Age- and sex-related differences in vertebral bone marrow fat content in healthy adults from east China

qingping Li
Wenzhou Medical University Second Affiliated Hospital
shaoqing Chen
Wenzhou Medical University Second Affiliated Hospital
panpan Zhou
Zhejiang University School of Medicine
anna Guo
Wenzhou Medical University Second Affiliated Hospital
peipei Ye
Wenzhou Medical University Second Affiliated Hospital
yingying Huang
Wenzhou Medical University Second Affiliated Hospital
zhihan Yan
Wenzhou Medical University Second Affiliated Hospital
jiawei He (hejw505@163.com)
Wenzhou Medical University Second Affiliated Hospital

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Abstract

Background

Bone-marrow water–fat composition is a useful imaging biomarker. However, the vertebral bone-marrow fat composition in healthy adults of east China is unknown. The aim of this study was to investigate differences in lumbar vertebral bone-marrow fat content between the sexes with age, using iterative decomposition of water and fat with echo asymmetry and least-squares estimation quantitation (IDEAL-IQ).

Methods

Three-hundred-and-twenty-one healthy volunteers (age range 20–29 years: 32/33 men/women; 30–39 years: 40/37; 40–49 years: 21/45; 50–59 years: 26/37; ≥ 60 years: 15/26) were included in the present study. All subjects underwent IDEAL-IQ sequence imaging on a 3.0-T MR scanner. Bone-marrow fat-fraction ratio (FF%) was calculated for each vertebral body from sagittal lumbar images. Men and women were compared within age-groups by independent-samples *t* -tests, and different age-groups and vertebral segments were compared by Bonferroni post-hoc test. FF% correlations with age and body mass index (BMI) were analyzed with Spearman's correlation coefficient. FF% and vertebral segment correlations were assessed by partial correlation analysis, after adjustment for sex and age.

Results

FF% averaged over L1–L5 was significantly higher in men than in women for the < 40-year age-groups ($P = 0.000$). Bone-marrow fatty conversion was accelerated in women compared to men aged 40–49 years, but was similar in women and men aged > 60 years ($P > 0.05$). FF% correlation with age was weakly positive in men ($r = 0.253$, $P = 0.003$), and moderately positive in women ($r = 0.581$, $P < 0.001$), but was non-significantly correlated with BMI and vertebral segments ($r = 0.218$; $r = 0.187$, respectively). FF% was higher in the lower than in the upper lumbar segments ($P < 0.05$).

Conclusion

IDEAL-IQ can accurately quantify lumbar bone-marrow fat infiltration. This increases with age, and differs between men and women and between lower and upper lumbar segments.

Background

Bone-marrow is a non-mineralized bone component, there are 2 main types of bone-marrow include the yellow marrow region and the red marrow region. From childhood, an age-related increase in fat content occurs first in the peripheral and later in the axial skeleton, such as the spine [1]. Bone-marrow is the major hematopoietic organ and participates in skeletal and systemic metabolism. It is a dynamic organ with constant changes occurring during healthy aging, altered hematopoietic needs, as well as many pathological conditions. Therefore, an accurate understanding of the normal composition of vertebral bone-marrow elements and the physiologic processes of spinal marrow conversion and reconversion can contribute to comprehension of pathological spinal changes and assess the treatment efficacy for a disease.

Changes in bone-marrow fat content in case of endocrine diseases, bone metabolism, and bone marrow microangiopathy have caused widespread concern among clinicians. A positive correlation between bone-marrow fat and visceral fat in premenopausal women with obesity and postmenopausal women with type 2 diabetes mellitus has been reported [2, 3]. Additionally, ectopic and serum lipid levels were positively associated with bone-marrow fat in obese men and women [4]. Bone-marrow fat composition is considered a novel imaging biomarker in postmenopausal women with prevalent fragility fractures, and higher marrow fat was associated with prevalent vertebral fractures in men [5, 6]. Subjects with osteoporosis or osteopenia have increased marrow fat as compared with subjects with normal bone density [7–9]. Previous clinical studies have shown that vertebral bone-marrow fat content is impacted by patients' sex and age. However, most of these studies had relatively small sample sizes. Baum et al's. study only had one-hundred-and-fifty-six subjects, and the proportion of men and women varied greatly (49/107 = men/women)[10]; Griffith et al.'s study was limited to elderly subjects[11].

Magnetic resonance imaging (MRI) is currently considered the best noninvasive imaging modality for evaluating vertebral bone-marrow. Advanced MR techniques allow quantification of changes in the bone-marrow water–fat composition, such as single-voxel proton magnetic resonance spectroscopy (^{1}H-MRS), chemical shift magnetic resonance imaging, and the iterative decomposition of water and fat with echo asymmetry and least-squares estimation quantitation (IDEAL IQ). However, ^{1}H-MRS has several limitations [12]. It has a long scan time, the imaging region is localized, and the post-processing process is complicated. Moreover, MRS and chemical shift magnetic resonance imaging are also affected by the inhomogeneity of magnetic field. The IDEAL IQ sequence is a new MR fat-quantification method that is based on the IDEAL sequence [13, 14]. It overcomes many factors that affect the accuracy of fat-fraction measurement, including an inhomogeneous magnetic field, T1 bias, T2* effect, noise deviation, electron eddy current, and multifrequency fat spectrum [15–18]. The IDEAL-IQ has been widely used to estimate the fat content within many organs, especially the bone-marrow and liver [19].

However, to date, few studies have investigated the vertebral bone-marrow fat composition in healthy adults of east China with the IDEAL IQ sequence. In this study, we investigated the change in lumbar vertebral bone-marrow fat content with age, and studied the differences between men and women in different age-groups by using the IDEAL IQ sequence.

Methods

Patient selection

This reproducibility study was approved by the institutional review board of the ___Hospital and ____Hospital of ____ University. Three-hundred-and-twenty-nine healthy adults aged more than 20 years volunteered to participate in this study between June 2016 and April 2018. Written informed consent was obtained from all study participants before examination and evaluation. Subjects were not recruited or were excluded from further analysis if they had (a) obvious low back pain, sciatica, limb numbness, and other related symptoms and signs of lumbar disc disease; (b) scoliosis and spinal dysplasia; (c) a history of pathological bone changes, such as hematological or metabolic bone disorders, aside from osteoporosis, and a history of diabetes; (d) a history of thoracolumbar fractures, lumbar spinal surgery, or irradiation; (e) contraindication to MR examination. Three subjects were excluded due to type 2 diabetes, 2 subjects were excluded due to a history of thoracolumbar fractures, 1 subject was excluded because of claustrophobia, and 11 subjects were excluded due to poor image quality. Finally, a total of 312 subjects were included in the study. The results of MR examination were made know to the participating subjects.

The subjects were classified into 5 groups: age range 20–29 years (twenties): 32/33men/women; 30–39 years (thirties): 40/37 men/women; 40–49 years (forties): 21/45 men/women; 50–59 years (fifties): 26/37 men/women; 60–74 years (sixties and above): 15/26 men/women.

Routine MR examination

All subjects underwent MRI with a 3.0-T scanner (GE Discovery 750, GE Healthcare, Milwaukee, WI, USA) with an 8-channel spine coil in the late afternoon; they were instructed to avoid heavy physical activities before examination. Subjects were positioned head-first in a supine position. Routine MRI for anatomical and morphological assessment of the lumbar vertebrae were performed with the following sequences: T1-weighted fast spin-echo sagittal (TR, 1050 milliseconds; TE, 7 milliseconds; echo train length, 3; slice thickness, 4 mm; slice spacing, 0.5 mm; number of slices, 9; matrix, 320 × 224; frequency direction A/P; field-of-view [FOV], 32 cm; and number of excitations, 2), T2-weighted fast spin-echo sagittal (TR, 2500 milliseconds; TE, 120 milliseconds; echo train length, 21; slice thickness, 4 mm; slice spacing, 0.5 mm; number of slices, 9; matrix, 320 × 192; frequency direction A/P; FOV, 32 cm; and number of excitations, 1), and T2-weighted fast spin-echo axial (TR, 3000 milliseconds; TE, 120 milliseconds; echo train length, 21; slice thickness, 3.5 mm; slice spacing, 0.5 mm; number of slices,15; matrix, 320 × 224; frequency direction A/P; FOV, 20 cm; and number of excitations, 1).

IDEAL IQ sequence and data measurement

Imaging parameters for the IDEAL IQ sequence were as follows: TR, 6.4 milliseconds; TE, minimum; slice thickness, 10 mm; number of slices, 1; flip angle, 3 degrees; bandwidth, 111.11 kHz; FOV, 35 cm; matrix, 160 × 160; number of excitations, 1, and total scan time, 1 minute and 24 seconds. The IDEAL IQ images were analyzed on an imaging workstation (Advantage Workstation 4.6, GE Healthcare).

To estimate vertebral bone-marrow fat-fraction, signal intensities from regions-of-interest (ROIs) in the vertebrae were assessed from the fat-fraction images by 2 radiologists. Maximum elliptical ROIs were manually segmented and placed at the center of each vertebra (L1–L5) in the mid-sagittal slices, as shown in Fig. 1. The basivertebral vein, vertebral cortex, end plates, and osteophytes were excluded when drawing the ROIs, and the fat content in the ROIs automatically calculated by the workstation. The mean of the measurements by the 2 radiologists were used as the vertebral bone-marrow fat content value.

Statistical analyses

Statistical analyses were performed with SPSS (vision 20.0, SPSS Inc., Chicago, IL, USA). P values less than 0.05 were considered statistically significant.

Descriptive statistics, including mean ± standard deviation (SD), were calculated. The Kolmogorov–Smirnov test was applied to assess the normality of FF% values, age, and body mass index (BMI). Sexes in each age-group were analyzed by chi-square test. Differences in FF% measurements of L1–L5 between men and women in the same age-group were compared with unpaired t-tests. The Bonferroni post-hoc test for multiple comparisons was used to compare FF% measurements of L1–L5 between age-groups for men and women, and to compare FF% measurements of every vertebral segment; false discovery rate correction was conducted to correct for multiple comparisons.

The presence of correlations between FF% and age, FF% and BMI were investigated using Spearman's correlation test, and a partial correlation was used to analyze the correlation between FF% and vertebral segments after controlling for sex and age. Correlation coefficients with $r = 0–0.25$ indicated no significant correlation, $r = 0.25–0.49$ indicated a weak correlation, $r = 0.50–0.69$ indicated a moderate correlation, $r = 0.70–0.89$ indicated a good correlation, and $r = 0.90–1.00$ indicated an excellent correlation. Furthermore, the intra-class correlation coefficient (ICC) was calculated to evaluate inter-observer reliability across 2 observers for the FF% measurements of each vertebral level.

Results

BMI data and the FF% measurements averaged over L1–L5 were normally distributed, but the age was non-normally distributed. There were no sex ratio differences in any of the age-groups except for the forties group. The ICC for the quantification of bone-marrow fat content averaged from 0.946 to 0.984 ($P < 0.001$). Mean and SD of age and BMI for each age-group are presented in Table 1.

Table 1
Number of subjects according to age and BMI for each age group.

	Men(n)	Women(n)	All(n)	Age(years)	BMI(kg/m^2)
20–29	32	33	65	25.46 ± 1.86	21.13 ± 2.13
30–39	40	37	77	34.58 ± 2.70	22.34 ± 2.51
40–49	21	45	66	44.26 ± 2.88	23.50 ± 2.70
50–59	26	37	63	54.19 ± 2.79	24.12 ± 3.12
≥ 60	15	26	41	65.10 ± 4.18	23.02 ± 2.96
All(n)	134	178	312	42.70 ± 13.41	22.78 ± 2.86

All data are described as mean ± standard deviation.

BMI = body mass index.

The FF% measurements of L1–L5 were significantly ($P < 0.05$) higher in men than women in the twenties and thirties groups. Women showed an accelerated increase in the vertebral bone-marrow fat content as compared to men in the forties group; consequently, FF% was greater in women than in men in the fifties group, although there was no statistically significant difference ($P > 0.05$) in both age-groups. The FF% measurements for women and men were almost equal in the sixties and above group, but the difference did not reach statistical significance ($P > 0.05$), as shown in Table 2, and Figs. 2 and 3.

Table 2
Bone marrow fat-fractions in each age group and at different vertebral segments.

		Bone Marrow Fat Fraction				
		L1	L2	L3	L4	L5
20–29	Men(n = 32)	46.321 ± 10.763	46.770 ± 11.788	49.854 ± 12.787	50.451 ± 12.998	49.040 ± 12.252
	Women(n = 33)	32.553 ± 8.323	34.882 ± 9.493	37.187 ± 10.039	39.209 ± 10.662	40.062 ± 9.844
	P-value	< 0.001*	< 0.001*	< 0.001*	< 0.001*	< 0.001*
30–39	Men(n = 40)	47.780 ± 9.369	48.177 ± 10.123	52.118 ± 11.010	53.372 ± 11.438	52.754 ± 11.176
	Women(n = 37)	36.292 ± 10.203	37.669 ± 10.186	40.050 ± 10.654	42.370 ± 11.998	42.062 ± 9.844
	P-value	< 0.001*	< 0.001*	< 0.001*	< 0.001*	< 0.001*
40–49	Men(n = 21)	44.120 ± 9.114	46.802 ± 10.719	49.675 ± 9.228	51.266 ± 9.069	51.998 ± 9.163
	Women(n = 45)	40.996 ± 12.337	41.405 ± 13.739	44.395 ± 14.651	47.591 ± 14.924	47.350 ± 13.582
	P-value	0.293	0.117	0.081	0.222	0.160
50–59	Men(n = 26)	48.505 ± 11.807	49.441 ± 13.185	53.440 ± 14.224	53.232 ± 13.822	53.875 ± 13.051
	Women(n = 37)	51.847 ± 11.973	54.205 ± 12.844	57.308 ± 14.084	58.895 ± 13.379	57.128 ± 12.228
	P-value	0.276	0.157	0.291	0.111	0.322
≥ 60	Men(n = 15)	56.336 ± 7.618	57.541 ± 7.004	61.757 ± 7.173	64.135 ± 7.990	63.556 ± 6.692
	Women(n = 26)	56.394 ± 12.087	56.801 ± 13.596	60.952 ± 13.465	61.301 ± 13.939	61.645 ± 11.854
	P-value	0.987	0.819	0.804	0.413	0.078

All data are described as mean ± standard deviation.

*P < 0.05 for men versus women in the same age group and at the same vertebral segment.

The FF% measurements of men in the sixties and above group were significantly higher than that in men in the twenties, thirties, forties, and fifties groups (all P < 0.05), and there was no statistically significant difference between the twenties, the thirties, the forties, and the fifties groups (P > 0.05). For women, there was no statistically significant difference between the twenties and the thirties groups (P > 0.05); however, there were statistically significant differences between the twenties group and the forties, the fifties, and the sixties and above groups (all P < 0.05); the thirties group was also statistically significantly different from the forties, the fifties, and the sixties and above groups (all P < 0.05). Nevertheless, there was no statistically significant difference between the fifties and the sixties and above groups (P > 0.05), as shown in Table 3.

Table 3
Comparison of bone marrow fat-fraction in each age group.

Age	Men				Women			
	20–29	30–39	40–49	50–59	20–29	30–39	40–49	50–59
30–39	0.211	-	-	-	0.137	-	-	-
40–49	0.357	0.357	-	-	< 0.001*	0.001*	-	-
50–59	0.079	0.357	0.211	-	< 0.001*	< 0.001*	< 0.001*	-
≥ 60	< 0.001*	< 0.001*	< 0.001*	< 0.001*	< 0.001*	< 0.001*	< 0.001*	0.070

* P < 0.05 versus in the different age groups for men and women, respectively.

There were statistically significant differences between the upper lumbar (L1 and L2) and the lower lumbar (L4 and L5) FF% (P < 0.05). The FF% measurements of the lower lumbar segments were higher than those of the upper lumbar segments, as shown in Table 4 and Fig. 4.

Table 4
Comparison of bone marrow fat-fraction in each vertebral segment.

Segment	Men				Women			
	L1	L2	L3	L4	L1	L2	L3	L4
L2	0.521	-	-	-	0.521	-	-	-
L3	0.021*	0.103	-	-	0.065	0.402	-	-
L4	0.003*	0.019*	0.521	-	0.003*	0.024*	0.521	-
L5	0.005*	0.031*	0.521	0.521	0.003*	0.032*	0.521	0.521

* P < 0.05 versus in the different vertebral segments for men and women, respectively.

The results of the Spearman correlation analysis showed that the FF% measurements were positively correlated with age for men and women (r = 0.253, P = 0.003; r = 0.581, P < 0.001), as shown in Fig. 5. The FF% measurements were also positively correlated with BMI (r = 0.218, P < 0.05), but not in the sixties and above group (r = 0.043,P = 0.540). We also found a positive correlation between the FF% measurements and vertebral levels (r = 0.187, P < 0.05).

Discussion

In the present study, we investigated the vertebral bone-marrow fat content in healthy men and women from east China, across a spectrum of ages. We found that the vertebral bone-marrow fat content of young men was significantly higher than that of young women. With aging, fatty conversion of the bone-marrow was accelerated and progressive in women, while the fatty conversion process was slower in men, and the bone-marrow fat content of women was similar to that in men after menopause. Correlation analysis showed that the vertebral bone-marrow fat content of women was significantly positively correlated with age, and this correlation in men was significantly weaker than that in women. In addition, the bone-marrow fat content of the lower lumbar segments was higher than those of the upper segments.

Both osteoblasts and adipocytes originate from the mesenchymal stem cells, but the differentiation of mesenchymal stem cell affects the dynamic balance of bone remodeling [20–22]. As early as 1990, Moore et al. showed that the increase in bone marrow adipose tissue (BMAT) begins in childhood [1], and there are sex differences in bone metabolism from puberty, and men have higher BMAT values than women. However, Ruschke et al. considered that vertebral bone-marrow development in children showed a sex-independent cross-sectional increase of proton density fat fraction (PDFF) which correlated with the natural logarithm of age [23]. Since the subjects in the present study were adults, the sex differences in BMAT in minors cannot be verified. The findings in the present study suggested that vertebral bone-marrow fat content was positively correlated with age; bone-marrow fat content in women increased significantly during perimenopause, but the increase in the bone-marrow fat content of men was relatively stable, consistent with previous research [10, 11, 24, 25]. Bone-marrow adipocyte infiltration is thought to be part of normal aging. Studies have indicated that marrow fat content was significantly elevated in osteoporotic and osteopenic subjects, as compared to normal subjects, and osteoporosis is closely related to vertebral fragility fractures in the elderly. Van Staa et al. reported that the lifetime risk of any fracture was 53.2% at age 50 years among women, and 20.7% at the same age among men [26]. Moreover, the incidence of fractures in perimenopausal women increased exponentially, while this increase in older men was delayed by about 15 years [27]. It is likely that the age-related changes in bone-marrow fat content were mostly related to differences in hormones between the sexes in adults.

Androgens and estrogens are considered to be the chief regulators of sex differences in bone metabolism, and studies indicated that sex steroid signaling may be used as a drug target to affect bone metabolism. Animal model studies have demonstrated that androgen acts directly on trabecular bone through the androgen receptor in osteoblasts and osteocytes, which is independent of aromatization. Estrogens acting via the estrogen receptor-α in osteoblast lineage cells are crucial for men cortical and trabecular bone [28],[29]. Although the interaction between estrogen and adipose cells is complex, it is clear that estrogen reduction leads to adipocyte infiltration of the bone-marrow, and adipocytes can inhibit osteoblast activity and promote bone absorption. With aging, the composition of the bone-marrow shifts to favor the presence of adipocytes; osteoclast activity increases, and osteoblast function declines[22]. There is a significant difference in bone-marrow fat content between men and women. Young adult men have a higher androgen level than their woman counterparts. Moreover, men' levels of estrogen, which contributes to the conversion of stem cells to adipocytes, are significantly lower than those of women. Thus, the vertebral bone-marrow fat content of men is higher than that of women. Ovarian function begins to decay before menopause, leading to a significant decline in estrogen levels in women, and a sharp increase in bone-marrow fat content in peri-menopausal women. The estrogen of postmenopausal women continues to decline gradually, and therefore the increase in bone-marrow fat content is relatively slow.

We found an anatomical variation in bone-marrow fat content, which was significantly higher in the lower lumbar segment than in the upper lumbar segment, consistent with previous studies [12, 30]. Most intervertebral disc (IVD) degeneration occurs in the lower lumbar segments, and Albert et al. reported that the prevalence of Modic changes and IVD pathology were greater in the L4/5 and L5/S1 regions than in the upper lumbar spine [31]. The lower IVDs are subjected to a greater load than the upper IVDs, and the incidence of degeneration is accordingly also higher. Therefore, vertebral adipocyte infiltration is consistent with anatomical IVD degeneration; lumbar fat content is closely related to the changes in lumbar load and stress distribution. In addition, studies by Ruschke et al. and by Baum et al. showed a decreasing PDFF from the lumbar to the cervical regions of the spine, which further confirmed segmental differences in vertebral fat distribution [23, 32].

We also found that the correlation between bone-marrow fat content and BMI was not significant, and there was no such correlation in older subjects. In a study of bone-marrow fat changes after gastric bypass surgery in obese women, nondiabetic women showed no significant mean change in bone-marrow fat [33]. Moreover, Cordes et al. reported that there were no statistically significant changes in bone-marrow FF% after a 4-week calorie restriction in obese women [34]. Furthermore, Bredella et al. suggested that bone-marrow fat was independent of BMI in young obese men and women [4]. Therefore, the small difference between the results of our study and of previous studies may be due to sampling errors; the age range of subjects in the present study was large. Overall, the process of bone-marrow fatty conversion appears to be independent of BMI.

There were several limitations to our study. First, the number of elderly subjects, i.e., those over 60 years old, especially those over 70 years old, was relatively small, and may not fully reflect the changes in bone-marrow fat in the elderly. We will expand the sample size and extend the period of observation to follow FF% in our future research. Second, we did not assess the bone mineral density. In a future study, dual-energy X-ray absorptiometry or computed tomography will be performed to evaluate the relationship between osteopenia, osteoporosis, and bone-marrow adipocytes infiltration. Third, all ROIs were manually segmented by two experienced radiologists, who ensured maximal avoidance of measurement related errors. However, future study should use a software to segment the ROIs of the vertebral bodies. Additionally, we did not have vertebral marrow biopsy specimens as a reference standard due to ethical issues in obtaining such samples from healthy people.

Conclusions

In conclusion, IDEAL-IQ can accurately quantify lumbar bone-marrow fat infiltration. The vertebral bone-marrow fat content increases with aging, and there are sex-related differences between men and women. An anatomical variation of bone-marrow fat content was also observed; the fat content is significantly higher in the lower lumbar segment than in the upper lumbar segment. These findings could form the basis for further studies, or may provide a set of normal reference values of lumbar bone-marrow fat content for comparison with that in pathological conditions.

Abbreviations

IDEAL-IQ:iterative decomposition of water and fat with echo asymmetry and least-squares estimation quantitation; FF:fat fraction; BMI:body mass index; MRI:magnetic resonance imaging; MRS:magnetic resonance spectroscopy; FOV:field of view; TR:repetition time; TE:echo time; ICC:intra-class correlation coefficient; BMAT:bone marrow adipose tissue; IVD:intervertebral disc; PDFF:proton density fat fraction

Declarations

Ethics approval and consent to participate

This study was approved by the IRB (Institutional Review Board) of the Second Affiliated Hospital and Yuying Children's Hospital of Wenzhou Medical University, and the informed consent was signed by all volunteers.

Consent for publication

We have obtained consent to publish from the participants.

Availability of data and materials

All data and materials were in full compliance with the journal's policy.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

QPL, SQC, and PPZ designed the study. QPL, SQC, ANG, PPY, and YYH recruited the volunteers. QPL, SQC, and PPZ examined MRI imaging. QPL and SQC performed the statistical analysis and interpreted the results. QPL drafted the manuscript. All of the authors critically revised the manuscript. The final manuscript was approved by all authors.

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Figures

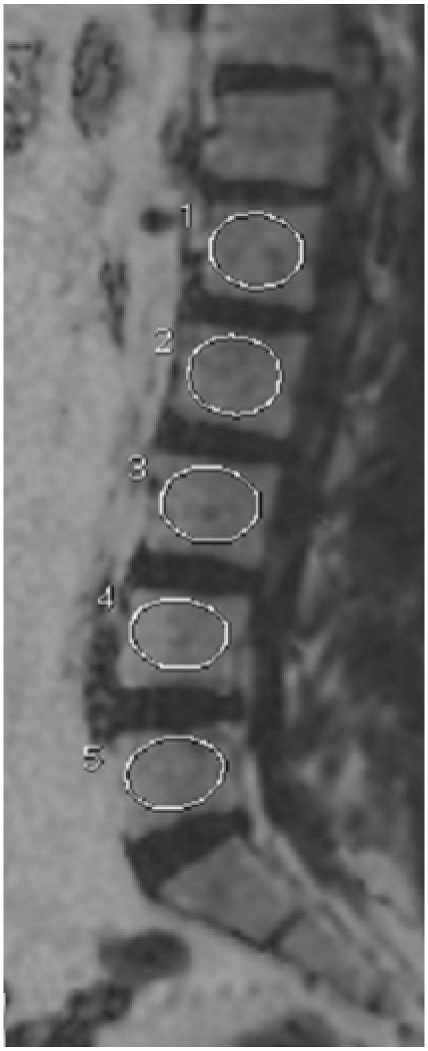

Figure 1

Maximum elliptical regions-of-interest were manually segmented and placed at the center of each vertebra (L1–L5) in the mid-sagittal slices of fat-fraction images from IDEAL-IQ sequence.

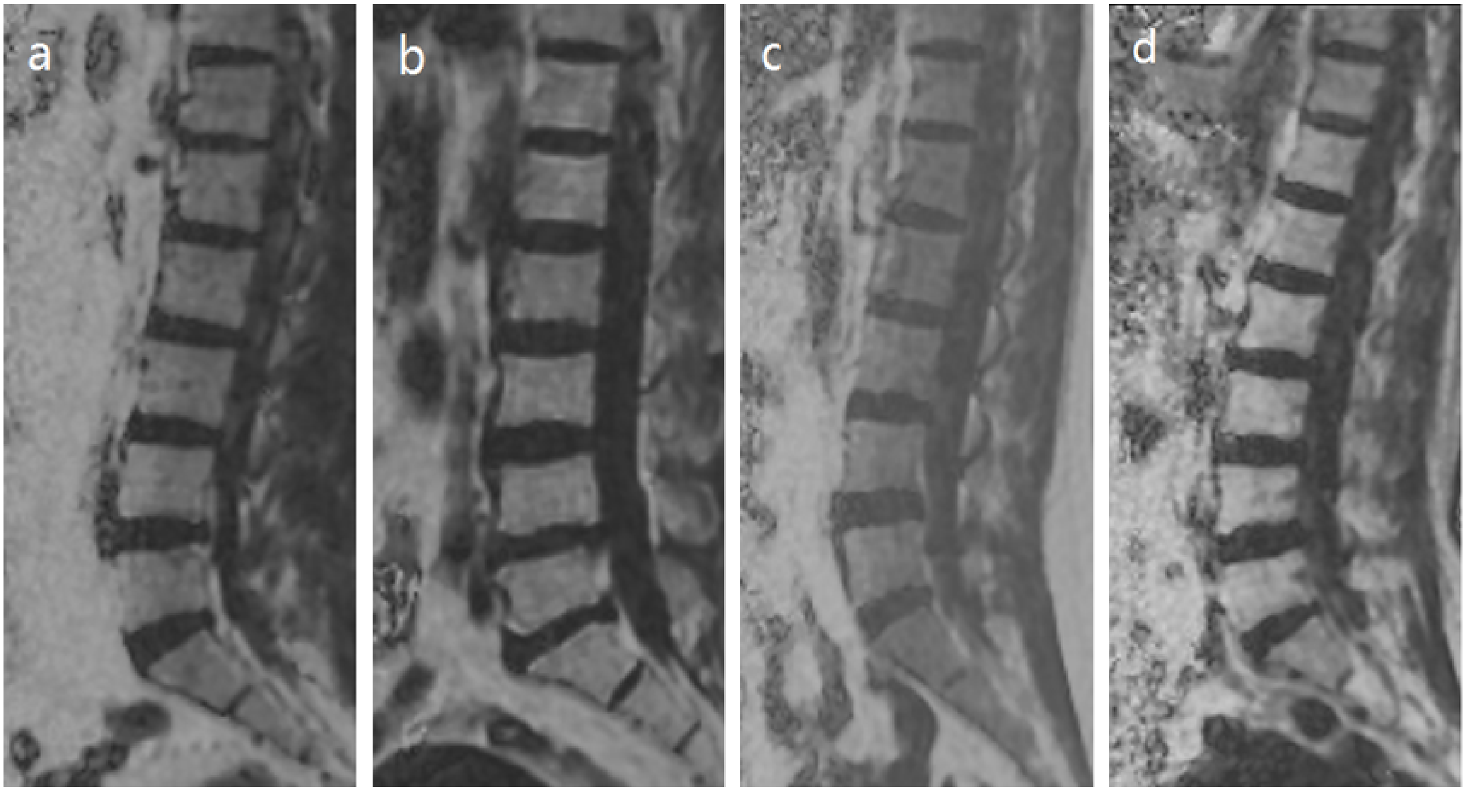

Figure 2

a Fat-fraction image of a 27-year-old young man with a FF of 52.146% averaged over L1–L5. b Fat-fraction image of a 68-year-old man with a FF of 61.317% averaged over L1–L5. c Fat-fraction image of a 28-year-old young woman with a FF of 37.847% averaged over L1-L5. d Fat-fraction image of a 66-year-old woman with a FF of 67.837% averaged over L1–L5. The greater the content of yellow bone marrow in vertebrae, the greater the fat content, and the higher the signal intensity of the vertebrae in fat-fraction images.

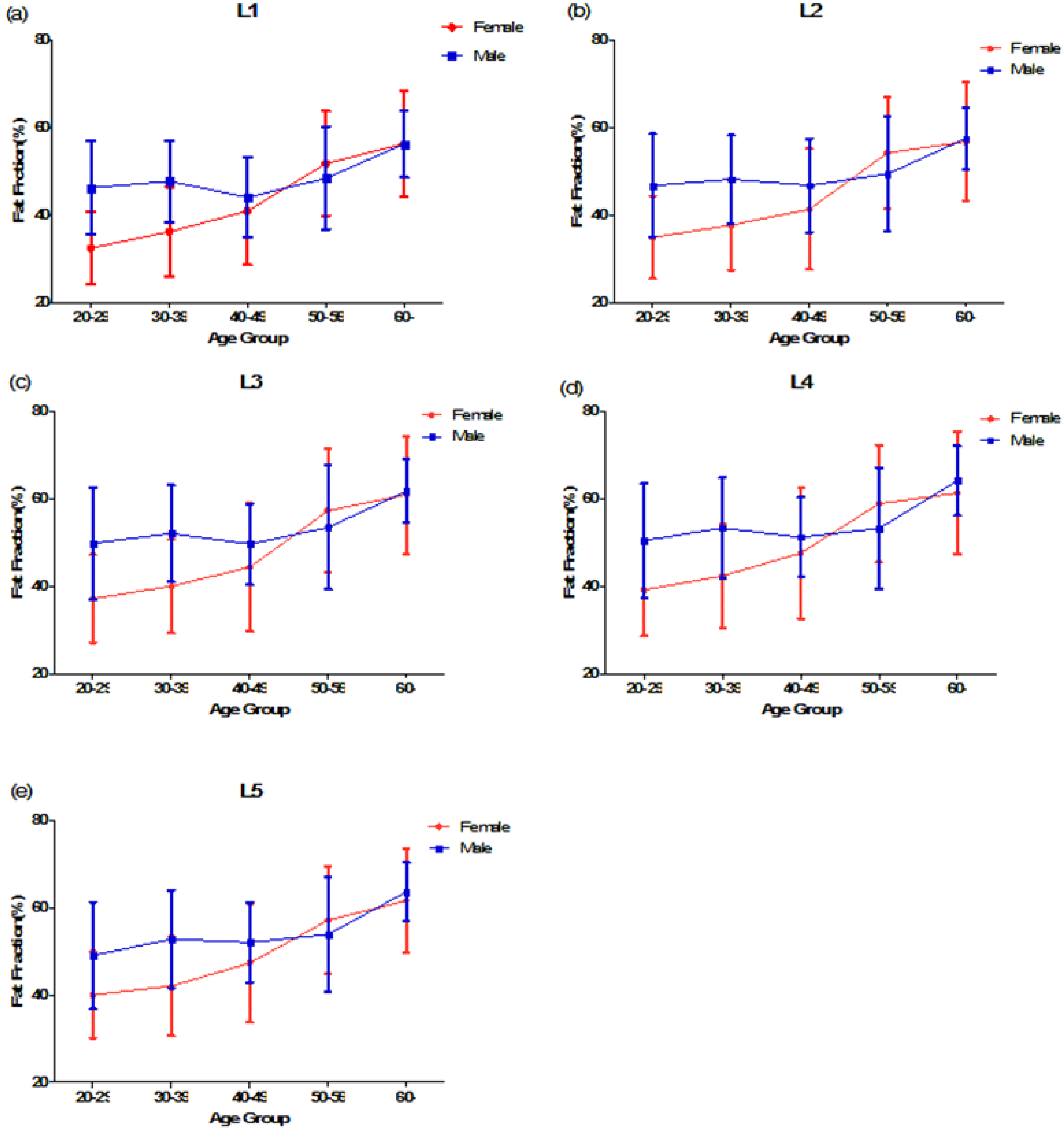

Figure 3

Difference in bone marrow fat content between men and women with aging. The FF% measurements of L1−L5 were significantly higher in men than women in their twenties and thirties. Women showed an accelerated increased after their forties as compared to men, and FF% was almost equal in women and men in the sixties and above group.

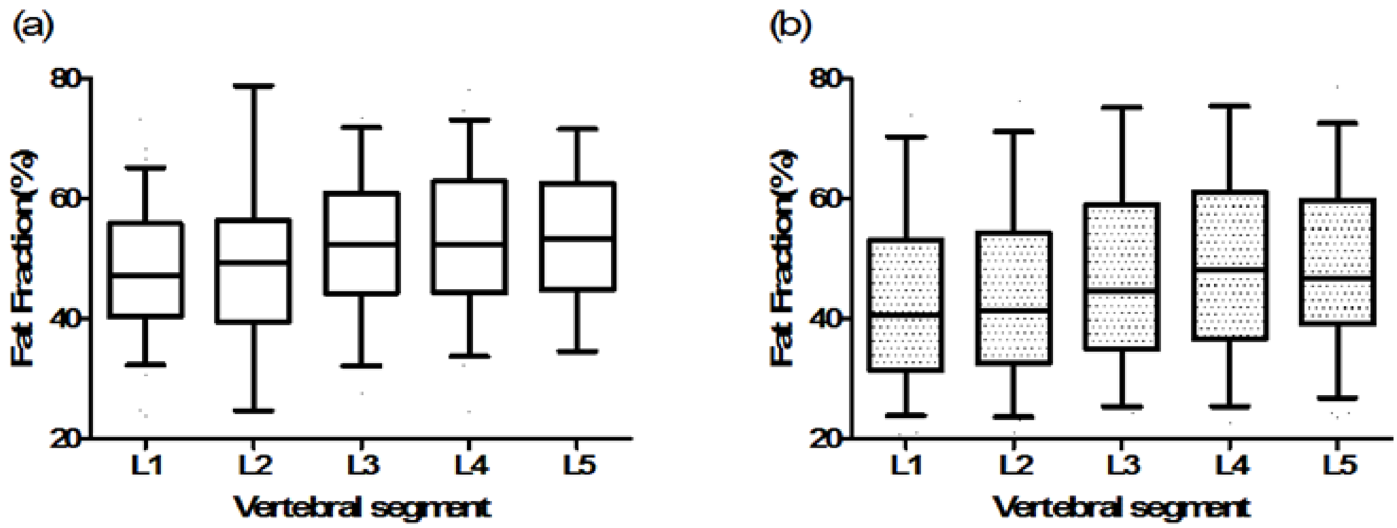

Figure 4

Difference in bone marrow fat content between men (a) and women (b) at different vertebral segments. The FF% measurements of the lower lumbar (L1 and L2) region were significantly higher than those in the upper lumbar region (L4 and L5).

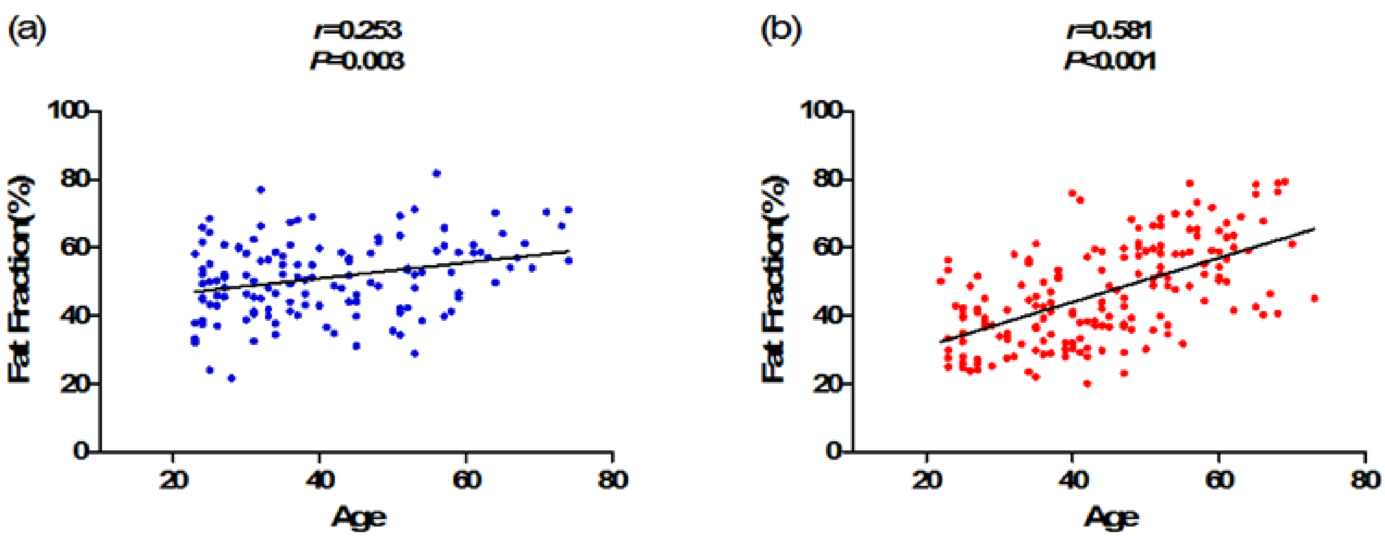

Figure 5

The correlation between vertebral bone fat content and age of men (a) and women (b). The FF% measurements were weakly positively correlated with age in men, and was moderately positively correlated with age in women.