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Original Article

Peak Bone Density in Croatian Women: Variations at Different Skeletal Sites

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Abstract

It is known that different skeletal sites have different peak bone mass at different times and lose bone at different rates. The purpose of the study was to assess bone mineral density (BMD) in healthy female student population (N = 220), aged 18–25 yr and to analyze whether young women of that age have already started to lose the bone mass at the trabecular and cortical parts of skeleton. The influence of dietary intake and physical activity on their bone mass was also assessed. BMD was measured, using dual-energy X-ray absorptiometry technique, in spine, proximal femur, and distal third of the radius and in total body. Significant negative correlation between age and bone mass was found in all skeletal regions ($p < 0.05$ spine; $p < 0.0001$ total femur; and $p < 0.01$ total body) except in cortical part of the radius. Peak bone mass in young Croatian women was achieved before the age of 20, but later in the long-bone cortical skeleton, where BMD continued to increase after mid-20s. The BMD values are comparable with those from National Health and Nutrition Examination Survey study, except for the cortical part of the radius, where it is significantly lower. Body weight and physical activity were the most significant positive predictors of bone density in all measured sites.

Key Words: Bone mineral density; Croatia; diet; physical activity; young women.

Introduction

Peak bone mass is an important predictor of fracture risk later in life. Variations in peak bone mass between individuals are mostly related to genetics, but environmental factors also play a significant role in maximizing the bone mass. Many cross-sectional and follow-up studies indicated that physical activity and calcium supplementation are beneficial throughout childhood and adolescence *(1–8)*. Although the determinants of peak bone mass are well recognized, its exact timing is still controversial. It is widely accepted that most of the skeletal mass is acquired by the age of 20 and it slowly continues to grow until the end of the third decade of life or even later *(9)*. More recent studies suggested that peak bone density is almost completely achieved earlier, by the end of the adolescence. Theintz et al *(10)* and Matkovic et al *(11)* reported that most of the bone mass may be attained even by the age of 16. Cross-sectional studies also observed that the age at which peak bone mass is attained varies with the site of bone measurement. Lin and colleagues *(12)* proposed that the age of attaining peak bone mass at the hip is younger than the age for the same at the spine. However, there is little data about the differences in obtaining peak density in cortical part of the radius in comparison with other skeletal regions.

In this study, we measured bone mineral density (BMD) in cortical and trabecular bones of healthy female student population, aged 18–25 yr. Dietary intake and physical activity were also assessed. The aim of the study was to evaluate whether the young women between 18 and 25 yr have already reached their peak bone mass in the spine, femur, and cortical part of the radius. The influence of dietary calcium, physical

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activity, weight, and height on bone density was also explored.

Materials and Methods

Subjects

The participants were girl students of Kinesiology and Food Technology, from the University of Zagreb. In the recruitment process, we arranged lectures on the faculties to present the purpose and aims of the study to the students. They also received letters explaining in detail the study protocol. Exclusion criteria were primary or secondary amenorrhea, previous atraumatic fracture, diabetes, hyperthyroidism, and chronic use of medication that interferes with calcium metabolism. The response rate was very high (approx 90%) and a final number of 220 volunteers, who satisfied all the criteria, participated in the study. The study protocol has been approved by the Ethical Committee of the Institute for Medical Research and Occupational Health. Informed consent was signed by all the participants.

Every subject was interviewed by a physician to obtain information about age, years after menarche, diseases, fracture history, and drug therapy. The exclusion criteria were diseases affecting bone metabolism, prolonged immobilization, previous atraumatic fracture, and present or previous therapy with corticosteroids and thyroxin.

Anthropometry

Height and weight were measured to the nearest 0.5 cm and 0.5 kg, respectively, for each subject. Body mass index (BMI) was calculated as weight (kg) divided by square of height (m^2).

Bone Densitometry

BMD was measured using dual-energy X-ray absorptiometry (DXA; Lunar-Prodigy, Madison, WI). Measurements were made in lumbar spine (L2−L4), proximal femur, distal third of the radius, and whole body. Quality control was maintained by scanning spine phantom weekly, with the coefficient variation of 0.5%, which was inside the reference limits *(13)*. For interpretation of BMD results, T- and Z-scores were used. T-score represents the number of standard deviations (SDs) with respect to the mean BMD of a control population between 20 and 40 yr, using the manufacturer's reference values. For calculation of Croatian T-scores, the following formula was used *(14)*:

$$\text{T-score} = \frac{\text{measured BMD} - \text{mean BMD (sex-matched population)}}{\text{SD (sex-matched population)}}$$

According to the WHO criteria *(15)*, subjects were classified as normal (T-score > -1) or osteopenic (T-score < -1), taking into account Croatian and US reference range T-scores. The Z-score measures the departure of the patient's BMD value from the mean BMD for a healthy age- and sex-matched population and it is not used to define osteoporosis.

Dietary Assessment

The Quantified Food Frequency Questionnaire (FFQ) was used for dietary assessment in the form of personal interview with trained personnel. The FFQ consisted of 173 food items and the reference period was the previous year. Each subject was asked to recall consumption frequency, ranging from once a month to once or more a day. The relevant period of consumption of seasonal items was taken into account. The FFQ used in this study was applied in our previous study involving young Croatian adults *(16)*. In this study, dietary calcium intake was used for further analysis.

Physical Activity

Physical activity was recorded by quantifying the duration (mo/yr) and frequency (h/wk) of a sport activity and intensity (moderate/hard) and frequency (h/wk) of other physical activities. Moderate physical activities included gardening, housework, riding bicycle, bowling, and other similar activities and hard physical activities included heavy weight lifting or fitness. The frequency of sport activities and the frequency of other moderate and/or hard physical activities were categorized and scored as: (1) never, (2) 30 min to 1 h/wk, (3) 2−3 h/wk, (4) 4−6 h/wk, (5) 7−10 h/wk, (6) 11−20 h/wk, (7) 21−30 h/wk, and (8) >31 h/wk. The final score of physical activity was calculated for each subject by adding the years of sport activity to the frequency score. According to final score, physical activity was categorized as follows: 0−5 low, 6−10 medium, 11−15 good, 16−20 high, and >20 very high.

Statistics

Data were analyzed using statistical software Statistica, version 6.0 (StatSoft Inc., Tulsa, OK). The results are shown as mean values ± SD. The distribution of variables was tested with the Kolmogorov−Smirnov test. If the test was significant, then the hypothesis that the respective distribution was normal was rejected. Variables that have not been distributed normally were recalculated to new variables, using logarithmic function. The differences between two mean values were calculated using the *t*-test. Correlation matrices were used as a measure of relation between two or more variables. The association between BMD (dependent variable) and anthropometry, calcium intake, and physical activity (independent variables) was analyzed using multiple regression, controlling the influence of age, height, and weight. *B* coefficient showed the direction of the relationship between variables; if *B* coefficient is positive, then the relationship of this variable with the dependent variable is positive. *p* Value lower than 0.05 was considered significant.

Results

Descriptive characteristics of the subjects are summarized in Table 1. According to the physical activity score, 65 students had low physical activity, 78 medium, 44 good, 32 girls had high, and 1 girl had very high physical activity. Fourteen percent of young women had fractures caused by trauma but

Table 1
Descriptive Characteristics and Physical Activity in Subjects (N = 220)

Characteristic	Mean ± SD
Age (yr)	21.3 ± 1.7
Years after menarche	7.9 ± 2.3
Height (cm)	167.9 ± 5.4
Weight (kg)	60.2 ± 7.7
Body mass index (kg/m^2)	21.3 ± 2.1
Smoking (N = 49)	
Number of cigarettes	12.7 ± 5.9
Years	5.0 ± 1.7
Calcium intake (mg/d)	1377.9 ± 630.2
Physical activity score	7.9 ± 0.6 (range: 2–21)

Abbr: SD, standard deviation.

there was no difference in BMD between those with and without fractures. No significant differences in BMD of each scanned region were found between smokers and nonsmokers and between those who used hormonal contraceptives and those who did not.

In all subjects, Z-scores in radius were significantly lower than Z-scores in other regions (Fig. 1). The mean Z-score in the radius was negative (−0.829), whereas in other measured sites it was positive.

Significant negative correlations were found between age and BMD in all measured sites ($p < 0.05$ spine; $p < 0.0001$ total femur; and $p < 0.01$ total body), except for the radius ($r = 0.037$) where the correlation was slightly positive (Figs. 2–5). Significant negative correlation was found between age and femoral neck BMD ($p < 0.05$) and trochanter ($p < 0.05$). The results are not graphically presented. The rate of annual bone loss for the lumbar and femoral regions was 0.47% and 2.12%, respectively, and 0.64% for total body.

The prevalence of low BMD (T-score ≤ −1) based on local population reference range was 5.2% in spine, 7.1% in total femur, 12.3% in cortical part of radius, and 5.4% in total body, which was less compared with the prevalence based on Lunar reference densitometer values: 6.3% in spine, 7.4% in total femur, 41% in radius, and 6.1% in total body.

Using multiple regression, we analyzed whether anthropometry, calcium intake, or physical activity predicted bone mass status at different sites (Table 2). The most significant positive predictor of bone density in all measured sites was body weight ($p < 0.0001$ in spine, radius, and total body and $p < 0.01$ in femur), followed by physical activity ($p < 0.01$ in spine; $p < 0.001$ in radius; and $p < 0.05$ in total body). Age was inversely related to the BMD of all measured sites, with significance in the spine ($p < 0.05$) and femur ($p < 0.01$), but not in radius, where the correlation was positive.

Discussion

This study presents the data of BMD in young healthy Croatian women. Although the peak bone mass is thought to be attained by the end of the third decade, many studies indicate that adults reach peak bone mass by the early 20s *(17,18)*. Like Bonjour et al *(19)* and Neville et al *(5)*, we found a significant negative correlation between age and bone mass in young population, which suggests that adults in their early 20s already start to lose bone. The exception was the cortical bone in the radius, because bone mass at this site did not correlate inversely with age. Moreover, Z-scores for the radius

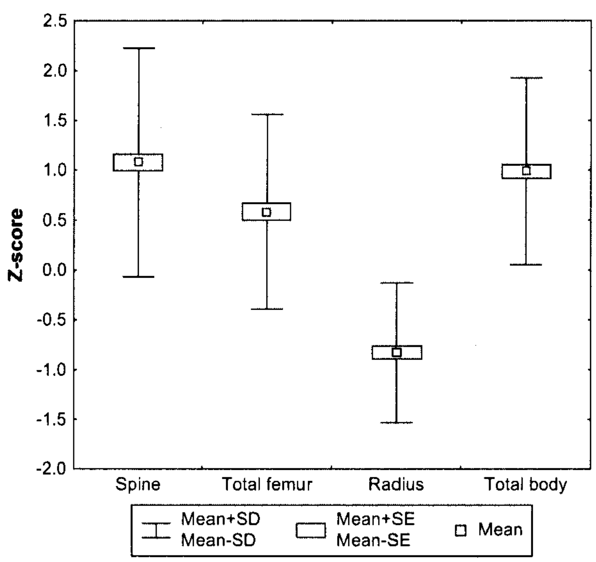

Fig. 1. Mean Z-score values of different skeletal sites in subjects.

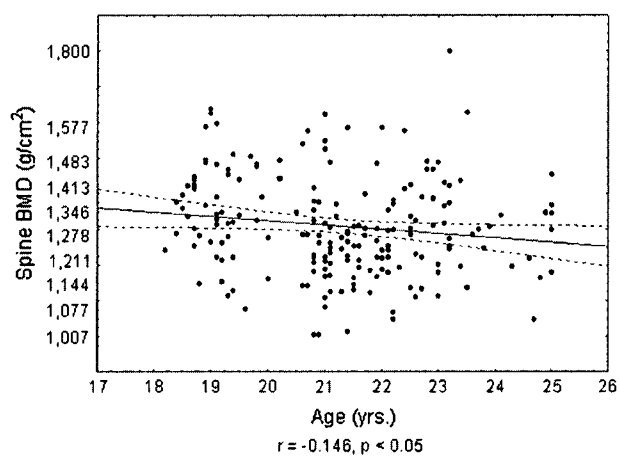

Fig. 2. Relationship of age to spine bone mineral density. Dotted curves are the limits of 95% confidence intervals.

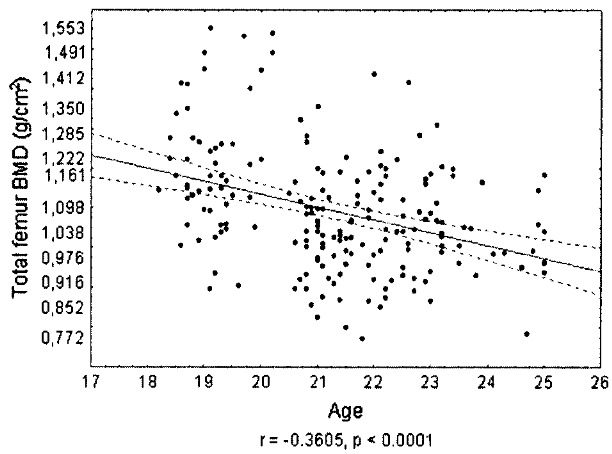

Fig. 3. Relationship of age to total femur bone mineral density. Dotted curves are the limits of 95% confidence intervals.

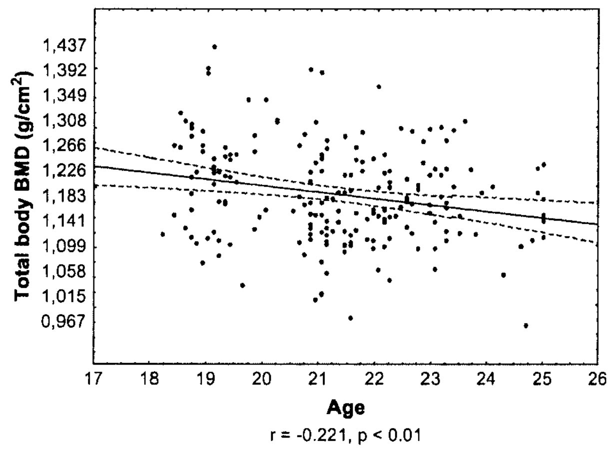

Fig. 5. Relationship of age to total body bone mineral density. Dotted curves are the limits of 95% confidence intervals.

were negative in most subjects, in contrast to positive Z-scores for other sites. This suggests that the peak bone mass of the cortical bone in radius is achieved later than in other parts of the skeleton. Regardless of that delay, it can be concluded that young women in Croatia have a lower peak bone mass in the cortical bone of the radius than the National Health and Nutrition Examination Survey (NHANES) reference values. Many authors suggest that the age at which peak BMD is obtained varies with the skeletal site. Lin et al *(12)* showed on 300 healthy white women, aged 18–32 yr, that peak BMD at the proximal femur was observed earlier (between 14.2 and 18.5 yr) than in the spine (23.0 yr). Lu et al *(20)* reported that peak BMD of the total body and spine occurred at 15.8 yr and in femoral neck at the age of 14.1 yr. Our results are also consistent with Matkovic et al *(11)*, who suggested that peak BMD for the trabecular part of the spine and femur was achieved at late adolescence or young adulthood. There are fewer data on peak BMD timing of the cortical bone in the radius. Long-bone shafts of the appendicular skeleton have a much larger proportion of cortical bone (>95%) than trabecular bone *(21)*. Several studies were consistent that bone mass of the radial shaft slightly continued to increase after the rapid cessation of accumulation of bone minerals at the age of 18 yr, in black and white women *(9,22,23)*. Our students had a significantly higher BMD in the spine, proximal femur, and total body and significantly lower BMD of the radial shaft, compared with the NHANES reference values. We can expect that cortical bone density in the radius will continue to rise in our young women, due to the positive correlation between

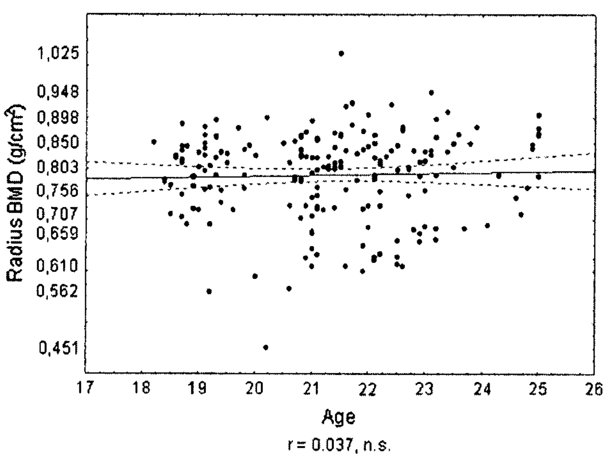

Fig. 4. Relationship of age to radius (distal third) bone mineral density. Dotted curves are the limits of 95% confidence intervals.

Table 2
Multiple Regression with BMD of Different Skeletal Sites as an Independent Variable and Anthropometry, Calcium Intake, and Physical Activity as Dependent Variables

Dependent variables	Significant predictor variables	*B* coefficient	*p* Value
BMD spine	Age	−0.009	0.05
	Body weight	0.005	0.0001
	Physical activity	0.008	0.001
	Calcium intake	0.010	0.05
BMD total femur	Age	−0.017	0.01
	Body weight	0.004	0.01
BMD radius	Body weight	0.004	0.0001
	Physical activity	0.007	0.001
	Calcium intake	0.008	0.05
BMD total body	Body weight	0.004	0.0001
	Physical activity	0.001	0.05

Abbr: BMD, bone mineral density.

age and cortical BMD. This increase will probably be slight, and eventually the cortical peak bone mass at that site will be lower in young Croatian women than in their American counterparts. Geographical variations in BMD worldwide are confirmed in many cross-sectional population-based studies. The EVOS study *(24)* has shown substantial differences in bone density between European populations. There is also evidence from a population-based sample that the peak BMD in the Middle East is lower than in young American subjects *(25)*. However, our results might be considered slightly specific, due to the marked differences between the bone mass in the radius and other skeletal sites.

From the epidemiological point of view, there are many studies on peak BMD or reference BMD data for many populations *(12,26–32)*, but none of them has determined midradius BMD using DXA technology. Therefore, we could not compare our reference results for radius BMD with the results of other female populations of the same age and to examine the possible discrepancy in their reference data.

As proposed by Heaney and Matkovic *(33)*, the peak bone mass is influenced by the propensity of some bones to expand with age. For example, the periosteal expansion on vertebral bodies increases slowly after rapid growth phase by the age of 18 until the menopause. As a result, total bone mass at that site increases slowly after adolescence, whereas bone density tends to fall. On the other side, little periosteal expansion after rapid growth occurs at the radial shaft and, therefore, bone mass and density rise slowly and in parallel with age at that site. That could be the possible reason for bone mass differences between midradius and other scanned sites in our young women.

Our results indicate that BMD in young adults is more influenced by physical activity than by calcium intake. The benefits of physical activity on acquisition and retention of bone mass are well known *(34–36)*. However, some studies have shown a greater influence on bone mass from calcium supplementation than physical activity *(37,38)*, whereas the others have shown the contrary *(39)*. Therefore, it is quite unclear whether physical activity or calcium intake is more important for bone mass acquisition. Because only a minority of young people consume optimal amounts of calcium, the physical activities in prepubertal and pubertal age may dominate as a positive factor in gaining an adequate bone mass early in life.

The limitation of this study is that the exact age of peak bone mass in our study group could have been established more accurately if we had included younger age groups. Due to the significant negative correlation between age and BMD in our young women, we might presume that their peak bone mass had been achieved even before the age of 18. To prove this, we should have recruited the younger, middle-school population, not just students. However, most studies on peak bone mass were based on participants not younger than 20 yr *(27–29,40,41)* and many of them recognized the highest BMD values in the youngest examined age group (20–25 yr or 20–30 yr), without presenting the data for younger population.

Due to the above-mentioned fact and also due to the relatively small number of participants, we think that the data from this study could not be used as normative peak BMD values for Croatian female population. However, some characteristics presented in this study, such as relatively early peak BMD timing, may lead to the conclusion that studies on peak bone mass should include participants younger than 20 yr.

We also could not look in a more detailed way at the effect of physical activity and calcium intake on bone mass because of the cross-sectional study design and retrospective data gathering.

Conclusions

Peak bone mass in Croatian female population is achieved before the age of 20, but later in the long-bone cortical skeleton. It is slightly higher than peak BMD of young American women, except in cortical part of the radius, where it appears to be lower. In our study sample, physical activity plays a more important role than calcium in maximizing bone mass in early adulthood.

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