

Full Length Article

Changes in vertebral dimensions in early adulthood – A 10-year follow-up MRI-study



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ABSTRACT

Previous studies have shown that vertebral height increases until the early twenties, but very few studies have been conducted on other vertebral dimensions. Growth in vertebral size is believed to take place in elderly age but not in early adulthood. In this study, we wanted to clarify the potential changes in the dimensions of the lumbar vertebrae during early adulthood. We used the Northern Finland Birth Cohort 1986 as our study material, with a final sample size of 375 individuals. We performed lumbar magnetic resonance imaging (MRI) when the participants were 20 and 30 years of age (baseline and follow-up, respectively). We recorded the width, depth, height, and cross-sectional area (CSA) of the fourth lumbar vertebra (L4) using the MRI scans. We used generalized estimating equation (GEE) models to analyse the data. Men had 7.6%–26.5% larger vertebral dimensions than women at both baseline and follow-up. The GEE models demonstrated that all the studied dimensions increased during the follow-up period among both sexes ($p < 0.001$). Men had a higher growth rate in vertebral depth and CSA than women ($p < 0.001$). Among women, small vertebral width ($p = 0.001$), depth ($p = 0.05$) and height ($p = 0.02$) at baseline were associated with a higher vertebral growth rate during the follow-up than among those with large dimensions at baseline. Among men, small baseline width was associated with higher vertebral growth rate ($p = 0.001$). Our results clearly indicate that vertebral dimensions increase after 20 years of age among both sexes.

1. Introduction

Osteoporosis is a skeletal disorder that leads to increased fracture risk [1]. Bone mineral density (BMD) measurement is useful when vertebral fracture risk is evaluated [2]. Ruysen-Witrand et al. [1] concluded that smaller vertebrae have higher fracture risk, and thus the vertebral size may indicate the likelihood of the vertebral fracture. As bone geometry is linked to skeletal fragility [3], a better understanding of skeletal and vertebral growth would be beneficial for the prevention of osteoporotic fractures.

The sex differences in skeletal dimensions and biomechanical characteristics are clear. Women have smaller bones, vertebrae and

vertebral body cross-sectional areas (CSA) than men at all ages [3]. Women are also at higher risk for vertebral fractures and osteoporosis than men. The higher prevalence of osteoporotic vertebral fractures among females could be partly explained by smaller vertebral size [3]. Vertebral CSA could also protect against vertebral fractures, as the CSA increases among men as they age, but not among women [4]. Furthermore, studies have shown the vertebral CSA of the fourth lumbar vertebra (L4) among osteoporotic individuals to be significantly smaller than that of the controls, and the CSA to be even more reduced among osteoporotic women with vertebral fractures than osteoporotic women with no fractures [5].

How vertebral dimensions expand in early adulthood is rather

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poorly known. The vertebral height may increase due to continued growth at the growth plate [6]. Also, vertebral depth and width must increase due to periosteal apposition. However, Oura et al. [7,8] have shown that lifestyle factors, particularly physical exercise, in both childhood and adulthood, influence in vertebral changes in midlife. Among females, high impact sports were associated with larger vertebral CSA whereas among males, there was no such finding [8].

Skeletal maturation differs from one site to another [9], but generally, bone mass peaks in mid-thirties, regardless of the skeletal site or sex [10]. Peak bone mineral content (BMC) velocity appears approximately six months after peak height velocity, the latter taking place among girls at approximately 12 years and among boys at 13.5 years [9]. Interestingly, Walsh et al. [9] also found that lumbar vertebrae seem to keep growing longer than the actual individual's growth in stature is visible, and that an increase takes place over ten years after most of the lumbar spine bone mass has been reached.

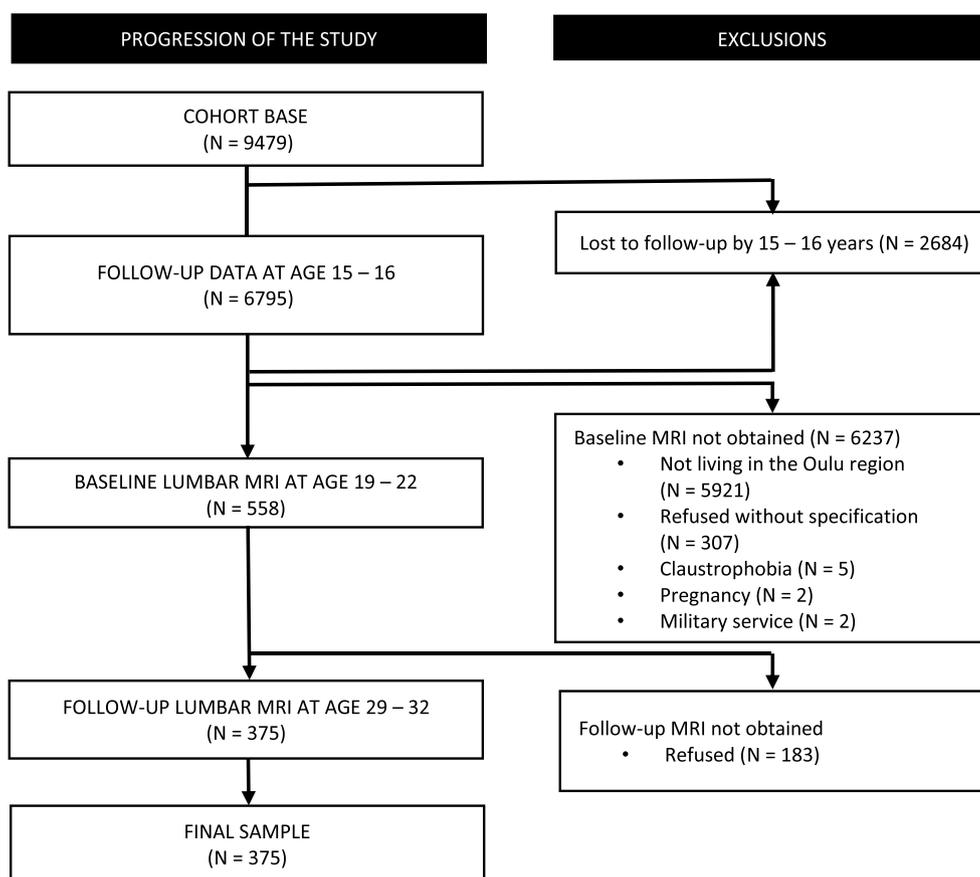
The aim of our study was to extend current knowledge of vertebral growth in early adulthood. We analysed whether the dimensions of the fourth lumbar vertebra modify between the ages of 20 and 30, using longitudinal magnetic resonance imaging (MRI) assessment. We also assessed the magnitude of potential modifications.

all the deliveries in the area at the time, and has been extensively followed ever since.

In 2001–2002, at the age of 15–16, all cohort members with known addresses ($n = 9215$) were invited to fill in questionnaires regarding their health and lifestyle habits and to attend clinical examinations. Questionnaire data was received from 7182 adolescents (78% of those invited) and clinical data from 6795 adolescents (74% of those invited).

In 2005–2008, at the age of 19–22, a subsample of the cohort ($n = 874$) was invited to participate in an MR scan of the lumbar spine. The subsample consisted of those who lived within a 100 km radius of the city of Oulu and had participated in the earlier follow-ups of the sub-cohort (Oulu Back Study). In all, 316 individuals did not participate in the study due to the reasons specified in the flow chart, thus a final total of 558 individuals (64% of those invited) underwent the baseline MRI scan.

In 2015–2017, at the age of 29–32, those who had attended baseline MRI a decade earlier were invited to a follow-up lumbar MR scan. Of those invited, 183 individuals did not participate (flow chart), thus 375 individuals underwent the follow-up MRI (43% of those originally invited to baseline MRI). The sample of the present study comprised 375 individuals who had undergone both MRI assessments.



2. Material and methods

2.1. Study population

The study populations consisted of a sub-cohort of the Northern Finland Birth Cohort 1986 (NFBC1986) which is a prospective, population-based birth cohort study [11]. A total of 9479 Northern Finnish children whose expected dates of birth fell between July 1, 1985 and June 30, 1986 belong to this cohort. The cohort initially covered 99% of

2.2. Magnetic resonance imaging of the lumbar spine

We performed the MRI of the lumbar spine using 1.5-T imaging. The scanner used in 2005–2008 (Signa HDxt, General Electric, Milwaukee, Wisconsin, USA) was replaced by a new scanner (Optima MR450w, General Electric, Milwaukee, Wisconsin, USA), which we used for 2015–2017 imaging. Imaging followed the routine lumbar spine protocol, including T2-weighted fast-recovery fast spin-echo images in sagittal and transverse planes [12]. Imaging parameters were as

Table 1
Measured vertebral dimensions.

| Measurement | Slice |
|-------------------------------|--|
| Superior width ^a | Superior ^d axial ^e slice |
| Superior depth ^b | Superior ^d axial ^e slice |
| Midway width ^a | Midaxial ^f slice |
| Midway depth ^b | Midaxial ^f slice |
| Inferior width ^a | Inferior ^f axial ^e slice |
| Inferior depth ^b | Inferior ^f axial ^e slice |
| Anterior height ^c | Midsagittal ^g slice |
| Posterior height ^c | Midsagittal ^g slice |
| Minimum height ^c | Midsagittal ^g slice |

^a Width = transverse dimension.
^b Depth = anterior-posterior dimension.
^c Height = inferior-superior dimension.
^d Superior = below the cranial endplate of L4.
^e Axial slices were parallel to the endplates of L4.
^f Inferior = above the caudal endplate of L4.
^g Sagittal slices were perpendicular to the endplates of L4.

follows: repetition time 3960 ms, echo time 116 ms, echo train length 29, number of excitations 4, acquisition matrix 448 × 224 px, field of view 280 × 280 mm, slice thickness 4 mm, and interslice gap 1 mm. Each MR scan was assessed for vertebral pathologies, but none were present in any scan. Our institution follows weekly quality assurance protocol for MRI scanners, including measurements for geometric accuracy.

2.2.1. Vertebral measurements

One researcher (P.O.), who was blinded to all the other data on the participants, systematically conducted the measurements using the NeaView Radiology software version 2.31 (Neagen Oy, Oulu, Finland).

Importantly, the two MR scans of each individual were assessed and measured independently from each other.

From each applicable MR scan, we recorded nine dimensions of the body of the fourth lumbar vertebra (L4) to an accuracy of 0.1 mm. The obtained measurements are summarized in Table 1 with annotated MR slices in Fig. 1. We also recorded exact ages at imaging.

The MRI scans had 5–6 axial slices and 6–7 sagittal slices of L4. The superior and inferior widths and depths of L4 were measured from the most superior and inferior slices next to the endplates. Correspondingly, the midway widths and depths were measured from the midaxial slice with equal distances to superior and inferior endplates of L4. The anterior, posterior and minimum heights were measured from the midsagittal slice, the plane which divided L4 into equally sized left and right parts.

The means of the obtained width, depth, and height measurements were calculated, and the averaged values were used in the analyses as the ‘width’, ‘depth’, and ‘height’ of L4. The means of several planes were used to control for the natural variety in vertebral shape across healthy individuals [13,14].

The axial CSA of L4 (mm²) was calculated using the previously validated [2,15] ellipsoid formula $CSA = \pi \times a / 2 \times b / 2$, in which a = vertebral width (mean of measured widths) and b = vertebral depth (mean of measured depths). We chose to investigate this parameter because 1) it substantially affects the weight-bearing capacity of the vertebra [5,16], 2) it is independently associated with vertebral fracture risk [1,3,17], and 3) it has been previously used in similar studies [8,18–23].

We chose L4 because 1) its caudal location in the spine exposes it to significant biomechanical loads [24], 2) it is more stable than L5 [24], 3) it seems to represent the other lumbar vertebrae well [21,25], and 4) it has been previously used in similar studies [8,18–23,26].

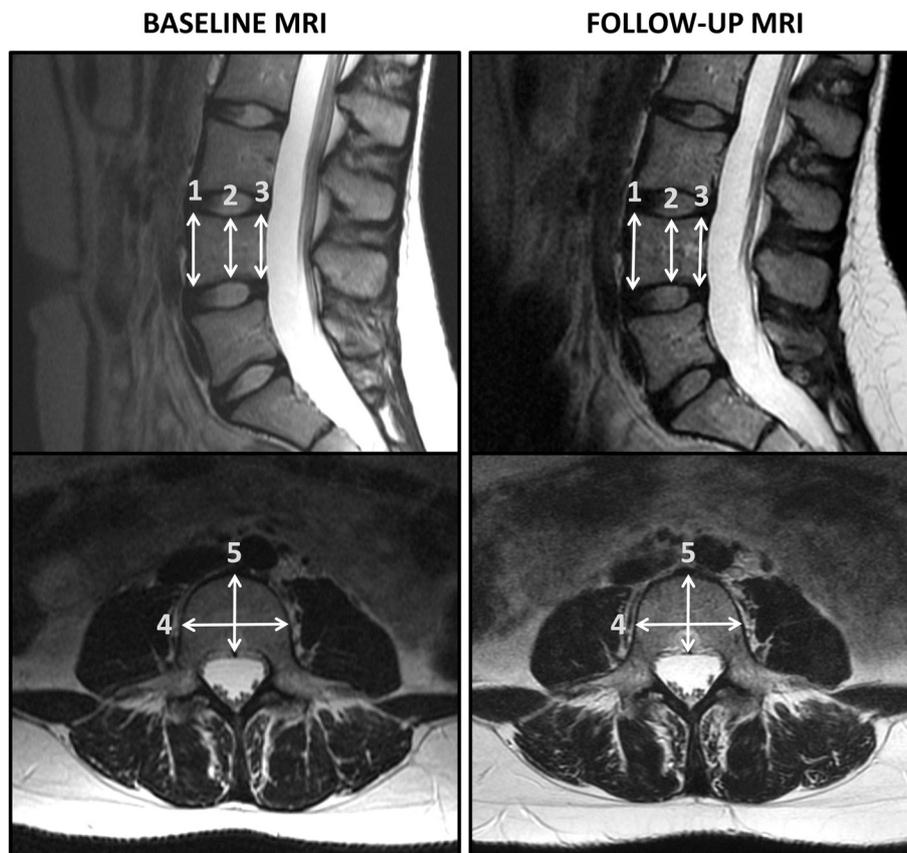


Fig. 1. Annotated MR scans of the same individual at age 21 (baseline MRI) and at age 30 (follow-up MRI). Above: Midsagittal scans with anterior height (1), minimum height (2) and posterior height (3) measurements marked on L4. Below: Midaxial scans of L4 with annotated width (4) and depth (5) measurements.

We have previously shown the high accuracy of MRI in estimating truthful vertebral dimensions [23].

2.2.2. Reliability of vertebral measurements

The reliability of the measurements was investigated by randomly choosing 20 MR scans (equivalent to 180 measurements) for reassessment. The original measurer retook the measurements under identical conditions after the initial measurement round. The measurements and the reassessments were thus conducted by the same researcher.

2.2.3. Anthropometry and lifestyle habits

At the 15/16-year follow-up, we used questionnaires and clinical examinations to gather data on the participants' height, weight, smoking habits, and physical activity. A trained study nurse systematically recorded the height and weight of the participants. Smoking habits were elicited using the question 'Do you currently smoke?' with the following response alternatives: 1) no, 2) occasionally, 3) on one day/week, 4) on 2–4 days/week, 5) on 5–6 days/week, 6) on 7 days/week. Those who did not report regular smoking (corresponding to response alternatives 1–2) were classed as 'non-smokers'. Physical activity level was elicited using the question 'How often do you exercise outside school hours for a period of at least 20 minutes?' with the following response alternatives: 1) never, 2) once/month or less often, 3) 2–3 times/month, 4) once/week, 5) 2 times/week, 6) 3 times/week, 7) 4–6 times/week, 8) daily. Those who reported exercising at least once a week (corresponding to response alternatives 4–8) were classed as 'active'.

2.3. Statistical analysis

We conducted statistical analyses using SPSS (IBM, Armonk, NY, USA) version 24, 64-bit edition. *p* values of < 0.05 were considered statistically significant.

Descriptive statistics were calculated for all applicable variables. We used frequencies and percentages for categorical variables. Means and standard deviations were used for continuous variables with normal distributions.

We further divided men and women into quartiles (Q1–Q4) according to their vertebral width, depth, height, and CSA at baseline MRI. For example, the men who had the smallest width dimension at baseline MRI were assigned to the first 'width quartile' (Q1). Each dimension had its own quartiles, which we also illustrate below in graphical format. The division into quartiles was made because we wanted to compare equally sized groups that were big enough for meaningful and systematic analyses. Quartiles proved to be the best division for our study.

We analysed the sex differences in vertebral dimensions at baseline and follow-up MRI using Student's independent samples *t*-test. The associations between body height, weight and vertebral dimensions were analysed using the Jonckheere–Terpstra test for trend [27] across the vertebral dimensions quartiles. It was hypothesized that an ascending trend would be observed in body height and weight from Q1 to Q4.

2.3.1. Longitudinal assessment of vertebral dimensions

We used generalized estimating equation (GEE) models to study the longitudinal vertebral dimension data. GEE is a regression-based model that is particularly suitable for the analysis of repeatedly measured or otherwise correlated data, and allows for flexible outcome distributions [28,29]. Vertebral width, depth, height, and CSA, all of which were fairly normally distributed among each sex, were separately analysed as longitudinal outcomes in the model. Sex, time, dimension quartiles, and their interaction terms were varyingly used as explanatory variables in the models. Each model is presented in the Results section. Apart from the analyses that specifically investigated sex differences in vertebral dimension slopes, all analyses were stratified by sex due to the significant sex discrepancy in vertebral size [24].

First, we tested whether any change had occurred in vertebral dimensions over the follow-up period. We analysed this by including the 'time' term in the models.

Second, we tested whether the sex differences in the growth rates of vertebral dimensions over the follow-up period were statistically significant. We analysed this by including the 'sex * time' interaction term in the models. The interaction term represented the difference in slopes between men and women [28]. The slopes were estimations of the average rate of change in vertebral dimensions across the follow-up period.

Third, we compared the quartiles of each dimension in terms of their rate of change over the follow-up period. For this purpose, we included a 'quartile * time' interaction term in the models. The interaction term denoted the difference between the slopes of the quartile groups [28].

We drew conclusions from the GEE models on the basis of the beta estimates (β) of the predictor terms and their 95% confidence intervals (CIs).

2.3.2. Measurement error and reliability

Using the repeated MR measurements, we assessed measurement error and intra-rater reliability. Following the guidelines set by the literature, we calculated the technical error of measurement (TEM) [30] and intra-class correlation coefficient (ICC) [31] for each dimension.

2.3.3. Analysis of representativeness

Due to the high exclusion rate of the study and the earlier findings that suggested minor selection bias [12,32], we investigated the representativeness of the present sample by comparing it to the general NFBC1986 population [11]. In the comparisons, we used Student's independent samples *t*-test for normally distributed continuous variables and the Chi squared test for categorical variables.

2.4. Ethical considerations

We obtained ethical approval from the Ethical Committee of the Northern Ostrobothnia Hospital District in Oulu, Finland. The study followed the principles of the Declaration of Helsinki. Written informed consent was collected from the study population and, where applicable, also their parents. All data were handled anonymously.

3. Results

3.1. Study sample

The present sample consisted of 147 men and 228 women who had undergone baseline MRI at the mean age of 21.3 years, and follow-up MRI at the mean age of 29.7 years (Table 2). The sample included more women (61% vs. 48%) and more male non-smokers (84% vs. 73%) than the rest of the NFBC1986 population. The women in the sample also weighed slightly less than the rest of the cohort (55.8 vs. 57.2 kg) (Table 2).

3.2. Vertebral dimensions

The mean widths, depths, heights, and CSAs of L4 are presented in Table 3 and Fig. 2. The measurement process showed an excellent intra-rater reliability (ICCs \geq 0.93) with low measurement errors (TEMs \leq 3.7%) (Supplementary Table 1). Men had generally larger vertebral width (~12%), depth (~12%), height (~8%), and CSA (~26%) than women in both MR scans (Table 3, Fig. 2).

According to the GEE models, all the studied dimensions increased over the follow-up period, regardless of sex and dimension quartile ($p < 0.001$) (Supplementary Tables 2, 3, Fig. 2). As regards the sex differences, the men's vertebral CSA ($p < 0.001$) and depth ($p = 0.001$) increased more steeply than those of the women. However,

Table 2
General characteristics of the sample (n = 375) and comparisons to the rest of the NFBC1986 population (n = 8848).

| Characteristic | Men | | | Women | | |
|--|-------------|-------------|----------------------|-------------|-------------|----------------------|
| | Sample | Excluded | p | Sample | Excluded | p |
| Sex ^a | 39.2 (147) | 52.1 (4612) | < 0.001 ^d | 60.8 (228) | 47.9 (4236) | < 0.001 ^d |
| MRI characteristics | | | | | | |
| Age ^b at baseline MRI (years) | 21.2 (0.6) | – | – | 21.3 (0.6) | – | – |
| Age ^b at follow-up MRI (years) | 30.5 (0.6) | – | – | 30.8 (0.5) | – | – |
| MRI interval ^b (years) | 9.3 (0.8) | – | – | 9.4 (0.7) | – | – |
| Anthropometry and smoking at age 16 ^c | | | | | | |
| Body height ^b (cm) | 175.3 (7.2) | 174.8 (6.8) | > 0.05 ^e | 163.9 (6.0) | 163.9 (5.9) | > 0.05 ^e |
| Body weight ^b (kg) | 66.0 (12.5) | 64.7 (12.6) | > 0.05 ^e | 55.8 (9.1) | 57.2 (10.0) | 0.04 ^e |
| Non-smokers ^a | 83.5 (66) | 72.7 (1562) | 0.03 ^d | 73.5 (100) | 67.6 (1600) | > 0.05 ^d |
| Physically active ^a | 84.4 (114) | 77.6 (2515) | > 0.05 ^d | 70.7 (152) | 73.5 (2519) | > 0.05 ^d |

BMI = body mass index, MRI = magnetic resonance imaging.

^a % (n).

^b Mean (standard deviation).

^c N varied due to missing data.

^d Chi square test.

^e Independent-samples t-test.

we detected no statistically significant differences in vertebral width and height (Supplementary Table 2, Fig. 2).

As regards the between-quartile differences, the vertebral width of men with the smallest vertebral width at baseline MRI (corresponding to Q1) increased over the follow-up period at a significantly higher rate than those with the largest width at baseline MRI (corresponding to Q4, p = 0.001) (Supplementary Table 3, Fig. 2). Similarly, the dimensions of women who were classed as having small width, depth, and height quartiles at baseline MRI increased at a higher rate than those in the largest quartiles (p < 0.05) (Supplementary Table 3, Fig. 2). However, despite these differences, the growth rate of vertebral CSA did not differ between any of the quartiles (Supplementary Table 3, Fig. 2). Mean body heights and weights are presented across the quartiles in Table 4. Generally, body size showed an upward trend across the vertebral dimensions quartiles.

4. Discussion

Our results clearly demonstrated some modifications in vertebral

dimensions between the ages of 20 and 30. Vertebral dimensions evidently tend to increase until late adulthood. We believe that the observed increase may be associated with normal growth.

This study posed three major research questions. First, we wanted to know if the L4 vertebra grows between the ages of 20 and 30, and the results showed a clear increase in all the observed measurements in both sexes. Interestingly, we detected some differences between men and women that answered our second question. We found that vertebral CSA and depth increases more among men than among women. Our third goal was to detect whether the size of a vertebra at the age of 20 affects its growth rate. We observed that a small vertebral size at baseline predicted larger growth in some of our measurements, but not in the CSA.

The persistent growth was one of the main reasons we became interested in studying L4 vertebra and its dimensional changes in adulthood.

Vertebral depth and width must increase due to periosteal apposition. This is believed to be regulated by IGF-I and testosterone. This might help explain why the increases are greater in men than women

Table 3
Dimensions of L4 among the study population (n = 375).

| Dimension | Baseline MRI | | | Follow-up MRI | | |
|-------------------------------------|----------------|-----------------|----------------|----------------|-----------------|----------------|
| | Men (n = 147) | Women (n = 228) | Sex difference | Men (n = 147) | Women (n = 228) | Sex difference |
| Width ^a (mm) | 45.7 (3.4) | 40.7 (2.7) | 12.3% | 46.9 (3.3) | 41.8 (2.5) | 12.2% |
| Q1 | 41.6 (1.2) | 37.5 (1.0) | | 45.7 (1.4) | 38.9 (1.3) | |
| Q2 | 44.5 (0.7) | 39.8 (0.4) | | 47.7 (0.9) | 41.0 (1.1) | |
| Q3 | 46.7 (0.7) | 41.4 (0.5) | | 51.0 (2.5) | 42.6 (0.9) | |
| Q4 | 50.2 (2.3) | 44.3 (1.4) | | 51.0 (2.5) | 44.8 (1.5) | |
| Depth ^a (mm) | 33.4 (2.3) | 29.8 (1.9) | 12.1% | 34.9 (2.3) | 31.0 (2.0) | 12.6% |
| Q1 | 30.5 (1.2) | 27.4 (1.0) | | 32.2 (1.4) | 28.7 (1.1) | |
| Q2 | 33.4 (0.4) | 29.3 (0.3) | | 34.3 (0.8) | 30.5 (1.0) | |
| Q3 | 35.0 (0.4) | 30.3 (0.3) | | 35.5 (1.1) | 31.6 (0.8) | |
| Q4 | 36.3 (1.2) | 32.3 (1.1) | | 37.7 (1.6) | 33.3 (1.3) | |
| Height ^a (mm) | 27.8 (1.7) | 25.8 (1.5) | 7.8% | 28.3 (1.7) | 26.3 (1.5) | 7.6% |
| Q1 | 25.7 (0.9) | 23.9 (0.6) | | 26.4 (1.2) | 24.6 (0.7) | |
| Q2 | 27.2 (0.3) | 25.3 (0.3) | | 27.6 (0.7) | 25.9 (0.6) | |
| Q3 | 28.3 (0.3) | 26.3 (0.3) | | 28.8 (0.8) | 26.8 (0.6) | |
| Q4 | 29.9 (1.0) | 27.6 (0.7) | | 30.4 (1.1) | 28.0 (0.9) | |
| CSA ^a (mm ²) | 1205.9 (154.6) | 955.5 (108.3) | 26.2% | 1291.2 (160.3) | 1020.5 (111.4) | 26.5% |
| Q1 | 1018.2 (52.1) | 820.3 (47.4) | | 1111.0 (67.5) | 887.9 (57.7) | |
| Q2 | 1148.3 (30.2) | 920.6 (21.8) | | 1238.1 (47.7) | 989.9 (49.5) | |
| Q3 | 1250.9 (27.5) | 987.4 (20.0) | | 1328.4 (54.3) | 1050.0 (40.7) | |
| Q4 | 1407.7 (102.2) | 1093.6 (64.3) | | 1492.7 (128.9) | 1154.2 (70.1) | |

CSA = cross-sectional area, MRI = magnetic resonance imaging, Q1–Q4 = Quartile 1–4.

^a Mean (standard deviation).

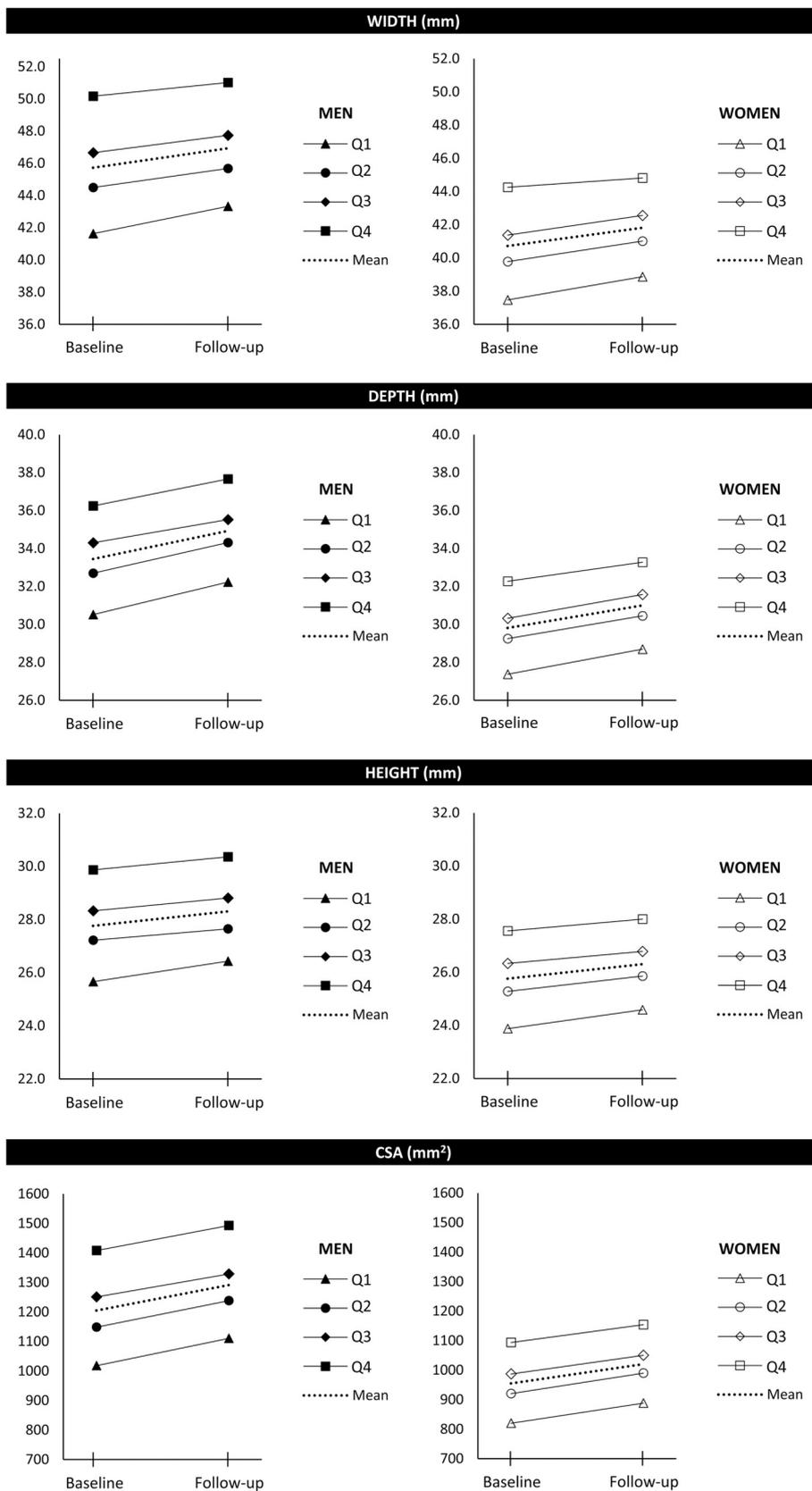


Fig. 2. Graphs illustrating the slopes (i.e., average rates of change) in vertebral dimensions over the follow-up period. Q1–Q4 = Quartiles 1–4.

[33,34].

The most outstanding strength of our study was the longitudinal MRI data from two time points. We had two MRI scans for each individual, which allowed us to measure the vertebral dimensions and

their changes over the follow-up decade. Three-dimensional imaging allowed us to precisely define changes in vertebral geometry.

The main limitation of this study was the relatively modest sample size (n = 375) and potential selection effect in representativeness.

Table 4
Mean body height and weight across vertebral width, depth, height, and CSA quartiles at baseline.

| Quartile | Men | | | | Women | | | |
|----------|-------------------------------|----------------|-------------------------------|----------------|-------------------------------|----------------|-------------------------------|----------------|
| | Body height ^a (cm) | p ^b | Body weight ^a (kg) | p ^b | Body height ^a (cm) | p ^b | Body weight ^a (kg) | p ^b |
| Width | | | | | | | | |
| Q1 | 170.5 (5.9) | | 60.7 (9.5) | | 160.4 (6.2) | | 52.4 (7.6) | |
| Q2 | 174.8 (5.3) | | 67.3 (13.0) | | 162.5 (5.8) | | 52.1 (6.6) | |
| Q3 | 175.7 (7.4) | | 63.8 (10.1) | | 165.9 (4.5) | | 57.9 (8.7) | |
| Q4 | 180.3 (6.7) | < 0.001 | 72.5 (14.1) | 0.001 | 166.6 (5.4) | < 0.001 | 60.7 (10.2) | < 0.001 |
| Depth | | | | | | | | |
| Q1 | 171.3 (5.5) | | 59.0 (7.4) | | 159.5 (6.0) | | 50.5 (6.2) | |
| Q2 | 173.4 (6.3) | | 63.5 (11.0) | | 163.1 (5.4) | | 54.7 (8.5) | |
| Q3 | 177.4 (6.4) | | 69.0 (12.8) | | 165.4 (5.2) | | 58.3 (8.5) | |
| Q4 | 178.9 (7.8) | < 0.001 | 72.4 (13.7) | < 0.001 | 167.4 (4.5) | < 0.001 | 59.7 (10.0) | < 0.001 |
| Height | | | | | | | | |
| Q1 | 171.7 (6.2) | | 66.7 (13.7) | | 160.5 (5.6) | | 54.0 (8.2) | |
| Q2 | 173.6 (6.8) | | 65.2 (10.7) | | 162.4 (6.0) | | 54.3 (8.6) | |
| Q3 | 176.2 (6.8) | | 66.6 (13.1) | | 164.9 (5.5) | | 55.5 (8.3) | |
| Q4 | 179.8 (6.3) | < 0.001 | 65.7 (12.6) | 0.922 | 167.9 (4.5) | < 0.001 | 59.4 (10.5) | 0.003 |
| CSA | | | | | | | | |
| Q1 | 171.0 (5.7) | | 59.4 (8.4) | | 159.2 (5.9) | | 51.1 (7.1) | |
| Q2 | 173.3 (6.3) | | 64.5 (12.3) | | 164.0 (5.7) | | 54.2 (8.1) | |
| Q3 | 176.4 (4.9) | | 67.2 (10.5) | | 164.4 (4.5) | | 55.8 (7.4) | |
| Q4 | 180.6 (7.8) | < 0.001 | 73.2 (14.2) | < 0.001 | 167.9 (4.6) | < 0.001 | 62.0 (9.9) | < 0.001 |

CSA = cross-sectional area, Q1–Q4 = Quartile 1–4.

^a Mean (standard deviation).

^b p value for trend across quartiles (Jonckheere–Terpstra test).

However, in view of the longitudinal study setting, we considered the sample size sufficient. As demonstrated by the analyses of representativeness, some selection inevitably occurred in our sample, and we acknowledge this as the main limitation of the study. However, the selection bias was rather mild [12,32] and we believe that the strengths of the study made up for this. We recognize the absence of non-extrapolated 3D analysis to be one limitation of this study as well. However, the fact that we have calculated the values of vertebral CSAs, instead of measuring them directly, has been shown to be accurate.

The fact that the women's L4 was smaller in vertebral width, depth, height and CSA than that of the men in both MRI scans is easy to understand, as men are generally larger than women. However, women also had smaller vertebral size in relation to their body size. We found that all the studied dimensions seemed to grow among both men and women over the follow-up period. This indicates that vertebral growth is likely to be a physiological event far into adulthood, potentially until peak bone mass is reached.

We discovered some differences between sexes. Men seemed to have a greater increase in vertebral depth and CSA than women. As we know that vertebral CSA suggests the likelihood of vertebral fracture, and that men have a smaller fracture risk than women, these two facts are likely to be linked [17]. The larger absolute CSA and the steeper increase in CSA in early adulthood are likely to contribute to the lower fracture risk among men. Men could thus potentially prevent vertebral fractures by increasing their vertebral CSA. In this sense, our results do not differ from previous studies [3]. We found no remarkable differences in growth rates in vertebral height and width between the sexes.

Our accurate results prove that vertebral dimensions clearly modify in early adulthood and that these changes are most detectable in the first quartile, i.e. in those individuals who have the smallest dimensions at the age of 20 years. In detail, this growth was most noticeable in vertebral width among males, and in depth, height and width among females, when comparing the smallest and largest quartiles (Q1 and Q4). It is however possible that in Q3 and Q4, both general and skeletal growth occur already before the age of 20. The division into quartiles enabled us to compare equally sized and relatively large groups.

Our findings establish a demand for further studies aiming to characterize factors that influence vertebral dimensions and their modifications in early adulthood. Further knowledge is needed on, for

instance, the association between physical activity and the growth of vertebral dimensions. A longitudinal study in particular would provide us with new information in this area.

Conflict of interest

The authors have no conflict of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.bone.2018.08.008>.

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