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Vertebral Size, Bone Density, and Strength in Men and Women Matched for Age and Areal Spine BMD

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Abstract

To explore the possible mechanisms underlying sex-specific differences in skeletal fragility that may be obscured by two-dimensional areal bone mineral density (aBMD) measures, we compared quantitative computed tomography (QCT)-based vertebral bone measures among pairs of men and women from the Framingham Heart Study Multidetector Computed Tomography Study who were matched for age and spine aBMD. Measurements included vertebral body cross-sectional area (CSA, cm²), trabecular volumetric BMD (Tb.vBMD, g/cm³), integral volumetric BMD (Int.vBMD, g/cm³), estimated vertebral compressive loading and strength (Newtons) at L₃, the factor-of-risk (load-to-strength ratio), and vertebral fracture prevalence. We identified 981 male-female pairs (1:1 matching) matched on age (± 1 year) and QCT-derived aBMD of L₃ ($\pm 1\%$), with an average age of 51 years (range 34 to 81 years). Matched for aBMD and age, men had 20% larger vertebral CSA, lower Int.vBMD (-8%) and Tb.vBMD (-9%), 10% greater vertebral compressive strength, 24% greater vertebral compressive loading, and 12% greater factor-of-risk than women ($p < 0.0001$ for all), as well as higher prevalence of vertebral fracture. After adjusting for height and weight, the differences in CSA and volumetric bone mineral density (vBMD)

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Disclosures

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between men and women were attenuated but remained significant, whereas compressive strength was no longer different. In conclusion, vertebral size, morphology, and density differ significantly between men and women matched for age and spine aBMD, suggesting that men and women attain the same aBMD by different mechanisms. These results provide novel information regarding sex-specific differences in mechanisms that underlie vertebral fragility.

Keywords

AGING; BONE MINERAL DENSITY; VERTEBRAL FRACTURE; BIOMECHANICS; OSTEOPOROSIS; POPULATION STUDIES

Introduction

Vertebral fractures are the most common clinical manifestation of osteoporosis, with a prevalence of 30% to 50% in those over age 50 years.^(1–3) Vertebral fractures result in pain, height loss, disfigurement, reduced pulmonary function, depression, and a five-year mortality equivalent to that seen with hip fractures.^(4–9) Despite the tremendous personal and societal costs of vertebral fractures, little is known regarding their biomechanical etiology.

Areal bone mineral density (aBMD) as measured by dualenergy X-ray absorptiometry (DXA) is used to diagnose osteoporosis and estimate fracture risk.^(10,11) However, two-dimensional aBMD measurements are subject to artifacts caused by aortic calcification and degenerative disease of the spine.⁽¹²⁾ Further, because aBMD is measured from a two-dimensional projection of a three-dimensional object, larger bones will have higher aBMD than smaller bones with the same volumetric density.⁽¹³⁾ Thus, the relationship between aBMD and bone strength may be different in men and women because of their different body sizes and prevalence of artifacts influencing the aBMD measures. Men on average have larger vertebrae than women, suggesting that when matched by aBMD, men might have larger but less dense (volumetrically) vertebrae than women. However, the extent of these structural differences and how they relate to differences in vertebral strength are not known. Because of the widespread use of aBMD in both clinical practice and research, it is important to determine how vertebral bone structure, strength, and the load-to-strength ratio (factor-of-risk) might differ between men and women with the same spine aBMD.

In this study, we determined differences in vertebral structure, spinal loading, and factor-of-risk between men and women of the same age and with the same spine aBMD. Specifically, we examined whether 3D quantitative computed tomography (QCT) bone measures (vertebral cross-sectional area, volumetric density, and estimated compressive strength), vertebral loading, the factor-of-risk, and vertebral fracture prevalence differed among pairs of men and women matched for age (± 1 year) and for spine aBMD ($\pm 1\%$, computed from 3D QCT data). We hypothesized that at a given aBMD men would have greater vertebral cross-sectional area, lower volumetric BMD, greater compressive strength, a lower factor-of-risk of fracture, and a lower prevalence of vertebral fracture compared with women. Because men are larger than women, we also examined how bone structure and compressive strength differed between the two sexes after adjusting for height and weight. We

hypothesized that sex-specific differences would be reduced when accounting for the larger size of men relative to women.

Materials and Methods

Participants

Participants included Framingham Heart Study Offspring and Third Generation Cohort members who had QCT scans of the abdomen and thorax for assessment of vascular calcification, acquired between 2002 and 2005, as part of the community-based Framingham Heart Study Multidetector CT Study.⁽¹⁴⁾ A total of 981 male-female pairs (aged 34 to 81 years) were selected from 3312 participants (1726 men and 1586 women) with QCT measurements at the third lumbar vertebrae (L₃), and no vertebral fracture at L₃. For each pair, one man was matched to one woman within 1 year of age and within 1% of QCT-derived L₃ aBMD (described below). To maintain the largest number of pairs, all potential pairs were created (with men as the “case”) using the above criteria. For cases with more than one matched woman, the pair with the lowest percent difference in aBMD was selected. Age (years) was reported at the time of the QCT scan. Height, measured using a stadiometer, and weight, using a balance beam scale, were available from the Framingham exam before the QCT scan or if missing, from the closest previous exam. Current use of osteoporosis medications, including estrogen, was assessed from information gathered at the most recently available Framingham Heart Study clinic visit. The Institutional Review Boards at Boston University, Hebrew SeniorLife, and Beth Israel Deaconess Medical Center approved this study protocol.

QCT-derived bone measures and estimated vertebral compressive strength

QCT scans were acquired using an eight-slice multidetector CT system (GE Lightspeed Ultra/Plus, General Electric Medical Systems, Milwaukee, WI, USA) with an in-plane pixel size of 0.68 by 0.68 mm, slice thickness of 2.5 mm, tube voltage of 120 kVp, data collection diameter of 500 mm, and a General Electric standard body reconstruction kernel. As described previously, a hydroxy-apatite phantom (Image Analysis, Columbia, KY, USA) was scanned with each patient to allow conversion of CT Hounsfield units to equivalent mineral density.^(15,16) Using custom software,^(17,18) individual L₃ vertebral levels were identified from abdominal CT scans, in combination with the lateral scout views, and used to estimate aBMD (g/cm²), determine cross-sectional area (CSA, cm²), trabecular volumetric BMD (Tb.vBMD, g/cm³), integral volumetric BMD (Int.vBMD, g/cm³), and to calculate compressive strength (Newtons) at L₃. The L₃ vertebral level was selected because the largest number of participants had valid measurements at this level.

Although it would have been desirable to match participants by DXA spine aBMD measures, only a small number of individuals had a DXA scan within 1 year of their QCT exam. Therefore, we estimated L₃ aBMD from the QCT scan by projecting the 3D QCT density onto a 2D region in the anterior-posterior plane. In a subset of 402 Framingham Offspring Cohort members who had both a QCT scan and a lumbar spine DXA scan within 1 year of each other, we found a strong correlation between L₃ DXA aBMD and L₃ aBMD estimated from QCT: $r = 0.81$ (root mean square error [RMSE] = 0.14, slope = 0.89, and

intercept = 0.06) for men ($n = 180$) and $r = 0.84$ (RMSE = 0.12, slope = 0.89, and intercept = -0.01) for women ($n = 222$).

The average CSA of the midvertebral body was calculated from a central 10 mm-thick slice. The volume of interest for Int.vBMD included the entire vertebral body (both cortical and trabecular compartments) but excluded the transverse and posterior processes.⁽¹⁷⁾ The volume of interest for Tb.vBMD measurements was an elliptical region encompassing the anterior vertebral body, centered at the midvertebral level and encompassing 70% of the volume between vertebral end plates. Vertebral compressive strength was estimated as a linear combination of Int.vBMD and CSA according to engineering beam theory, an approach that assumes the vertebral body is primarily loaded in compression and that the failure load of the vertebra, or its strength, is proportional to its structural rigidity at its weakest cross section. Structural rigidity depends on bone size and bone elastic modulus. In this case, the elastic modulus of vertebral bone was estimated using a previously published empirical relationship relating Int.vBMD to elastic modulus, which was then used in combination with CSA to estimate vertebral strength according to the following equation: Vertebral Strength = $0.0068 \times \text{Elastic Modulus} \times \text{CSA}$.⁽¹⁹⁾

Compressive force and factor-of-risk

For each subject, a quasistatic musculoskeletal model of the spine was used to estimate compressive force on L₃ for two different activities of daily life.^(20,21) The model is similar to previously published musculoskeletal models of the lumbar spine.^(22,23) In brief, the body was modeled as a series of linked segments, and the weight, length, and center of mass position of each body segment was estimated using each individual's height and weight together with published anthropometric data. The major trunk muscles present in the model included pectoralis major, rectus abdominus, serratus anterior, trapezius, latissimus dorsi, external oblique, internal oblique, sacrospinalis, trans-versospinalis, psoas major, and quadratus lorum. Trunk muscle cross-sectional areas and moment arm lengths were estimated using regression equations that derived these properties from each subject's age, sex, height, and weight.⁽²⁴⁾ The forces and moments applied to L₃ because of body mass, as well as any weights or forces applied to the hands, were calculated for each activity. The muscle forces required to maintain static equilibrium were determined using an optimization algorithm that minimized the sum of cubed muscle intensities (equivalent to minimizing muscle fatigue) while limiting the maximum allowable muscle stress to 1 MPa to keep solutions within a physiologically acceptable range.⁽²⁵⁾ For each activity, compressive force on L₃ was calculated as the sum of body weight and muscle loading acting in the axial direction of the vertebral body. The two activities modeled for each subject were lifting (30° of trunk flexion with 10-kg weights in each hand and arms hanging down) and opening a window (bending forward 20° with both arms and shoulders flexed 40°, the elbows flexed 70°, and a 15 N downward force on the hands).

The factor-of-risk for vertebral fracture was computed for each of the activities and calculated as the ratio of the applied compressive force at L₃ to the estimated compressive strength of L₃.⁽¹⁹⁾ Theoretically, when the applied force exceeds bone strength, a fracture will occur, thus higher values of the factor-of-risk indicate greater risk of fracture.

Vertebral fracture assessment

Two experienced radiologists visually identified prevalent vertebral fractures in all Framingham Heart Study Multidetector CT Study participants with lateral CT scout views ($n = 3469$) using Genant's semiquantitative algorithm.⁽²⁶⁾ The radiologists were blinded to subject age, and each evaluated approximately half of the study participants. Individual vertebral bodies (T₄ through L₅) were graded as no fracture (SQ 0), mild (SQ 1), moderate (SQ 2), or severe (SQ 3) fracture. We compared vertebral fracture prevalence in men versus women in the age- and aBMD- matched subjects ($n = 981$ pairs or 1962 subjects), as well as in the larger sample of Framingham Heart Study Multidetector CT Study subjects with lateral CT scout views ($n = 3469$), which included the subset of individuals included in the age- and aBMD-matched cohort. We examined prevalent vertebral fracture in four different age groups: <50 years, 50 to 59 years, 60 to 69 years, and ≥ 70 years. Subjects were counted as a fracture case if they had one or more prevalent vertebral fracture of grade SQ 1 or above.

Statistical analysis

Mixed-effect regression models with a random term for matched pairs (SAS, proc mixed) were used to assess differences in QCT bone measures, predicted compressive strength, loading, and factor-of-risk in male-female pairs. These approaches account for the correlation within the pairs of men and women, matched on age and aBMD. In the mixed-effect regression models, the QCT measure was the dependent variable, and sex and other covariates were the independent variables. Sex-related differences in QCT bone measures and predicted compressive strength were assessed 1) with only sex in the model; 2) after adding height and weight to sex as the independent variables; and 3) after adding height, weight, and osteoporosis medication use (including estrogen) to sex in the model. All analyses were performed using SAS software (Windows, 9.2, SAS Institute Inc, Cary, NC, USA).

Results

A total of 981 male-female pairs were included in this study (Table 1). For comparison, descriptive characteristics for all Framingham subjects with lateral CT scout views are also presented in Table 1, as well as descriptive characteristics for the Framingham subjects that were not paired during the matching process. For the matched male-female pairs, the average age of participants was 51 years, ranging from 34 to 81 years. Mean (SD) spine aBMD was 1.23 (0.18) g/cm² and ranged from 0.75 to 1.86 g/cm² for both men and women. The men were 21% heavier and 8% taller than the women. A total of 192 women (20%) reported current use of osteoporosis medication, including 180 women who reported current use of estrogen. The estimated spine aBMD of the men in the matched sample was lower than that of all Framingham men together, whereas the average aBMD of the women in the matched sample was higher than the average aBMD of all Framingham women together. The average aBMD of the unpaired men was higher than the average aBMD of all Framingham men together, and the average aBMD of the unpaired women was lower than the average aBMD of all Framingham women together. Average age, height, and weight

were similar across the three samples, except that the unpaired women were slightly older compared with the matched women and all Framingham women together.

Volumetric bone measures

All QCT-derived bone measures differed significantly ($p < 0.0001$) between men and women matched for age and aBMD (Table 2). Thus, at the same aBMD, men had on average 8% lower Int.vBMD and 9% lower Tb.vBMD but had 20% larger vertebral CSA and 10% higher predicted compressive strength than women. These patterns remained after adjusting for height and weight, although the differences were attenuated, and compressive strength no longer differed significantly between men and women (Table 2). Sex-specific differences were similar after further adjustment for use of osteoporosis medications. Fig. 1 shows QCT cross-sectional images at L₃ for one representative male-female pair matched by age and aBMD to highlight the differences in vertebral CSA and vBMD.

Biomechanical measures—compressive force and factor-of-risk

For both lifting and opening a window, L₃ compressive loads and L₃ factor-of-risk differed significantly between men and women matched for age and aBMD ($p < 0.0001$). L₃ compressive loads were 24% higher in the men for lifting, and 24% higher in the men for opening a window (Table 3). L₃ factor-of-risk was 12% higher in the men for lifting, and 11% higher in the men for opening a window (Table 3). For both activities, the values for the factor-of-risk were below one, suggesting low risk of fracture. Results remained the same after adjusting for use of osteoporosis medications.

Vertebral fracture status

In the sample of 981 men and women pairs matched for age and spine aBMD, there were 519 pairs aged <50 years, 255 pairs 50 to 59 years, 136 pairs 60 to 69 years, and 71 pairs 70 years. In the larger Framingham CT Study cohort, there were 930 men and 720 women aged <50 years, 395 men and 441 women 50 to 59 years, 267 men and 304 women 60 to 69 years, and 203 men and 209 women 70 years. In men and women matched for age and aBMD, vertebral fracture prevalence increased with increasing age, and there were more men with vertebral fracture than women in all age groups (men versus women: 13% versus 5% for <50 years, 15% versus 9% for 50 to 59 years, 16% versus 9% for 60 to 69 years, and 31% versus 24% for 70 years) (Fig. 2). In comparison, when examining all Framingham Heart Study Multidetector CT Study subjects with lateral CT scout views (of which the age- and aBMD-matched subjects are a subsample), vertebral fracture prevalence also increased with increasing age. However, whereas more men had prevalent vertebral fracture than women in the younger three age groups, in contrast to the matched aBMD sample, women had a higher vertebral fracture prevalence in the oldest age group (men versus women: 13% versus 5% for <50 years, 17% versus 8% for 50 to 59 years, 21% versus 13% for 60 to 69 years, and 25% versus 28% for 70 years) (Fig. 2).

Discussion

In this study, we evaluated sex-specific differences in vertebral volumetric bone density measures, cross-sectional area, vertebral fracture prevalence, and biomechanical estimates of

vertebral loading and factor-of-risk (ie, load-to-strength ratio) in pairs of men and women matched closely for age and spine aBMD. We found that when matched for age and aBMD, men have larger vertebral CSA, lower volumetric BMD, and higher vertebral compressive strength compared with women. The larger CSA in men was expected because they were taller and heavier than their female aBMD-matched counterparts, and it would be expected that larger individuals would have bigger vertebrae.⁽²⁷⁾ The greater CSA of vertebral bodies in men compensated for their lower vBMD, resulting in higher estimated compressive strength in the men than in the women, despite equal aBMD.

Height and weight adjustment attenuated, but did not eliminate, the differences in vertebral size and density, implying that factors other than body size contributed to these findings. However, when adjusted for height and weight, compressive strength no longer differed between men and women matched for aBMD. This finding makes sense from a biomechanical perspective because one would expect individuals of the same size to experience similar loads and therefore require similar vertebral strength regardless of gender. However, from a clinical perspective, it is important to note that men and women of the same age and aBMD will typically not have similar vertebral strength unless they are also of similar height and weight. When matched for age and aBMD, men had higher vertebral compressive loads than women for the two activities simulated with our musculoskeletal model. This was expected because the men were taller and heavier than the women, and height and weight are two of the major determinants of vertebral loading for a given activity. Interestingly, the factor-of-risk (ie, load-to-strength ratio) for vertebral fracture was higher (ie, worse) in men despite their greater vertebral compressive strength than women. Therefore, these findings imply that when matched for both age and aBMD, men should have a higher risk of vertebral fracture than women because for a given vertebral strength they experience proportionally greater compressive loads on their vertebrae.

Notably, the patterns we observed for vertebral size and density among men and women matched for aBMD are similar to those previously reported by Srinivasan and colleagues, who studied 114 pairs of men and women matched for femoral neck aBMD, and reported that men had 38% greater femoral neck cross-sectional area and 16% lower volumetric BMD compared with women.⁽²⁸⁾ In a small subset of subjects with QCT-based finite element analysis ($n = 28$ pairs), they found the larger femur size of the men offset their lower vBMD, such that femoral strength estimates were similar between men and women matched for femoral neck aBMD. This contrasts with our finding that men had higher lumbar vertebral compressive strength than women when matched by aBMD. However, after height and weight adjustment, we found no significant compressive strength difference between men and women. Srinivasan and colleagues did not evaluate differences in femoral strength after height and weight adjustment, and given that the men were taller, this type of analysis may have revealed men to have lower femoral strength than women when matched for aBMD. Srinivasan and colleagues also found that men and women who were matched for femoral aBMD had similar femoral loads during a simulated sideways fall and, therefore, similar factor-of-risk for hip fracture. However, their estimates of femoral loading did not account for individual differences in trochanteric soft-tissue thickness, which has a large

influence on femoral loading⁽²⁹⁾ and which varies markedly between men and women.^(30,31) Further, men and women in the Srinivasan study were not matched for age, and this resulted in the men being approximately 6 years older than the women after the aBMD matching, so the observed differences between men and women may not have been solely sex related.

In the entire Framingham CT Study cohort, we found a greater percentage of men had prevalent vertebral fracture than women in the younger three age groups, but that more women had prevalent vertebral fracture in the oldest age group, a pattern consistent with prior studies.^(32–34) The greater vertebral fracture prevalence in younger men compared with women may result from more frequent exposure to high load activities and injuries earlier in life, with the women eventually surpassing the men because of accelerated bone loss⁽¹⁶⁾ and a greater incidence of vertebral fracture after age 50.⁽³⁵⁾ We observed a similar pattern in the age- and aBMD-matched subset of subjects, except in the oldest age group, where the matched men had a greater prevalence of vertebral fracture than their female counterparts, contrasting with the entire Framingham CT cohort, where women had higher vertebral fracture prevalence in this age group. Consistent with the patterns we observed in our age- and aBMD-matched sample, Lunt and colleagues⁽³⁶⁾ reported that after adjusting for body mass index and spine aBMD, men had higher prevalence of vertebral deformity than women at all ages. Our observation that men in the age- and aBMD-matched sample had a higher prevalence of vertebral fracture than women in all age groups is consistent with our finding that men in the age- and aBMD-matched cohort had a higher factor-of-risk for vertebral fracture than women, and thus would be predicted to have higher risk for vertebral fracture than women.

At least one prospective study of incident vertebral fracture supports our prediction of higher vertebral fracture risk in men and women matched for age and spine aBMD,⁽³⁷⁾ whereas others conflict with it.^(38,39) Specifically, despite a higher BMD, men in the Canadian Multicenter Osteoporosis Study⁽³⁷⁾ had a similar incidence of vertebral fracture as women, implying that after adjustment for BMD, men would have had a higher incidence of vertebral fracture than women.⁽³⁷⁾ In contrast, the European Osteoporosis Study (EPOS) found that whereas the age-adjusted risk of incident vertebral fracture was 2.3-fold greater in women than men, after adjusting for lumbar spine aBMD there was no longer a sex difference in the age-specific incidence of vertebral fracture.⁽³⁸⁾ Similarly, the Rotterdam study found that there was no sex difference in the risk of incident vertebral fracture after adjusting for both age and spine aBMD.⁽³⁹⁾

There are several possible reasons why our predictions differ from these latter two prospective studies. First, it is important to note that whereas these investigations had a large number of subjects, in fact there were relatively few incident fractures in men: 26 in the EPOS study and 47 in the Rotterdam study. Second, whereas the current study used specific 1:1 matching of men and women by age and spine aBMD, these other studies used a statistical adjustment to remove the confounding effects of age and aBMD on the association between sex and vertebral fracture. However, if the distribution of aBMD between women and men at the same age was not sufficiently overlapping, statistical adjustment may be inadequate, resulting in residual confounding by age and aBMD. Finally, we did not have

DXA-based aBMD, but rather estimated aBMD from 3D-QCT data, and this may have led to errors in the selection of pairs of men and women matched for spine aBMD.

Finally, differences could be the result of the limitations in our factor-of-risk model that might overestimate risk in the men and/ or underestimate the risk in the women. For example, we estimated vertebral strength using engineering beam theory and an empirically derived formula relating CSA and Int.vBMD to vertebral compressive strength measured in vitro.⁽¹⁹⁾ Although this approach predicts the compressive strength of cadaver vertebrae fairly well ($r^2 = 0.65$),⁽⁴⁰⁾ there are additional factors affecting vertebral strength not captured by this approach that might influence the differences in vertebral strength between men and women. Additionally, we only assessed vertebral strength and vertebral loading at L₃. However, vertebral fractures occur throughout the spine with peaks in frequency at the mid-thoracic and thoraco-lumbar junction.⁽⁴¹⁾ Despite this, vertebral strength and loading estimates at different spinal levels are typically correlated with each other,⁽⁴²⁾ making it reasonable to look for sex-related differences in loading and factor-of-risk at just one vertebral level.

Further, there may be sex-specific factors that influence vertebral loading that were not accounted for in our musculo-skeletal model.⁽⁴²⁾ For instance, women on average have greater thoracic kyphosis than men, and previous biomechanical studies have shown that a larger kyphosis angle results in increased compressive loads on both the thoracic and lumbar spine.^(20,43–45) In the current study, measurements of spinal curvature were not available, so our musculoskeletal model used the same spinal curvature for both men and women and thus would not have captured possible sex-related differences in vertebral loading owing to altered spinal curvature. A greater kyphosis angle in women may result in higher compressive loads and thus an increased factor-of-risk in women. Future studies should incorporate individualized spinal curvatures into musculoskeletal models to better delineate sex-specific differences in vertebral loading and factor-of-risk. Finally, it is not clear which activities are most likely to result in vertebral fracture,^(41,46) and it is possible that there are sex-specific patterns of loading and factor-of-risk for activities not considered here.

These limitations notwithstanding, major strengths of the current study include the large number of men and women pairs matched closely for aBMD and age, the use of QCT to assess compartment-specific differences in volumetric bone density, and the use of the factor-of-risk approach to integrate estimates of vertebral loading and vertebral strength to understand risk of vertebral fracture.

In conclusion, we found that when matched for both age and spine aBMD at L₃, men have higher vertebral CSA, lower volumetric density, higher vertebral compressive strength, and higher factor-of-risk for vertebral fracture compared with women. This study provides new insights into the sex-specific structural and biomechanical differences that exist between the vertebra of men and women, and has important clinical implications concerning the use of aBMD to predict vertebral fracture and diagnose osteoporosis in both men and women. Taken together, the results of this study suggest that men and women do not have similar risk of vertebral fracture at the same absolute level of spine aBMD and that the use of sex-

specific spine aBMD reference values to predict fracture risk in men and women deserves further investigation.

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	Sample Male	Sample Female
Age (yrs)	40	40
Estimated L3 aBMD (g/cm ²)	1.25	1.25
Integral vBMD (g/cm ³)	0.156	0.215
Cross-sectional area (cm ²)	13.89	6.68
Compressive Strength (N)	4425	3003

Fig. 1.

QCT cross-sectional image of L₃ in a man (left) and woman (right) matched for both age and aBMD. Note the larger CSA in the male vertebra and the higher volumetric density in the female vertebra.

Fig. 2.

Percentage of men and women with one or more prevalent vertebral fractures in the age- and aBMD-matched sample (left) and in the larger Framingham CT study cohort (right), of which the matched subjects are a subsample. In the matched sample, there were 519 pairs aged <50 years, 255 pairs 50 to 59 years, 136 pairs 60 to 69 years, and 71 pairs 70 years. In the larger Framingham CT Study cohort, there were 930 men and 720 women aged <50 years, 395 men and 441 women 50 to 59 years, 267 men and 304 women 60 to 69 years, and 203 men and 209 women 70 years.

Descriptive Data for All Framingham Subjects With Lateral CT Scout Views, Subjects Matched for Age and Estimated Spine aBMD, and Framingham Subjects Who Were Not Paired During the Matching Process

Table 1

	All subjects		Matched pairs		Unpaired subjects	
	M (n =1726)	W (n =1586)	M (n = 981)	W (n = 981)	M (n =745)	W (n = 605)
	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Age (years)	51.24± 12.13	53.84 ± 11.20	51.22 ±10.03	51.24 ±9.96	51.27 ±14.44	58.06 ± 11.81
Estimated L ₃ aBMD (g/cm ²)	1.29 ±0.22	1.14 ±0.22	1.23±0.18	1.23 ±0.18	1.38 ±0.23	1.01 ±0.22
Height (cm)	176.86 ± 6.68	162.97 ±6.40	177.01 ±6.30	163.75 ±6.35	176.68 ±7.14	161.69 ±6.28
Weight (kg)	89.03 ± 15.20	71.96 ±16.05	88.66 ±15.30	73.36 ± 16.91	89.42 ± 15.06	69.58 ±14.20

M = men; W = women.

Table 2

Comparison of Unadjusted and Height/Weight-Adjusted Bone QCT Measures and Estimated L₃ Compressive Strength in Men and Women Matched for Age and Estimated Spine aBMD

	<i>N</i> = 981 matched pairs		
	Men	Women	% Diff
	Mean ± SE	Mean ± SE	
Unadjusted			
Cross-sectional area (cm ²)	12.39 ±0.0407	10.33 ±0.0407	20% [*]
Trabecular vBMD (g/cm ³)	0.137 ±0.0011	0.150 ±0.0011	−9% [*]
Integral vBMD (g/cm ³)	0.181 ±0.001	0.196 ±0.001	−8% [*]
Compressive strength (N)	4,623 ± 30	4,217 ± 30	10% [*]
Height and weight adjusted			
Cross-sectional area (cm ²)	11.86 ±0.0461	10.88 ±0.0467	9% [*]
Trabecular vBMD (g/cm ³)	0.138 ±0.0013	0.148 ±0.0013	−7% [*]
Integral vBMD (g/cm ³)	0.182 ±0.0013	0.195 ±0.0013	−7% [*]
Compressive strength (N)	4443 ± 37	4400 ± 37	1%

Least squares means and standard errors (SE) from mixed-effect regression analysis are presented.

* $p < 0.0001$ for men versus women.

Table 3

Comparison of Mean L₃ Compressive Loads and Factor-of-Risk for Two Activities of Daily Living in Men and Women Matched for Age and Estimated Spine aBMD

	<i>N</i> = 981 matched pairs		
	Men	Women	% Diff
	Mean ± SE	Mean ± SE	
Compressive force on L ₃ (N)			
Lifting	2080 ± 8	1671 ± 8	24% *
Open window	1846 ± 8	1491 ± 8	24% *
Factor of risk (load-to-strength ratio)			
Lifting	0.47 ± 0.0036	0.42 ± 0.0036	12% *
Open window	0.42 ± 0.0033	0.38 ± 0.0033	11% *

Least squares means and standard errors (SE) from the mixed-effect regression analysis are presented.

* $p < 0.0001$ for men versus women.