Osteoporosis Int (1994) 4:264–272

Osteoporosis International

Original Article

Relative Contribution of Vertebral Body and Posterior Arch in Female and Male Lumbar Spine Peak Bone Mass

P.-E. Fournier[1], R. Rizzoli[1], D. O. Slosman[2], B. Buchs[1] and J.-P. Bonjour[1]

[1]Division of Clinical Pathophysiology, WHO Collaborating Centre for Osteoporosis and Bone Disease, Department of Medicine; and [2]Division of Nuclear Medicine, Department of Radiology, University Hospital, Geneva, Switzerland

Abstract. Peak bone mass (PBM) is an important reference value in the diagnosis of osteoporosis. It is usually established by determining the areal bone mineral density (BMD in g/cm^2) for a given site of the skeleton in young healthy adults. This measurement takes into account both the thickness and the integrated mineral density of the bone scanned. It should therefore be a major determinant of the resistance to mechanical stress. However, in lumbar spine the mean BMD as determined by dual-energy either isotopic or X-ray (DXA) absorptiometry in antero-posterior (ap) view was repeatedly found not to be different between male and female young healthy adults despite the greater volume of lumbar vertebral bodies in males. A greater contribution of the posterior vertebral arch to areal BMD-ap in females than in males could account for such an apparent discrepancy. In order to clarify this issue we have determined in 65 (32 male and 33 female) young healthy adults aged 20–35 years the relative contribution of the vertebral body (VB) and posterior vertebral arch (VA) to BMD and bone mineral content (BMC) of L2–3 measured by both antero-posterior and lateral (lat) scanning using DXA. In young healthy adults mean BMC in antero-posterior view was found not to be significantly different from the total BMC determined by lateral scanning including both VB and VA. This allowed us then to calculate the VA BMC by substracting VB BMC-lat from BMC-ap. The results indicated that the mean value for males was significantly greater than that for females for BMC-ap (male/female ratio (mean ± SEM): 1.16 ± 0.05, $p<0.01$), BMC-lat (1.38 ± 0.07, $p<0.001$) and VB BMD-lat (1.16 ± 0.04, $p<0.001$). In sharp contrast, no sex difference was found in BMD-ap (male/female ratio: 0.99 ± 0.03) and VA BMC (male/female ratio: 0.97 ± 0.06). VA BMC represented 44% and 53% ($p<0.001$) of BMC-ap in males and females, respectively. Furthermore, in neither sex was any correlation between VA BMC and VB BMC found. In summary, this study indicates that the relative contribution of the posterior vertebral arch to the bone mineral content of L2–3 is significantly smaller in males than in females. This difference could partly explain the absence of a sex difference in areal BMD as measured in antero-posterior view. In agreement with lumbar anthropomorphometric data this study further shows that the sex difference in vertebral body size, an important component in mechanical resistance, is expressed when areal BMD is measured in lateral but not in antero-posterior scanning. Finally, the data analysis underlines the quantitative importance of the vertebral arch in the value of areal BMD as measured by DXA in the classical antero-posterior view, and demonstrates the absence of a significant quantitative relationship between the bone mineral content of the vertebral body and that of the posterior vertebral arch.

Keywords: Bone mineral density; Dual X-ray absorptiometry; Sex difference; Vertebral arch; Vertebral body

Correspondence and offprint requests to: Professor Jean-Philippe Bonjour, MD, Division of Clinical Pathophysiology, Department of Medicine, University Hospital, CH-1211 Geneva 14, Switzerland. Fax: (41–22) 382 99 73.

Introduction

Measurement of bone mineral density (BMD) or content (BMC) provides useful information for the detection and treatment of osteoporosis [1]. Dual

photon isotopic absorptiometry (DPA), and more recently dual-energy X-ray absorptiometry (DXA), have been widely used for BMD/BMC determination in the clinical and research settings of osteoporosis. The DXA technique provides non-invasive precise assessment of BMD/BMC at critical sites such as lumbar spine and femoral neck [2,3]. Compared with quantitative computed tomography (QCT), which has the capability to measure true volumetric mineral density (in mg hydroxyapatite/cm^3) and to differentiate trabecular from cortical bone, DXA provides areal BMD (in g hydroxyapatite/cm^2) measurements. Both the size (more precisely the thickness) and the volumetric mineral density of the scanned skeleton are integrated in the values of areal BMD. These two variables are important determinants of the resistance to mechanical stress [4–7] – hence the inverse relationship found between the incidence of osteoporotic fracture and areal BMD [8,9].

At the lumbar spine level, no significant difference was found between female and male young healthy adults in areal BMD as obtained in the classical antero-posterior (ap) view by either DPA or DXA. This is in sharp contrast to the sex difference commonly recorded in the areal BMD of the radial [10,11] or femoral [12,13] diaphysis. Note that at the lumbar spine level no significant difference in volumetric trabecular bone density between female and male young healthy adults has been detected by QCT [12–17]. Likewise, in adults younger than 50 years direct assessment of ash density of either trabecular bone or of the whole vertebral body of L2 did not reveal any significant difference between females and males [18–20]. Therefore, the absence of a sex difference in areal BMD as determined by DPA/DXA in the antero-posterior view of the lumbar vertebrae is difficult to explain given that the volume of a lumbar vertebra is greater in males than in females, whereas no sex difference can be detected in their mean trabecular mineral density [17,21–24]. This may suggest an important sex difference in the relative contribution of the posterior arch to the total bone mass of a lumbar vertebra. In order to clarify this issue we have determined in female and male young healthy adults aged 20–35 years the relative contributions of the vertebral body (VB) and posterior vertebral arch (VA) to BMD and BMC of L2–3 as evaluated in both antero-posterior and lateral scanning using DXA.

Subjects and Methods

Subject Recruitment

The cohort studied consisted of 65 Caucasian healthy subjects (33 females and 32 males) aged 20–35 years. The subjects were recruited from the technical, administrative and medical staff of the University Hospital of Geneva. Exclusion criteria comprised any chronic disease, gastrointestinal disease with a medical history of malabsorption, congenital or acquired bone disease, and intensive practice of physical exercise (more than 10 h/week). None of the subjects had a history of chronic alcohol consumption. One third of the subjects were or had been tobacco users.

Measurements of Bone Variables

BMD and BMC were determined by DXA, using Hologic QDR–1000/1000W instruments. The acquisition was made in both antero-posterior (ap) and lateral (lat) views according to a technique initially introduced for DPA [25] and then used for DXA [26–28]. For lateral scanning, the subjects were placed in the left lateral decubitus position with hips and knees in flexion. The pelvis was maintained perpendicular to the board of the instrument with a posterior support to ensure a stable position during scanning. The arms were placed above and in front of the head to avoid superimposition of ribs on the L2 vertebral body. A high-resolution mode of acquisition was used for the lateral view. For the determination of BMD/BMC of the vertebral body in the lateral view (VB BMD-lat/VB BMC-lat), the posterior limit of the scanned area was a line tangential the posterior wall of the vertebral body (see Fig. 1).

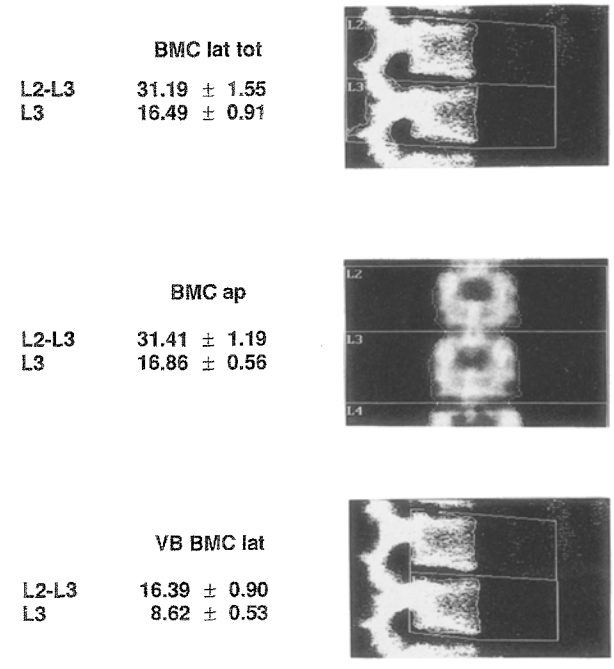

Fig. 1. Determination of L2–3 BMC in anteroposterior (ap) and lateral (lat) views. The figures illustrate the three scans used to determine by DXA the L2–3 BMC and how the derivation of the vertebral arc (VA) BMC was validated. In 20 young healthy subjects (see Methods for further details), bone scans of the lumbar spine were made in the classical antero-posterior view (*middle scan*) and in two different lateral views including (BMC lat tot, *top scan*) or excluding (VB BMC lat, *bottom scan*) the vertebral posterior elements. As indicated the mean BMCs (±SEM) were found to be identical in the antero-posterior and in the lateral view, thus validating the derivation of VA BMC by subtracting the vertebral body (VB) BMC-lat from BMC-ap.

The data were analyzed using the standard software (version 4.25) throughout the study. The coefficients of variation determined in healthy volunteers were 1.0% for L2–4 in antero-posterior view and 2.1% in lateral view [26]. The following variables were determined: BMD-ap and VB BMD-lat in g/cm^2; BMC-ap and VB BMC-lat in g; scanned area (Area-ap, VB Area-lat) in cm^2. BMC vertebral (posterior) arch (VA) was obtained by subtracting VB BMC-lat from BMC-ap. This derivation of VA BMC was validated as follows: in 20 young healthy subjects (11 males, mean age 31.2 ± 0.7 years; 9 females, mean age 27.3 ± 1.9 years), bone scans of the lumbar spine were made in both antero-posterior and lateral views. In the lateral view, the scanned area included both VB and the posterior elements, i.e. VA (Fig. 1). The mean BMCs were found to be identical in antero-posterior (L2–3 = 31.41 ± 1.19 g; L3 = 16.86 ± 0.56 g) and lateral views (L2–3) = 31.19 ± 1.55 g; L3 = 16.49 ± 0.91 g) (Fig. 1). The correlation coefficients between BMC in the antero-posterior and lateral views including both VB and VA were 0.85 for L2–3 ($p<0.001$) and 0.79 for L3 alone ($p<0.001$). The coefficient of variation (CV) of VA BMC measurement was determined from 15 paired scans obtained from the same subjects after repositioning, using the formula:

$$CV = \sqrt{(\Sigma\, d^2/2n)} \times 100/[(\text{mean}_1 - \text{mean}_2/2]$$

where d is the difference between two values for a given individual. It was 3.6% and 3.2% for L2 and L3, respectively.

Statistical Analysis

Results are expressed as the mean ± SEM. Significance of the difference was evaluated by one-way analysis of variance (ANOVA). The relations between variables were examined by calculating linear correlation coefficients. The t values of the differences between the slopes of the linear regressions were calculated according to the formula: $t = (b1 - b2)/\sqrt{(Sb1)^2 + (Sb2)^2}$, where $b1$ and $b2$ are the slopes of the regression lines, and $Sb1$ and $Sb2$ are the standard errors of these slopes [29].

Results

Anthropometric Characteristics

Table 1 presents the anthropometric variables of both female and male cohorts. As expected, both height and weight mean values were greater in males than in females. It is important to underline that these anthropometric variables did not differ from the age- and sex-matched reference values (Z-scores not significantly different from zero) previously established for the Swiss population [30]. Furthermore, there was no statistical significance sex difference in the mean Z-scores calculated for either height or weight. Thus, the mean (±SEM) Z-score for height was +0.030 ± 0.174 in females (n=33) and +0.074 ± 0.142 in males (n=32); the corresponding mean Z-score for weight was −0.123 ± 0.188 in females and −0.014 ± 0.157 in males. Hence, any difference in the lumbar bone variables between the

Table 1. Subject characeristics

	Males	Females
Number of subjects	32	33
Age (yr)	26.5±0.8	25.6±0.8
Height (cm)	179 ±1.1	165 ±1.2***
Weight (kg)	72.9±1.5	57.7±1.4***
BMI (kg/m^2)	22.9±0.4	21.1±0.4**

Values are the mean ± SEM.
Body mass index (BMI) was calculated as the weight/height^2 ratio and kg and m^2, respectively.
**$p<0.01$, ***$p<0.001$ as compared with males.

Table 2. Bone mineral density (BMD), bone mineral content (BMC) and scanned area (AREA) of lumbar vertebrae L2 and L3 measured in anteroposterior (ap) and lateral (lat) views

View	L2		L3	
	Males	Females	Males	Females
Antero-posterior				
BMD-ap (g/cm^2)	1.063±0.022	1.027±0.019	1.064±0.022	1.066±0.019
AREA-ap (cm^2)	15.35 ±0.26	12.65 ±0.28***	16.97 ±0.33	14.48 ±0.31***
BMC-ap (g)	16.39 ±0.52	13.03 ±0.41***	18.06 ±0.52	15.51 ±0.50**
Lateral[a]				
VB BMD-lat (g/cm^2)	0.788±0.019	0.711±0.019**	0.806±0.018	0.696±0.017***
VB AREA-lat (cm^2)	11.74 ±0.23	9.93 ±0.21***	12.42 ±0.23	10.41 ±0.25***
VB BMC-lat (g)	9.21 ±0.34	7.10 ±0.27***	10.07 ±0.35	7.30 ±0.29***

Values are the mean ± SEM.
[a] In lateral view, only vertebral body values were taken into account. The posterior limit of the scanned area was a line tangential to the posterior wall of the vertebral body.
** $p<0.01$, *** $p<0.001$ as compared with males.

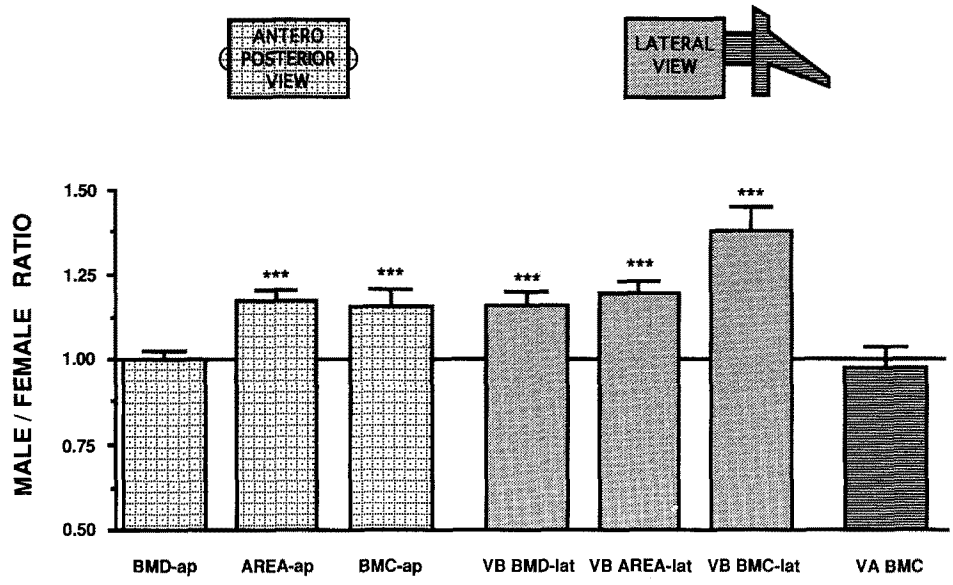

Fig. 2. Male to female ratio in densitometric and morphometric variables of L3 vertebra in young healthy adults. The values are the mean ± SEM determined in 32 male and 33 female subjects. BMD, bone mineral density in g/cm^2; BMC, bone mineral content in g; VA, vertebral arch; VB, vertebral body; ap, scanning in anteroposterior (frontal) view; lat, scanning in lateral (sagittal) view. VA BMC corresponds to the difference between BMC-ap and VB BMC-lat. See Methods for the validation of this calculation. ***$p<0.001$ as compared with a sex ratio of 1.0.

two genders cannot be ascribed to a biased selection of the cohort used in the present comparative study.

Bone Densitometric and Morphometric Variables

The absolute mean values of the bone variables are presented in Table 2. The corresponding male to female ratios of the densitometric and morphometric variables for L3 are depicted in Fig. 2. The male to female ratios for both VB BMD-lat (1.16 ± 0.04) and VB BMC-lat (1.38 ± 0.07) are much greater than those calculated for BMD-ap (0.99 ± 0.03) or BMC-ap (1.16 ± 0.05). Note that the male to female ratio of the scanned area was very similar in antero-posterior (1.17 ± 0.03) and lateral (1.19 ± 0.04) views. In contrast to VB BMC, VA BMC was not greater in males (7.99 ± 0.39 g) than in females (8.20 ± 0.36 g). The male to female ratio for VA of L3 was 0.97 ± 0.06 (Fig. 2). The relative contribution of the posterior elements to the total L2–3 BMC was significantly greater in females as compared with males. In L3 it amounted to 44 ± 1.4% and 53 ± 1.4% ($p<0.001$) in males and females, respectively (Fig. 3). The same trend was observed for L2 although the sex difference in the percentage contribution of VA BMC to the total BMC did not reach statistical significance for this vertebra.

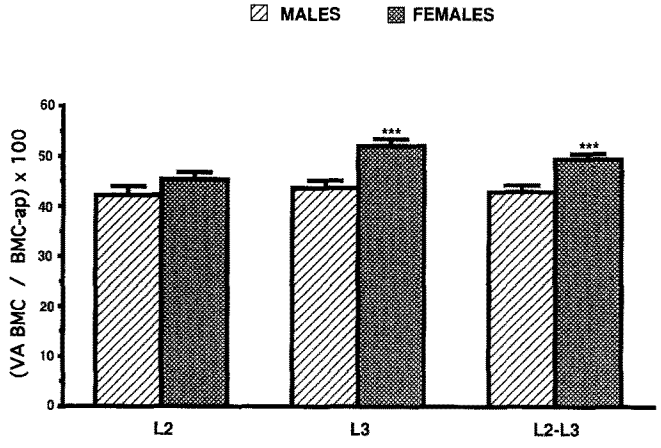

Fig. 3. Contribution of the vertebral arch to the total bone mineral content of vertebrae L2 and L3 in female and male young healthy adults. The values corresponds to the mean ± SEM of the vertebral arch (VA) BMC over that of the total BMC of L2 or L3 as determined by DXA in antero-posterior (ap) view in 32 male and 33 female subjects. VA BMC represents the difference between BMC-ap and VB BMC-lat (see Methods and Fig. 1). ***$p<0.001$ as compared with males.

Relation Between Vertebral Arch and Vertebral Body BMC

The relationship between VA BMC and BMC measured in antero-posterior or lateral view is shown in Fig. 4. As expected from the foregoing analysis indicating that VA BMC represents about half the mineral content determined in antero-posterior view, a significant positive relationship between L2 or L3 VA BMC and BMC-ap (Fig. 4) was found in both genders. Interestingly, no significant correlation was found between L2 or L3 VA BMC and VB BMC. This holds true for the relationships obtained in both the male and female cohorts (Fig. 4).

Relation Between Vertebral Body Size and Statural Height

The mineral content of axial and appendicular skeletal components has been shown to depend in part upon the

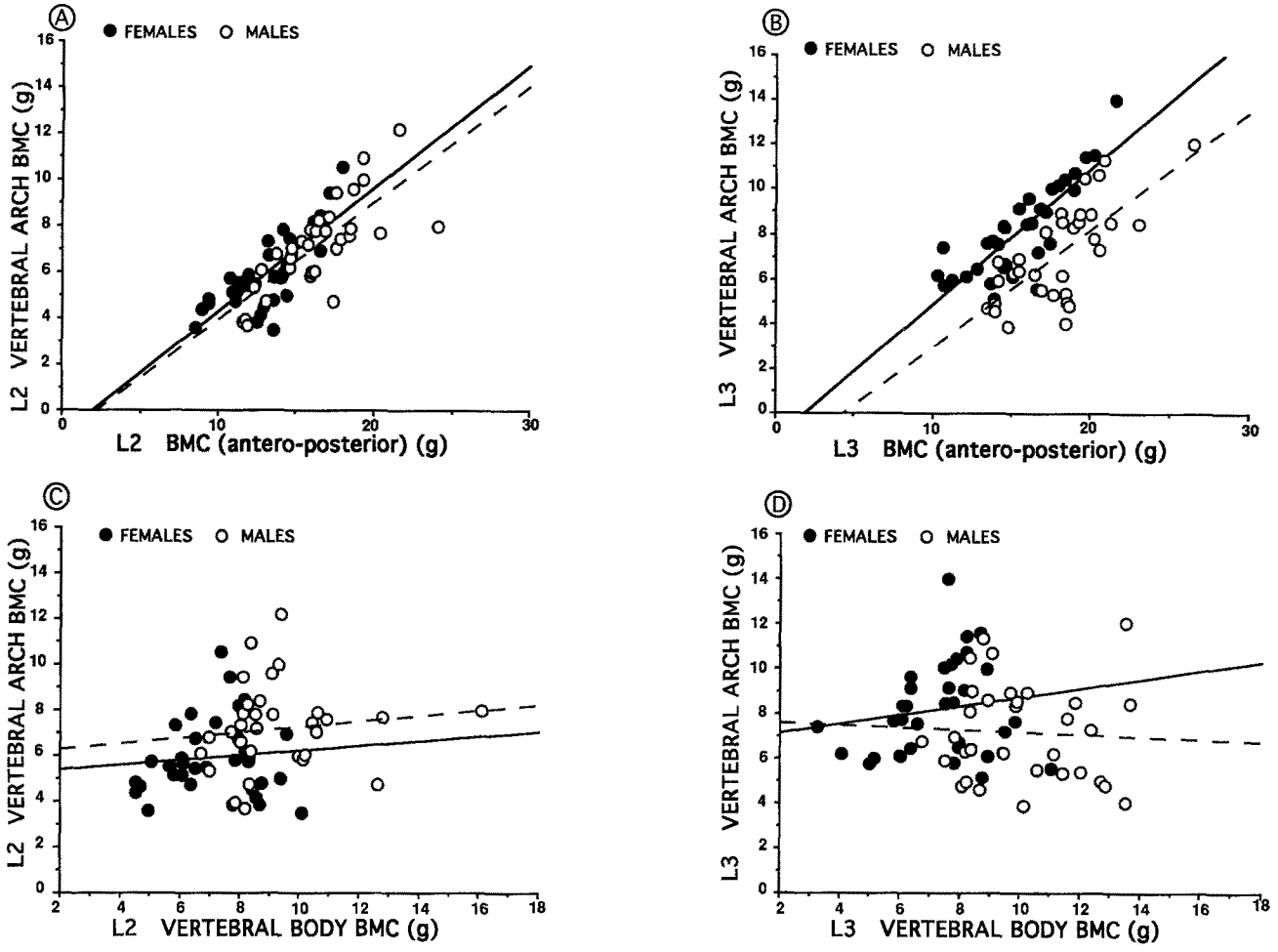

Fig. 4A–D. Relationships between vertebral arch BMC of L2–3 vertebrae and total BMC as measured in antero posterior view, or vertebral body BMC in female and male young healthy adults. Vertebral body BMC was measured as described in Methods. VA BMC represents the difference between BMC-ap and VB BMC-lat. In **A** (L2) the coefficients of correlation were: $r = 0.754$ ($p<0.001$) in males, and $r=0.762$ ($p<0.001$) in females. In **B** (L3) the coefficients of correlation were: $r=0.711$ ($p<0.001$) in males and $r=0.822$ ($p<0.001$) in females. The relations presented in **C** and **D** were not statistically significant.

statural height of the individual. The foregoing results indicated a sex difference in VB but not in VA BMC. Therefore, it appeared of interest to analyze the relationship between the size of VB in both its antero-posterior and lateral views and statural height. In both females and males tight correlations between frontal or sagittal area of VB and statural height were found for L2 and L3 (Fig. 5). However, as indicated in the legend to Fig. 5, the slopes (regression coefficients) of the linear regressions between statural height and L2–3 VB surface as measured in antero-posterior view were significantly steeper than those between statural height and L2–3 VB surface as determined in lateral view (L2: + 36%, $p<0.025$; L3: + 31%, $p<0.025$).

Biological Variability of the Bone Densitometric and Morphometric Values

Table 3 indicates the coefficients of variation of the different bone densitometric and morphometric variables in the two cohorts. The data confirm that the variability of the bone parameters is much greater than that of the statural height, the former being only slightly dependent upon the latter.

Discussion

Sex Difference in Peak Bone Mass Detected in Areal BMD-lat, but not in Areal BMD-ap

The determination of surface or areal BMD of the lumbar spine in antero-posterior view is widely used for the diagnosis of vertebral osteoporosis and thereby to predict the fracture risk of the axial skeleton. BMD-ap measurement includes not only the vertebral body but also the vertebral arch. The foregoing analysis from data collected in an anthropometrically representative sample of the young healthy adult population confirms that lumbar spine BMD in antero-posterior view as determined by DPA or DXA is not greater in men than

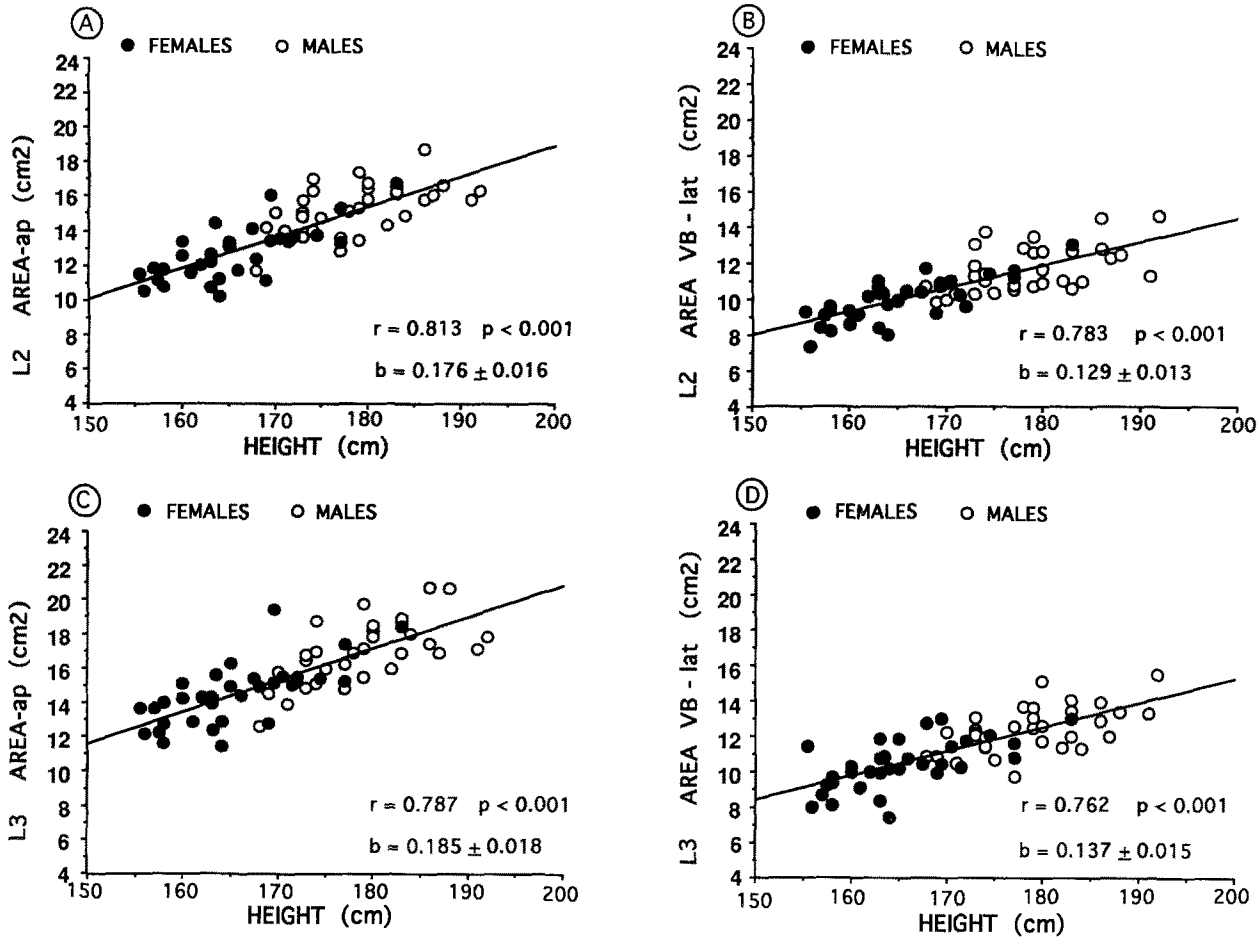

Fig. 5A–D. Relationship between the area of lumbar vertebra as determined by DXA and statural height in female and male young healthy adults. L2 (**A**) or L3 (**C**) AREA-ap corresponds to the surface of the vertebra scanned in antero-posterior (ap) view. L2 (**B**) or L3 (**D**) AREA VB-lat corresponds to the area of the vertebral body scanned in lateral (lat) view. The regression equations of the linear relationships were in **A**: $Y = 0.176X - 16.196$; in **B**: $Y = 0.129X - 11.318$; in **C**: $Y = 0.185X - 16.048$; in **D**: $Y = 0.137X - 12.101$. The slopes (b) of the relationships between statural height and either L2 or L3 AREA-ap (in **A**, $b = 0.176$ and in **C**, $b = 0.185$) were significantly ($p<0.025$) greater than those of the relationships between statural height and either L2 or L2 AREA-lat (in **B**, $b = 0.129$ and **D**, $b = 0.137$).

in women [12,13,17]. This finding can be expected to reduce the predictive value of this measurement for assessing the fracture risk of the vertebral body. Indeed, the resistance to mechanical stress is determined not only by the true mineral density, but also by the size or volume of the vertebral body which is generally greater in male than in female subjects. This gender difference in vertebral size was detectable by VB BMD-lat, therefore explaining, at least in part, the higher VB BMD-lat in males. Previous in vitro and in vivo investigations using gravimetry or QCT have indicated that the true trabecular mineral density of vertebral body was not greater in males than in females between 20 and 35 years of age [14–16,18–20]. In contrast the width of the vertebral body in the frontal plane was found, by direct morphometric analysis, to be about 15% greater in males [22,23]. Therefore, it appears that the 16% mean difference in VB BMD-lat we detected by DXA probably resulted, to a large extent, from the greater width of the vertebral body in the frontal plane in males.

The size of the bones is an important determinant of the resistance to stress. The notion is especially true for vertebral bodies, which are subjected to compression with superimposed bending forces in the sagittal plane and torsion around the long axis of the spine [4]. The axial stress that a vertebral body undergoes will be inversely related to its cross-sectional area. Thus, the cross-sectional area of the vertebral body is a critical determinant of the resistance to fracture besides the true mineral density, the orientation and spacing of the trabecular network, the thickness and porosity of the cortical shell, and the distribution of the bony tissue around the load axis [4–7].

Importance of the Vertebral Arch

The foregoing analysis furthermore indicated that only half of the total amount of mineral contained in L3 as measured by DXA scanning in antero-posterior view was present in the VB, i.e. in that part of the skeleton

Table 3. Variability (SD/mean × 100) of statural height, bone densitometric and morphometric variable of L3 vertebra in young healthy adults

	Males	Females
n	32	33
Height	3.58	4.04
BMC-ap	16.25	18.61
BMC-ap/height	15.48	16.74
VB BMC-lat	19.65	22.61
VB BMC-lat/height	18.48	21.84
VA BMC	27.31	25.46
VA BMC/height	27.17	23.71
BMC-ap	11.71	10.25
BMC-ap/height	12.80	10.41
VB BMC-lat	12.62	14.07
VB BMC-lat/height	12.66	15.01
Area-ap	10.91	12.50
Area-ap/height	9.11	10.12
VB area-lat	10.51	13.64
VB area-lat/height	8.91	11.78

actually at risk of fracture. A distribution of similar magnitude could be derived from data obtained in a study in which BMC of the vertebral body was compared with that obtained by antero-posterior view using DXA in female subjects [31]. Our results regarding the VB BMC-lat/BMC-ap ratios found in both sexes are consistent with two in vitro studies in which the calcium contents of the vertebral body and posterior arch were determined by ash chemical measurements [32] or neutron activation analysis [33]. At the level of L3, the vertebral body BMC corresponded to 42.8% and 50.6% of the whole vertrebra in females and males, respectively [32]. In isolated vertebrae before and after removal of the posterior elements, the BMC of the body as determined by DXA corresponded to 51.3% and 56.3% in females and males, respectively [33].

The fact that the contribution of the posterior arch to the total BMC of the vertebra is far from negligible would not introduce a flaw into the estimate of BMD-ap if the value of the VA/VB ratio were constant among individuals. However, as shown in the present study this did not appear to be the case, since in this cohort of young healthy adults no relation was found between VB and VA BMC over a wide range of values.

Whereas mean VB BMC was significantly greater in males than in females, no sex difference was found in VA BMC. The reason for this observation is intriguing. Among various hypotheses, one might evoke a difference in the mechanical forces exerted on the posterior arch. Such a difference could be related to the degree of lordosis, which at first sight may appear to be more pronounced in females. However, direct measurement of the degree of lordosis has not provided unequivocal results favouring the notion that it would be greater in females [34–36]. The fact that VA BMC is not greater in young healthy adult males than in females can explain, at least in part, the absence of a sex difference in 'peak' lumbar spine BMD as determined in antero-posterior view.

Sex Difference in Vertebral Body Morphometry

There is a relationship between some of the vertebral dimensions and statural height. Such a correlation has already been documented as far as the height of the vertebral body is concerned [37,38]. Postmortem morphometric analyses [17,21,22] indicate that the greatest sex difference is observed in the frontal plane (width) of the vertebral body. In Aharinejad's study [21], the male to female ratio was found to be about 1.11 in the frontal plane as compared with only 1.02 in the sagittal plane (depth) of the vertebral bodies.

Our analysis indicates that the male to female ratio in VB BMC-lat was reduced from 1.38 to 1.16 after correction by the area of the vertebral body. The slope of the relation between frontal area and statural height was steeper than that between sagittal area of vertebral body and statural height (see Fig. 4). Therefore, it is not surprising that correction by the statural height reduced the sex difference in VB BMD-lat, as the male to female ratio fell from 1.16 ± 0.04 to 1.07 ± 0.02 in L3, and from 1.11 ± 0.04 to 1.02 ± 0.04 in L2.

Our data do not entirely explain why mean BMD-ap was not greater in young healthy adult males than in females. Indeed, although both VA BMC as shown in this study, and volumetric trabecular bone density as previously documented [14,16,18], are not sex-dependent variables, nevertheless in lumbar vertebral bodies both the anterior and the posterior cortical margins were found to be thicker in males than in females [21]. The reason why this difference in the cortical thickness of the vertebral body was not translated into a greater mean BMD-ap in males suggests that another, currently unknown variable tends to cancel out this difference. In one of the rare morphometric studies comparing sex difference in young adult lumbar vertebrae [21], the mean anterior height of the vertebral body was greater than the corresponding mean posterior value in males but not in females. Therefore, the projected area in antero-posterior scanning of the lumbar spine could be somewhat overestimated in males as compared with females, and thereby results in some underestimation of BMD-ap in the former. It is obvious that the bone tissue corresponding to the rectangular surface in antero-posterior view is heterogeneously distributed. Thus, other discrete sex differences in the morphology of the vertebral body or of its posterior element could contribute to variation in the distribution of bone tissue corresponding to the DXA scanned surface [22,23].

Influence of Height on the Variability of Lumbar Spine Values

Finally, the study shows that the large scatter in the bone densitometric and morphometric variables of

lumbar vertebrae was only slightly reduced after correction for the statural height in both sexes. Half of the variance of VB BMC appears to be due to the size of the vertebra. The other half of the variance is probably related to the interindividual difference in both volumetric trabecular mineral density and the thickness of the cortical margin as observed in vivo by QCT and in vitro by direct morphometric and gravimetric analyses [14,16,18,21].

In summary, this study indicates that the relative contribution of the posterior vertebral arch to the bone mineral content of L2–3 is significantly smaller in males than in females. The difference could explain, at least in part, the fact that areal BMD as measured in antero-posterior view is not greater in males than in females. In agreement with data from anthropomorphometric studies of the lumbar spine, the foregoing results further show that the sex difference in vertebral body size, an important component in the resistance to mechanical stress, is expressed when areal BMD is measured using lateral but not antero-posterior scanning. Finally, the data analysis underlines the quantitative importance of the vertebral arch in the value of areal BMD as measured by DXA in the classical antero-posterior view, and demonstrates the absence of significant correlation between the bone mineral content of the vertebral body and that of the posterior vertebral arch.

Acknowledgements. We thank Eric Fleury, Christine Perron and Patrick Wagner for their technical assistance. R. Rizzoli is a recipient of a Max Cloetta career development award. We are grateful to Mrs Marie-Christine Brandt for preparation of this manuscript. This study was supported by the National Swiss Science Foundation (grant 32.32411.91). We are very grateful to Professor Ego Seeman (Endocrine Unit, Austin Hospital, Melbourne, Australia) for his critical review of the manuscript.

References

1. Johnston CC, Melton LJ, Lindsay R, Eddy DM. Clinical indication for bone mass measurements: a report from the Scientific Advisory board of the National Osteoporosis Foundation. J Bone Miner Res 1989;4 Suppl 2:1–28.
2. Genant HK, Steiger P, Faulkner KG, Majumbar S, Lang P, Glüer CC. Non-invasive bone mineral analysis: recent advances and future directions. In: Christiansen C, Overgaard K, editors. Osteoporosis 1990. Copenhagen: 435–47.
3. Slosman DO, Rizzoli R, Buchs B, Piana F, Donath A, Bonjour JP. Comparative study of the performance of X-ray and gadolinium-153 bone densitometers at the level of the spine, femoral neck and femoral shaft. Eur J Nucl Med 1990;17:3–9.
4. Melton JL, Chao E, Lane J. Biomechanical aspects of fractures. In: Riggs L, Melton LJ, editors. Osteoporosis: etiology, diagnosis and management. New York: Raven Press, 1988.
5. Einhorn TA. Bone strength: the bottom line. Calcif Tissue Int 1992;51:333–9.
6. Vesterby A, Mosekilde L, Gundersen JG, Melson F, Mosekilde L, Holme K, Sørensen S. Biologically meaningful determinants of the in vitro strength of lumbar vertebrae. Bone 1991;12:219–24.
7. Martin BR. Determinants of the mechanical properties of bone. J Biomech 1991;24:79–88.
8. Melton LJ, Kan SH, Wahner HW, Riggs BL. Lifetime fracture risk: an approach to hip fracture risk assessment based on bone mineral density and age. J Clin Epidemiol 1988;41:985–94.
9. Black DM, Cummings SR, Genant HK, Nevitt MC, Palermo L, Browner W. Axial and appendicular bone density predict fractures in older women. J Bone Miner Res 1992;7:633–8.
10. Hui SL, Johnston CC, Mazess RB. Bone mass in normal children and young adults. Growth 1985;49:34–43.
11. Geusens P, Dequeker J, Verstraeten A, Nijs J. Age-, sex-, and menopause-related changes of vertebral and peripheral bone: population study using dual and single photon absorptiometry and radiogrammetry. J Nucl Med 1986;27:1540–9.
12. Bonjour JP, Theintz G, Buchs B, Slosman D, Rizzoli R. Critical years and stages of puberty for spinal and femoral bone mass accumulation during adolescence. J Clin Endocrinol Metab 1991;73:555–63.
13. Buchs B, Rizzoli R, Slosman D, Nydegger V, Bonjour JP. Densité minérale osseuse de la colonne lombaire, du col et de la diaphyse fémoraux d'un échantillon de la population genevoise. Schweiz Med Wochenschr 1992;122:1129–36.
14. Genant HK, Cann CE, Pozzi-Mucelli RS, Kanter AS. Vertebral mineral determination by quantitative CT: clinical feasibility and normative data. J Comput Assist Tomogr 1983;7:554.
15. Gilsanz V, Gibbens DT, Roe TF, Carlson M, Senac MO, Boechat MI, et al. Vertebral bone density in children: effect of puberty. Radiology 1988;166:847–50.
16. Kalender WA, Felsenberg D, Louis O, Lopez P, Osteaux M, Fraga J. Reference values for trabecular and cortical vertebral bone density in single- and dual-energy quantitative computed tomography. Eur J Radiol 1989;9:75–80.
17. Kelly PJ, Twoney L, Sambrook PN, Eisman JA. Sex differences in peak adult bone mineral density. J Bone Miner Res 1990;5:1169–75.
18. Arnold JS. Amount and quality of trabecular bone in osteoporotic vertebral fractures. J Clin Endocrinol Metab 1973; 2:221–38.
19. Dunhill MS, Anderson JA, Whitehead R. Quantitative histological studies on age changes in bone. J Pathol Bacteriol 1967;94:275–91.
20. Mosekilde L, Mosekilde L. Sex differences in age-related changes in vertebral body size, density and biochemical competence in normal individuals. Bone 1990;11:67–73.
21. Aharinejad S, Bertagnoli R, Wicke K, Firbas W, Schneider B. Morphometric analysis of vertebrae and intervertebral discs as a basis of disc replacement. Am J Anat 1990;189:69–76.
22. Scoles PV, Linton AE, Latimer B, Levy ME, Digiovanni BF. Vertebral body and posterior element morphology: the normal spine in middle life. Spine 1988;13:1082–6.
23. Berry JL, Moran JM, Berg WS, Steffee AD. A morphometric study of human lumbar and selected thoracic vertebrae. Spine 1987;12:362–7.
24. Minne HW, Leidig G, Wüster C, Siromachkostov L, Baldauf G, Bickel R, et al. A newly developed spine deformity index (SDI) to quantitate vertebral crush fractures in patients with osteoporosis. Bone Miner 1988;3:335–49.
25. Uebelhart D, Duboeuf F, Meunier PJ, Delmas PD. Lateral dual-photon absorptiometry: a new technique to measure the bone mineral density at the lumbar spine. J Bone Miner Res 1990;5:525–31.
26. Slosman DO, Rizzoli R, Donath A, Bonjour JP. Vertebral bone mineral density measured laterally by dual-energy X-ray absorptiometry. Osteoporosis Int 1990;1:23–9.
27. Rupich R, Pacifici R, Griffin M, Vered I, Susman N, Avioli LV. Lateral dual energy radiography: a new method for measuring vertebral bone density: a preliminary study. J Clin Endocrinol Metab 1990;70:1768–70.
28. Larnach TA, Boyd SJ, Smart RC, Buttler SP, Rohl PG, Diamond TH. Reproducibility of lateral spine scans using dual energy X-ray absorptiometry. Calcif Tissue Int 1992;52:255–8.
29. Glanz SA, Slinker BK. Primer of applied regression and analysis of variance. Singapore McGraw-Hill, 1990.
30. Lentner C, editor. Geigy scientific tables. Basle, 1982.
31. Mazess RB, Gifford CA, Bisek JP, Barden HS, Hanson JA. DEXA measurement of spine density in the lateral projection. I. Methodology. Calcif Tissue Int 1991;49:235–9.
32. Nottestad SY, Baumel JJ, Kimmel DB, Recker RR, Heaney RP.

The proportion of trabecular bone in human vertebrae. J Bone Miner Res 1987;2:221–9.
33. Louis O, Van Den Winkel P, Covens P, Schoutens P, Osteaux M. Dual-energy X-ray absorptiometry of lumbar vertebrae: relative contribution of body and posterior elements and accuracy in relation with neutron activation analysis. Bone 1992;13:317–20.
34. Stagnara P, De Mauroy JC, Dran G, Gonon GP, Costanzo G, Dimnet J, Pasquet A. Reciprocal angulation of vertebral bodies in a sagittal plane: approach to references for the evaluation of kyphosis and lordosis. Spine 1982;7:335–42.
35. Fernand R, Fox DE. Evaluation of lumbar lordosis: a prospective and retrospective study. Spine 1985;10:799–803.
36. Carr AJ, Jeffersn RJ, Turner-Smith AR, Beavis A. An analysis of normal back shape measured by ISIS scanning. Spine 1991;16:656–9.
37. Gallagher JC, Hedlund LR, Stoner S, Meeger C. Vertebral morphometry: normative data. Bone Miner 1988;4:189–96.
38. Smith-Bindman R, Cummings SR, Steiger P, Genant HK. A comparison of morphometric definitions of vertebral fracture. J Bone Miner Res 1991;6:25–34.

Received for publication 12 July 1993
Accepted in revised form 15 December 1993