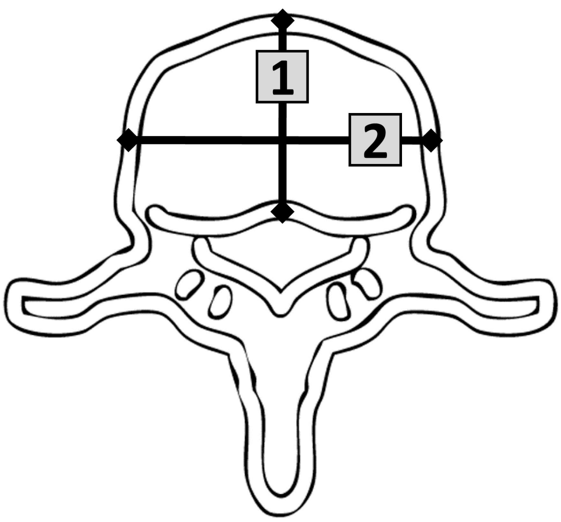
*RMA slope estimates cannot be tested for significance.

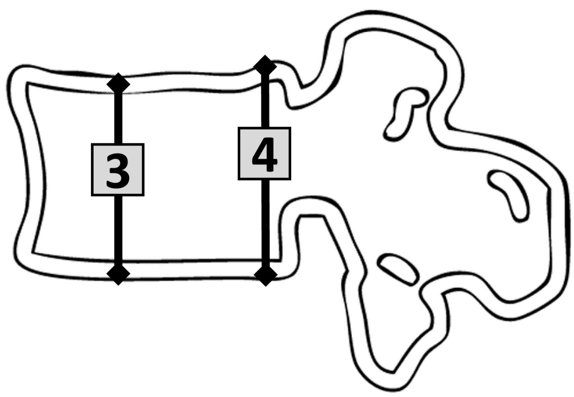
LEGENDS TO FIGURES

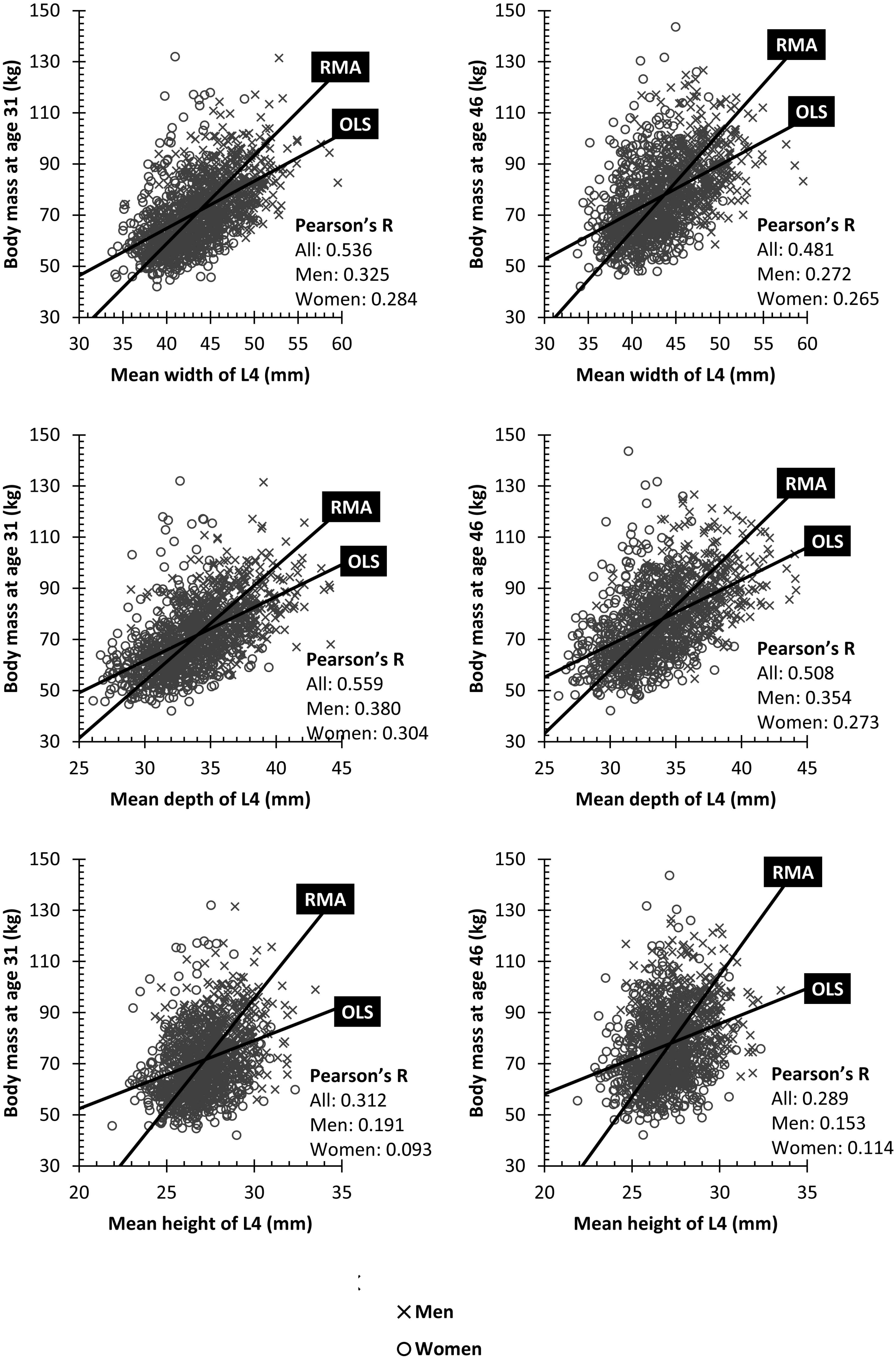
Fig. 1 Measured L4 dimensions: Maximum and minimum widths (1), depths (2), and heights (3—4).

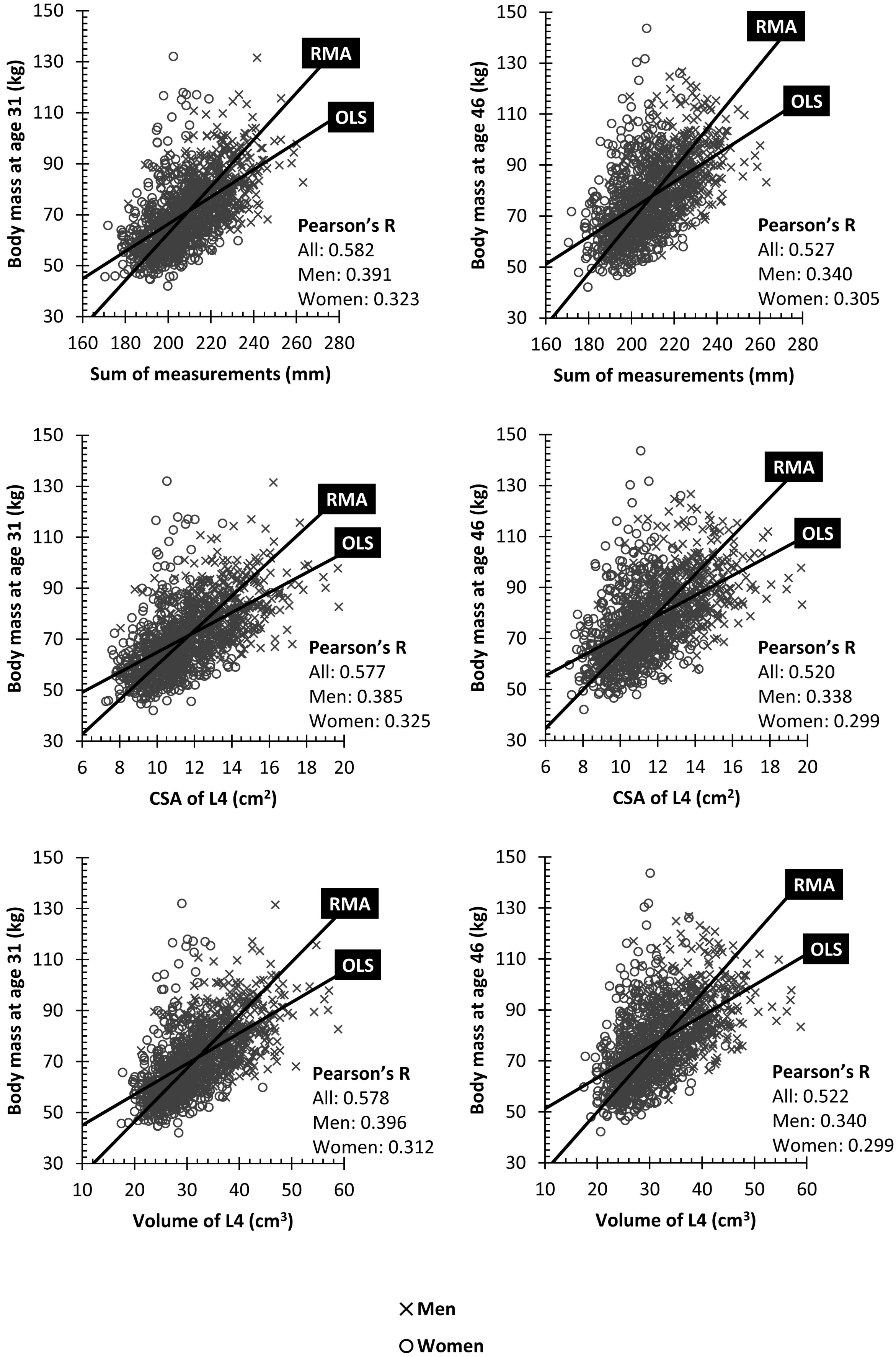
Fig. 2 Scatter plots demonstrating the correlation of the mean width, depth and height of L4 with body mass among the full sample. RMA = Reduced major axis regression line, OLS = Ordinary least squares regression line.

Fig. 3 Scatter plots demonstrating the correlation between L4 parameters and body mass among the full sample. RMA = Reduced major axis regression line, OLS = Ordinary least squares regression line.


1
2


3
4


Body mass at age 31 (kg)
Mean width of L4 (mm)
RMA
OLS
Pearson's R
All: 0.536
Men: 0.325
Women: 0.284
Body mass at age 46 (kg)
Mean width of L4 (mm)
RMA
OLS
Pearson's R
All: 0.481
Men: 0.272
Women: 0.265
Body mass at age 31 (kg)
Mean depth of L4 (mm)
RMA
OLS
Pearson's R
All: 0.559
Men: 0.380
Women: 0.304
Body mass at age 46 (kg)
Mean depth of L4 (mm)
RMA
OLS
Pearson's R
All: 0.508
Men: 0.354
Women: 0.273
Body mass at age 31 (kg)
Mean height of L4 (mm)
RMA
OLS
Pearson's R
All: 0.312
Men: 0.191
Women: 0.093
Body mass at age 46 (kg)
Mean height of L4 (mm)
RMA
OLS
Pearson's R
All: 0.289
Men: 0.153
Women: 0.114
Men
Women



Body mass at age 31 (kg)
Body mass at age 46 (kg)
RMA
OLS
Pearson's R
All: 0.582
Men: 0.391
Women: 0.323
All: 0.527
Men: 0.340
Women: 0.305
Sum of measurements (mm)
All: 0.577
Men: 0.385
Women: 0.325
All: 0.520
Men: 0.338
Women: 0.299
CSA of L4 (cm²)
All: 0.578
Men: 0.396
Women: 0.312
All: 0.522
Men: 0.340
Women: 0.299
Volume of L4 (cm³)
Men
Women