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Bone mineral density by age, gender, pubertal stages, and socioeconomic status in healthy Lebanese children and adolescents

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Abstract

Gender, ethnicity, and lifestyle factors affect bone mass acquisition during childhood, thus the need for age- and sex-adjusted *Z* scores using ethnic-specific data for bone mineral density (BMD) measurement. This study aimed at establishing normative data for BMD in healthy Lebanese children and adolescents. Three hundred sixty-three healthy children aged 10 to 17 years (mean ± SD: 13.1 ± 2.0) were studied. BMD, bone mineral content (BMC), and lean mass were measured by dual-energy X-ray absorptiometry (DXA) using a Hologic 4500A device, and apparent volumetric BMD (BMAD) of the lumbar spine and the femoral neck were calculated. BMD, BMC, and BMAD were expressed by age groups and Tanner stages for boys and girls separately. There was a significant effect of age and puberty on all bone parameters, except at the femoral neck BMAD in boys. BMC and BMD were higher at cortical sites in boys, including subtotal body and hip; whereas, in girls, it was higher at a site more enriched in trabecular bone, namely the lumbar spine. At several skeletal sites, girls had significantly higher BMD adjusted for lean mass than boys. By the end of puberty, adolescents had a mean BMD that was 43–66% higher at the lumbar spine and 25–41% higher at cortical sites than pre-pubertal children, depending on the gender. Mean BMD values in the study group were significantly lower ($P < 0.01$) than Western normative values, with *Z* scores ranging between −0.2 and −1.1. In both genders, children of lower socioeconomic status tended to have lower BMD than those from a higher socioeconomic background.

This study allows additional insight into gender dimorphism in mineral accretion during puberty. It also provides a valuable reference database for the assessment of BMD in children with pubertal or growth disorders who are of Middle Eastern origin.

Keywords: Bone mineral density; Children; Puberty; Ethnicity; Gender

Introduction

Osteoporosis is a common health disorder of the elderly with pediatric roots [1]. Bone mass acquired during childhood is a key determinant of adult bone health, and a low peak skeletal mass is considered an important risk factor for accelerated involutional osteoporosis [2]. Indeed, some reports have related growth in infancy and childhood to the later risk of hip fractures [3]. Thus, determining the timing of bone mineral acquisition is an important step in the prevention of osteoporosis. Although there is no consensus regarding the age at which peak bone mineral density is acquired [4–6], a substantial amount of bone mineral accumulates during the adolescent years [7].

We have previously shown that peak bone mineral density (BMD) is slightly lower in Lebanese subjects as compared to Americans standards [8], and we have also

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demonstrated a high prevalence of hypovitaminosis D in Lebanese schoolchildren [9]. Because children with low vitamin D may be at high risk for reduced bone acquisition during growth, bone density values in children, and adolescents in Lebanese children may be lower than those of others. Furthermore, some studies have shown ethnic differences in bone mass [10–13], but we are unaware of any normative databases for BMD in children from the Middle East. Thus, ethnic-specific reference databases are needed to differentiate normal from impaired bone mass accretion in the Lebanese pediatric population.

This study aimed at providing ethnic-, gender-, and puberty-specific reference values for bone mineral density and content in healthy Lebanese children and adolescents.

Materials and methods

Subjects

Three hundred and sixty-three healthy school children (184 boys and 179 girls), between 10 and 17 years of age, were enrolled in a randomized, double-blind, placebo-controlled trial evaluating the efficacy of vitamin D supplementation on skeletal health. The data obtained at baseline were used for the purposes of this study. Participants were recruited during the period extending between December 2001 and June 2002 from four schools in the Greater Beirut area. To have balanced socioeconomic representation, the four schools were selected from school fees. Therefore, two private schools with yearly school fees exceeding US$ 5000 and two public schools with yearly school fees of less than US$ 700 were chosen.

The subjects were considered to be normal, based on a negative history for conditions known to affect bone metabolism, as well as on a careful physical examination by the study physicians. At entry, the subjects had a normal serum calcium, phosphorus, and alkaline phosphatase for age, and their mean serum 25 hydroxy-vitamin D (25 OH vitamin D) was 15.3 $\pm$ 7.4 ng/ml. Excluded were children with renal disease, liver disease, chronic diarrhea, and gastric and bowel surgery. Also excluded were children on high-dose vitamins within 6 months of study entry, as well as those on corticosteroid therapy, anti-epileptic drugs, rifampicin, or cholestyramine.

All the participants and/or one of their parents gave written informed consent to participate in the study, which was approved by the Institutional Review Board of the American University of Beirut.

Assessments

At baseline, the physical examination included height, weight, and pubertal stage assessment. The subject's standing height, using a wall stadiometer, was recorded in triplicate in centimeters to the nearest 1 mm, and the average was used in the analyses. Weight was recorded in kilograms, to the nearest 0.5 kg, with the participants wearing light clothes without shoes, and using a standard clinical balance. Mean height and weight were rounded to the nearest integer. Because national standards are not available, the height and weight percentiles were derived using American growth curves published by the U.S. National Center for Health Statistics [14]. Therefore, the children who were below the 3rd percentile or above the 95th percentile for height ($n = 9$ and $n = 7$, respectively) and for weight ($n = 5$ and $n = 34$, respectively) were considered healthy and were not excluded from the study. However, children who were below the 3rd percentile for height ($n = 9$) were excluded when BMD Z scores in the Lebanese subjects were compared to Western standards, to exclude the effect of body size on this variable. Pubertal status was determined by a physician (HK, MN, or MC), using breast and pubic hair stages in girls, testicular and pubic hair stages in boys, according to the established criteria of Tanner [15]. The results were reported using breast/testicular size staging only.

Exercise frequency was assessed from a questionnaire inquiring about the number of hours spent on sports per week. Calcium intake was assessed through a food frequency questionnaire that stressed the consumption of dairy products by adolescents in our population. The following vitamins were assessed: calcium pills, multivitamins, fluoride, and vitamin D. Socioeconomic status was considered high for the children attending private schools and low for those attending public schools. Blood was drawn for serum calcium, phosphorus, and alkaline phosphatase levels, which were measured by standard calorimetric methods, using the Hitachi 912 analyzer (Mannheim, Germany). In addition, 25(OH) vitamin D was assessed by RIA, and the normal range as reported in the kit insert was 10–60 ng/ml.

Areal bone mineral density BMD (g/cm^2) at the antero-posterior lumbar spine (L1–L4), the left femur (total hip, femoral neck and trochanter), the left 1/3 radius, BMC of the subtotal body (excluding head) and the subtotal body lean mass were measured by a dual-energy X-ray absorptiometry (DXA), using a Hologic 4500A device (Hologic, Bedford, MA, USA) in the fast array mode. The Canadian database provided by the densitometer software was used for comparison of the data obtained in this study [16]. There is a systematic difference in BMD, whether analyzed using the low density or the standard software [17–19]. Thus, to express BMD in the same analytic units, the pediatric low-density software was applied to all analyses. As per the recommendation of the Hologic manufacturer, the lumbar spine BMD Z scores were adjusted upward by 0.6 to compensate for the systematic difference between the two analysis protocols and to allow for comparison with the standard reference database in the analyses

(*Hologic manual, Lumbar spine analysis*, Chapter 8, pp. 8–36). Because inclusion of the head BMD in the calculation of total body BMD may lower the predictive value of some parameters for this variable, we elected to use subtotal body measurements in our analyses [20]. In our center, the mean ± SD for precision, expressed as the coefficient of variation (CV %) for 78 serial duplicate scans performed in vivo at the time of the study, were as follows: 0.89 ± 0.74% for the spine BMD, 0.47 ± 0.42% for the total hip BMD, 0.72 ± 0.61% for the femoral neck BMD, 1.16 ± 0.99% for the trochanter areal BMD and 1.01 ± 0.71% for the 1/3 radius. These

Table 1
Clinical characteristics of the study population

Variables	Boys (n = 184)	Girls (n = 179)	Whole group (n = 363)
Age (years)	13.0 ± 1.9	13.2 ± 2.1	13.1 ± 2.0
Height (cm)*	155 ± 13	153 ± 10	154 ± 12
Height percentile	47 ± 28	44 ± 29	45 ± 28
Weight (kg)**	52 ± 16	48 ± 12	50 ± 14
Weight percentile	59 ± 30	52 ± 28	55 ± 29
Body mass index (kg/m^2)*	21.0 ± 4.1	20.2 ± 3.5	20.6 ± 3.8
Muscle strength (psi)***	12.7 ± 3.6	11.2 ± 2.2	11.9 ± 3.1
Calcium intake (mg/day)*	766 ± 351	679 ± 366	723 ± 360
Exercise (h/week)***	7.9 ± 6.9	3.7 ± 4.8	5.9 ± 6.4
Sun exposure (min/week)**	547 ± 328	442 ± 332	496 ± 333
Socioeconomic status (high/low)	62/122	86/93	148/215
Serum calcium (mg/dl)	10.0 ± 0.3	9.91 ± 0.36	9.97±0.37
Serum phosphorus (mg/dl)	4.6 ± 0.5	4.3 ± 0.6	4.4±0.6
Serum alkaline phosphatase (mg/dl)	292 ± 101	212 ± 126	252±121
Subtotal lean mass (kg)***	33.0 ± 10.5	27.3 ± 5.7	30.2 ± 8.9
Bone area scanned (cm^2)			
Lumbar spine	55.2 ± 9.9	54.2 ± 8.0	54.7 ± 9.0
Subtotal body	1900 ± 347	1859 ± 287	1880 ± 319
Forearm***	2.5 ± 0.3	2.3 ± 0.2	2.4 ± 0.3
Total hip***	31.8 ± 7.1	28.5 ± 3.9	30.1 ± 6.0
Femoral neck***	4.8 ± 0.5	4.5 ± 0.5	4.7 ± 0.5
Tanner staging			
I	48	22	70
II	49	38	87
III	33	52	85
IV	34	61	95
V	20	6	26

Values are mean ± SD.
* Statistically significant difference between boys and girls subjects at $P < 0.05$.
** Statistically significant difference between boys and girls subjects at $P < 0.01$.
*** Statistically significant difference boys and girls subjects at $P < 10^{-4}$.

Table 2
Gender-specific values of bone mineral content (BMC), bone mineral density (BMD) and apparent volumetric BMD (BMAD) by age group

		10–10.9 years	11–11.9 years	12–12.9 years	13–13.9 years	14–14.9 years	15–15.9 years	16–16.9 years	17–17.9 years
L1–L4 BMD[a,*] (g/cm^2)	Boys	0.56 ± 0.04	0.58 ± 0.06	0.61 ± 0.07	0.65 ± 0.08	0.75 ± 0.09	0.79 ± 0.09	0.85 ± 0.13	0.91 ± 0.10
	Girls	0.59 ± 0.07	0.63 ± 0.09	0.67 ± 0.09	0.75 ± 0.12	0.83 ± 0.1	0.85 ± 0.08	0.84 ± 0.08	0.91 ± 0.09
L1–L4BMAD[a,*] (g/cm^3)	Boys	0.083 ± 0.006	0.083 ± 0.007	0.086 ± 0.010	0.086 ± 0.008	0.095 ± 0.008	0.097 ± 0.010	0.102 ± 0.010	0.109 ± 0.090
	Girls	0.088 ± 0.009	0.090 ± 0.010	0.094 ± 0.010	0.101 ± 0.010	0.109 ± 0.001	0.108 ± 0.010	0.107 ± 0.010	0.110 ± 0.010
Subtotal body BMC[a,*] (grams)	Boys	973 ± 226	1157 ± 238	1270 ± 249	1510 ± 302	1810 ± 373	1968 ± 339	2065 ± 315	2239 ± 155
	Girls	1004 ± 209	1132 ± 250	1323 ± 212	1429 ± 297	1622 ± 292	1629 ± 198	1672 ± 225	1701 ± 193
Forearm BMD* (g/cm^2)	Boys	0.49 ± 0.04	0.52 ± 0.04	0.54 ± 0.06	0.57 ± 0.04	0.61 ± 0.06	0.64 ± 0.05	0.67 ± 0.07	0.68 ± 0.06
	Girls	0.49 ± 0.04	0.52 ± 0.03	0.55 ± 0.04	0.58 ± 0.05	0.62 ± 0.03	0.63 ± 0.05	0.63 ± 0.04	0.63 ± 0.03
Total hip BMD[a,*] (g/cm^2)	Boys	0.70 ± 0.13	0.74 ± 0.08	0.77 ± 0.09	0.86 ± 0.12	0.95 ± 0.12	0.95 ± 0.13	1.05 ± 0.16	1.01 ± 0.10
	Girls	0.64 ± 0.07	0.72 ± 0.10	0.75 ± 0.09	0.80 ± 0.12	0.84 ± 0.09	0.85 ± 0.09	0.86 ± 0.09	0.88 ± 0.10
Femoral neck BMD[a,*] (g/cm^2)	Boys	0.66 ± 0.13	0.72 ± 0.09	0.73 ± 0.09	0.80 ± 0.10	0.86 ± 0.11	0.87 ± 0.11	0.90 ± 0.16	0.98 ± 0.06
	Girls	0.61 ± 0.06	0.66 ± 0.09	0.71 ± 0.08	0.74 ± 0.11	0.77 ± 0.10	0.79 ± 0.08	0.80 ± 0.09	0.84 ± 0.11
Femoral neck BMAD (g/cm^3)	Boys	0.153 ± 0.03	0.159 ± 0.03	0.158 ± 0.02	0.165 ± 0.02	0.169 ± 0.02	0.162 ± 0.02	0.164 ± 0.03	0.174 ± 0.01
	Girls*	0.148 ± 0.01	0.154 ± 0.02	0.156 ± 0.02	0.161 ± 0.03	0.159 ± 0.02	0.169 ± 0.02	0.174 ± 0.02	0.171 ± 0.03
Trochanter BMD[a,*] (g/cm^2)	Boys	0.57 ± 0.13	0.60 ± 0.07	0.61 ± 0.08	0.69 ± 0.10	0.76 ± 0.10	0.75 ± 0.11	0.80 ± 0.12	0.76 ± 0.09
	Girls	0.51 ± 0.06	0.57 ± 0.08	0.60 ± 0.08	0.64 ± 0.09	0.66 ± 0.08	0.66 ± 0.07	0.66 ± 0.08	0.67 ± 0.07

Values are mean ± SD.
[a] Statistically significant effect of gender on BMC/BMD/BMAD after adjustment for age in linear regression ($P < 0.001$).
* Statistically significant effect of age within gender (one-way ANOVA).

values fell within the values we and others have reported [21–23]. Because differences in areal BMD may be a reflection of differences in bone size between genders and pubertal stages, we reported the area of bone scanned for all skeletal sites of interest. In addition, to correct bone density for bone size, apparent volumetric BMD (BMAD g/cm^3) of the lumbar spine and the femoral neck were calculated as previously described, using the following formula: spine BMAD = BMC/A$^{3/2}$ and femoral neck BMAD = BMC/A^2, where BMC is the bone mineral content and A is the projected area [24]. Because of the substantial impact of lean mass on BMD in general and the changes in both lean mass and bone mass during puberty in particular, areal BMD and total body BMC were expressed as a function of lean mass [25,26]. Therefore, the gender difference in BMD and BMC was assessed both before and after such correction.

Statistical analysis

Analyses were performed for boys and girls separately. Differences between the two groups were assessed by independent *t* test. Children were subdivided into eight age groups at one-year intervals in each. The effects of age and puberty on bone parameters within each gender were assessed using one-way analysis of variance (ANOVA). The effect of gender on bone parameters, adjusting for age or pubertal stage, was assessed using linear regression analyses. General linear models were used to evaluate interactions between gender and Tanner stages at different skeletal sites. All results are expressed as mean ± SD; *P* values < 0.05 were considered as statistically significant and were not adjusted for multiple testing. All analyses were carried out using SPSS software, version 10.0 (SPSS, Chicago, IL).

Results

Clinical characteristics

Clinical characteristics of the study population are shown in Table 1. The mean age of study participants was 13.1 ± 2.0 years, with no difference in age between boys and girls. As anticipated, boys were taller, had higher BMI, calcium intake, sun exposure, muscle strength, and exercise level than girls (Table 1). There was balanced representation from both genders. A history of peripheral fracture was reported in 58 children (28% of boys and 10% of girls). Serum calcium, phosphorus, and alkaline phosphate levels were normal in all children (Table 1).

Effect of gender, age, and puberty on skeletal parameters

Normative values for BMD, BMC, and BMAD, expressed by age and gender subgroups, are shown in Table 2. In general, areal BMD values were higher in boys than in girls at cortical sites, including subtotal body BMC (Table 2). Conversely, values were higher at the lumbar spine in girls, including areal BMD values and BMAD (Table 2), despite similarities in the area scanned in the overall group (Table 1) and in the subgroups matched by pubertal stages between the two genders. In both genders, BMD, BMC, and BMAD increased significantly with age at all skeletal sites, except for the femoral neck BMAD in boys (ANOVA, Table 2).

Normative values for BMD, BMC, and BMAD, expressed by gender and Tanner stage subgroups, are shown in Table 3. In both genders, BMD, BMC, and BMAD increased significantly with increments in pubertal stages at all skeletal sites, except for femoral neck BMAD in boys (ANOVA, Table 3, Figs. 1–3). The general linear model procedure demonstrated a significant interaction between gender and

Table 3
Gender-specific values of bone mineral content (BMC), bone mineral density (BMD) and apparent volumetric BMD (BMAD) by Tanner stages

		Tanner I	Tanner II	Tanner III	Tanner IV	Tanner V
L1–L4 BMD[a,*] (g/cm^2)	Boys	0.57 ± 0.07	0.6 ± 0.05	0.64 ± 0.06	0.78 ± 0.10	0.86 ± 0.08
	Girls	0.54 ± 0.06	0.63 ± 0.07	0.75 ± 0.10	0.84 ± 0.09	0.90 ± 0.09
L1–L4 BMAD[a,*] (g/cm^3)	Boys	0.084 ± 0.009	0.085 ± 0.007	0.087 ± 0.008	0.097 ± 0.01	0.103 ± 0.01
	Girls	0.082 ± 0.007	0.090 ± 0.009	0.101 ± 0.01	0.109 ± 0.01	0.114 ± 0.01
Subtotal body BMC[a,*] (g)	Boys	1141 ± 273	1176 ± 270	1406 ± 258	1955 ± 347	2150 ± 135
	Girls	926 ± 226	1161 ± 226	1403 ± 255	1642 ± 260	1686 ± 206
Forearm BMD[*] (g/cm^2)	Boys	0.52 ± 0.07	0.53 ± 0.04	0.55 ± 0.06	0.63 ± 0.06	0.67 ± 0.05
	Girls	0.44 ± 0.03	0.52 ± 0.03	0.58 ± 0.05	0.62 ± 0.04	0.64 ± 0.05
Total hip BMD[a,*] (g/cm^2)	Boys	0.73 ± 0.13	0.77± 0.09	0.81 ± 1.0	0.97 ± 0.13	1.03 ± 0.08
	Girls	0.60 ± 0.08	0.70 ± 0.07	0.79 ± 0.08	0.86 ± 0.09	0.85 ± 0.10
Femoral neck BMD[a,*] (g/cm^2)	Boys	0.70 ± 0.14	0.73 ± 0.08	0.76 ± 0.09	0.89 ± 0.13	0.93 ± 0.07
	Girls	0.58 ± 0.08	0.66 ± 0.06	0.73 ± 0.08	0.79 ± 0.10	0.80 ± 0.10
Femoral neck BMAD (g/cm^3)	Boys	0.156 ± 0.03	0.163 ± 0.02	0.160 ± 0.02	0.166 ± 0.02	0.170 ± 0.018
	Girls[*]	0.147 ± 0.02	0.149 ± 0.01	0.161 ± 0.02	0.169 ± 0.02	0.159 ± 0.02
Trochanter BMD[a,*] (g/cm^2)	Boys	0.58 ± 0.10	0.62 ± 0.08	0.65 ± 0.07	0.78 ± 0.11	0.79 ± 0.08
	Girls	0.48 ± 0.06	0.55 ± 0.06	0.63 ± 0.07	0.67 ± 0.08	0.64 ± 0.07

Values are mean ± SD.
[a] Statistically significant effect of gender on BMC/BMD/BMAD after adjustment for Tanner stage in linear regression ($P < 0.001$).
[*] Statistically significant effect of puberty within gender (one-way ANOVA).

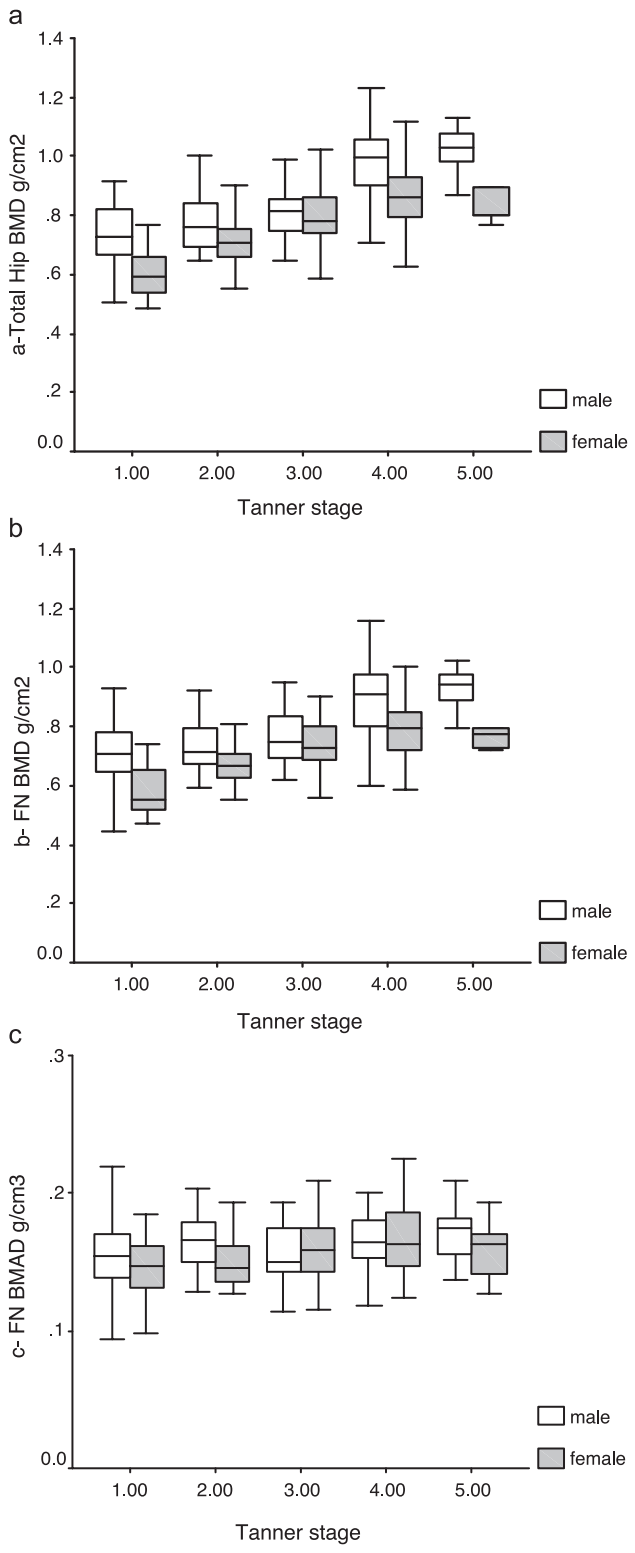

Fig. 1. Boxplots showing the median and interquartile range of total hip bone mineral density (BMD) panel a, femoral neck bone mineral density (FN BMD) panel b, and femoral neck apparent volumetric bone mineral density (FN BMAD) panel c, for males and females by Tanner stages. There was a significant effect of puberty on BMD at all skeletal sites within each gender, and a differential effect of gender on BMD increments with pubertal stages, (gender xTanner interaction, $P < 0.05$).

Tanner stages at all these skeletal sites, thus implying gender differences in BMD increments with pubertal stages (Figs. 1–3).

Girls who completed their pubertal development (Tanner stage V) had mean BMD values at the lumbar spine, the forearm, the total hip, the femoral neck, and the trochanter that were 66%, 34%, 41%, 37%, and 33% higher than corresponding values in pre-pubertal girls (Tanner stage I). Similarly, boys who reached Tanner stage V had a mean BMD value that was 43% higher at the spine, 25% at the forearm, 35% at the hip, 28% at the femoral neck, and 32% at the trochanter than corresponding values in pre-pubertal boys.

When parallel analyses were done using pubic hair for Tanner staging, the results were similar to those derived by using testicular and breast development for Tanner staging (data not shown).

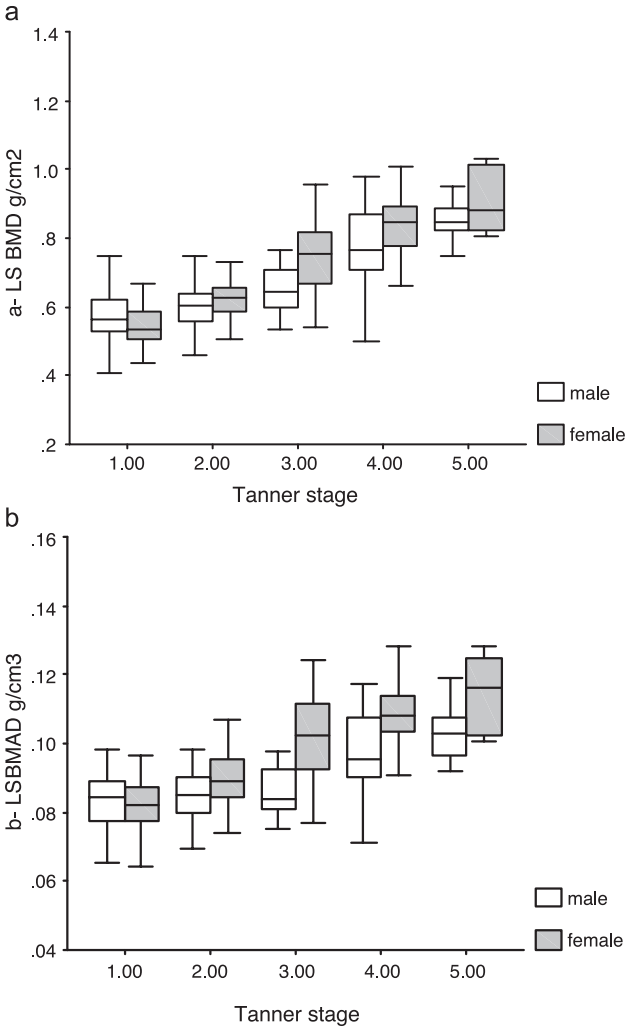

Fig. 2. Boxplots showing the median and interquartile range of lumbar spine bone mineral density (LS BMD) panel a, and apparent volumetric bone mineral density (LS BMAD) panel b, for males and females by Tanner stages. There was a significant effect of puberty on BMD and BMAD within each gender, and a differential effect of gender on BMD increments with pubertal stages, (gender xTanner interaction, $P < 10^{-4}$).

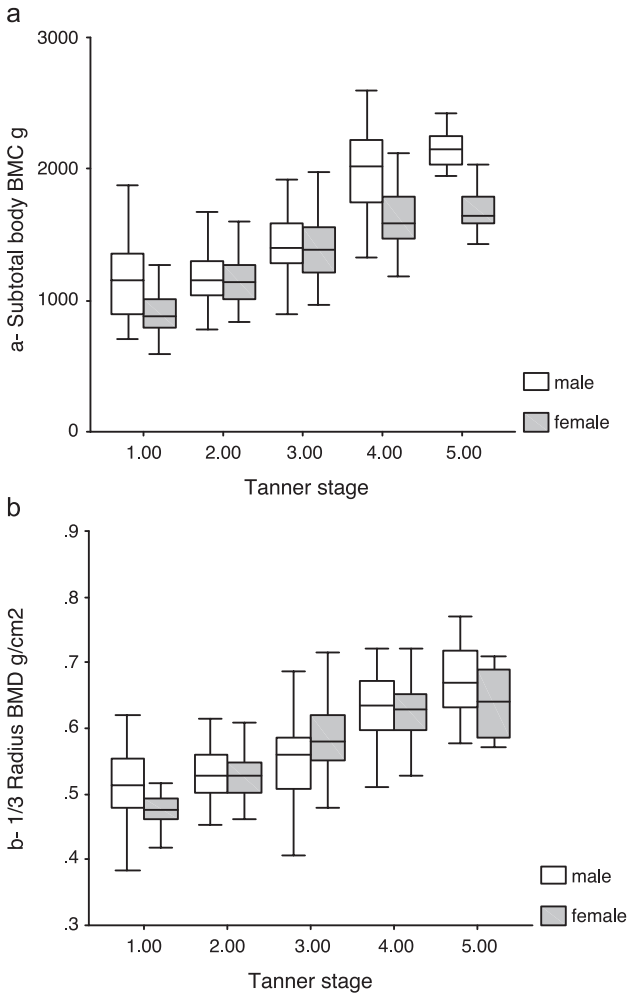

Fig. 3. Boxplots showing the median and interquartile range of subtotal body bone mineral content (BMC) panel a, and forearm bone mineral density (BMD) panel b, for males and females by Tanner stages. There was a significant effect of puberty on BMC and BMD within each gender, and a differential effect of gender on BMD increments with pubertal stages (gender xTanner interaction, $P < 0.01$).

Effect of gender, age, and puberty on skeletal parameters adjusted for lean mass

In boys, but not in girls, there was a significant decrement in the subtotal body BMC/lean mass and in the BMD/lean mass at all skeletal sites, with increasing Tanner stages, $P < 0.05$ by ANOVA (Figs. 4 and 5). The general linear model demonstrated a significant effect of gender on these parameters at all skeletal sites. In children with advanced pubertal stages (Tanner stages III–V), girls had significantly higher values of subtotal body BMC/lean mass and of BMD/lean mass at all skeletal sites than boys of the same Tanner stage, $P < 0.05$ by t test (Figs. 4 and 5).

Comparison with Western databases

Z scores in the study group were derived through the densitometer software using a Canadian database as reference. For girls, the mean Z scores were: −0.2 at the spine, −1.2 at the total body, −0.2 at the total hip, −0.4 at the femoral neck and −0.2 at the trochanter. For boys, the mean Z scores were: −0.3 at the spine, −1.1 at the total body, −0.05 at the total hip, −0.2 at the femoral neck and −0.06 at the trochanter. Comparing these Z scores against zero demonstrated that, except at the trochanter and the total hip in boys, mean BMD in healthy Lebanese pediatric subjects is lower than that of age- and gender-matched Canadian children ($P < 0.01$).

Socioeconomic status

Pre-pubertal and peri-pubertal children of high socio-economic status (SES) were taller than those of low SES

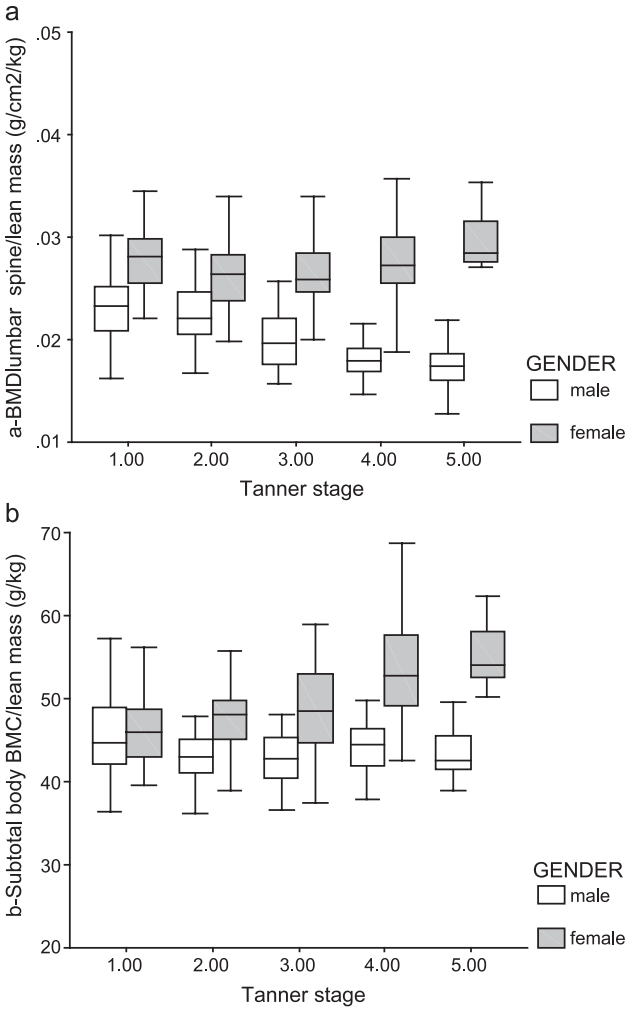

Fig. 4. Boxplots showing the median and interquartile range of lumbar spine bone mineral density (BMD)/lean mass panel a, and subtotal body bone mineral content (BMC)/lean mass panel b, for males and females by Tanner stage. In boys, there was a significant effect of puberty on lumbar spine BMD/lean mass and subtotal body BMC/lean mass ($P < 0.001$, $P = 0.06$ respectively). There was a gender effect on lumbar spine BMD/lean mass and subtotal body BMC/lean mass ($P < 0.001$).

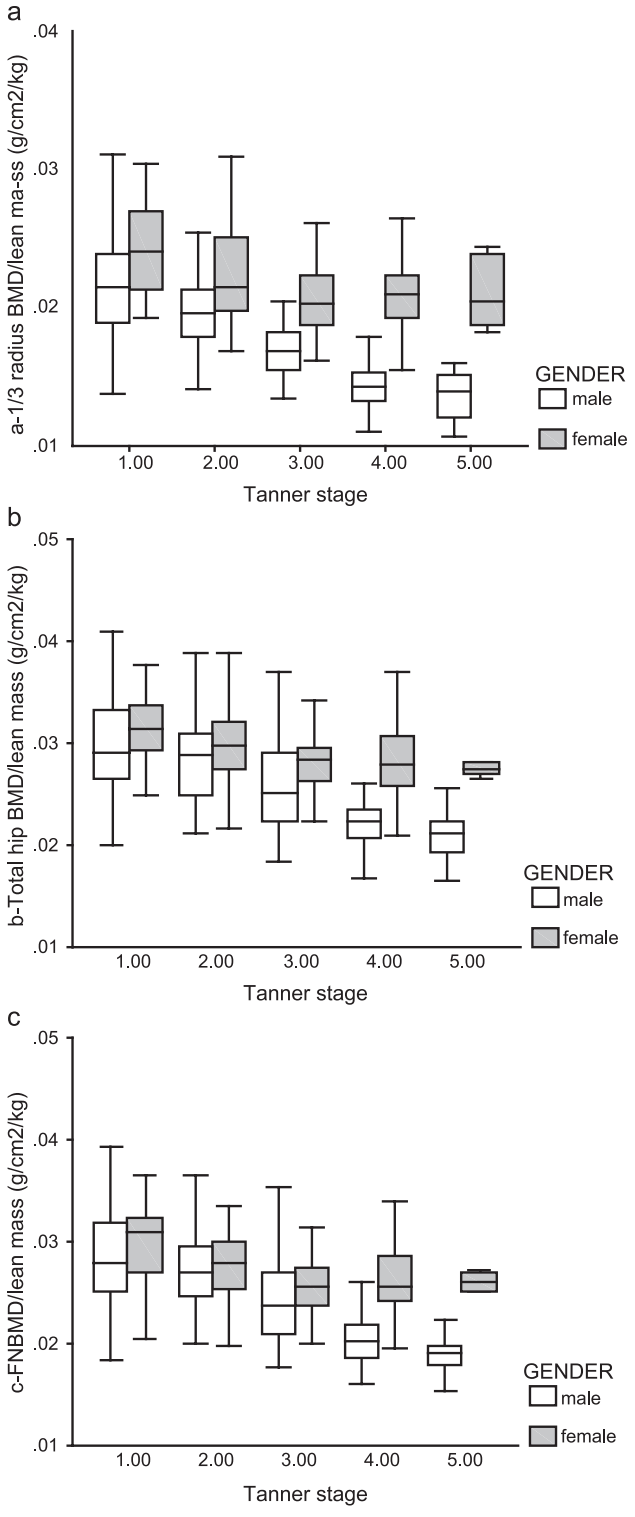

Fig. 5. Boxplots showing the median and interquartile range of forearm bone mineral density (BMD)/lean mass panel a, total hip BMD/lean mass panel b and femoral neck (FN) BMD/lean mass panel c, for males and females by Tanner stage. In boys, there was a significant effect of puberty on BMD/lean mass at the three sites ($P < 0.0001$). There was a gender effect on BMD/lean mass at the three sites ($P < 0.0001$).

of the same gender, but this difference was not observed in those who were at an advanced stage of their pubertal development (data not shown).

Table 4
Gender-specific mean values of bone mineral content (BMC), bone mineral density (BMD) and apparent volumetric bone mineral density (BMAD) by Tanner stages according to the socioeconomic status (SES)

		Tanner I		Tanner II		Tanner III		Tanne IV		Tanner V	
		Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys	Girls	Boys
Number	H	7	15	13	13	23	8	38	15	5	11
	L	15	33	25	36	29	25	23	19	1	9
L1–L4 BMD	H	0.57 ± 0.08	0.60 ± 0.07	0.61 ± 0.06	0.61± 0.05	0.78 ± 0.09	0.65 ± 0.07	0.86 ± 0.07	0.79 ± 0.13	0.92 ± 0.1	0.89 ± 0.07
	L	0.52 ± 0.04	0.56 ± 0.07	0.64 ± 0.08	0.60 ± 0.05	0.73 ± 0.10	0.64 ± 0.06	0.81 ± 0.12	0.78 ± 0.08	0.82	0.83 ± 0.09
L1–L4 BMAD	H	0.08 ± 0.008	0.09 ± 0.01	0.09 ± 0.006	0.08 ± 0.005	0.10 ± 0.01	0.08 ± 0.008	0.11 ± 0.008	0.09 ± 0.01	0.12 ± 0.01	0.10 ± 0.006
	L	0.08 ± 0.008	0.08 ± 0.007	0.09 ± 0.01	0.08 ± 0.007	0.1 ± 0.01	0.09 ± 0.008	0.11 ± 0.01	0.09 ± 0.009	0.1	0.1 ± 0.01
Subtotal Body BMC	H	1127 ± 293	1261 ± 330	1162 ± 193	1297 ± 217	1512 ± 266	1626 ± 250	1696 ± 230	1960 ± 417	1704 ± 225	2183 ± 126
	L	833 ± 104	1086 ± 229	1161 ± 246	1132 ± 277	1316 ± 213	1336 ± 221	1552 ± 286	1953 ± 293	1596	2109 ± 142
Forearm BMD	H	0.49 ± 0.04	0.55 ± 0.11	0.53 ± 0.04	0.53 ± 0.05	0.60 ± 0.05	0.58 ± 0.05	0.63 ± 0.03	0.63 ± 0.06	0.65 ± 0.05	0.69 ± 0.04
	L	0.47 ± 0.03	0.51 ± 0.04	0.52 ± 0.04	0.53 ± 0.04	0.57 ± 0.05	0.54 ± 0.06	0.61 ± 0.05	0.62 ± 0.06	0.57	0.65 ± 0.05
Total hip BMD	H	0.65 ± 0.09	0.76 ± 0.13	0.68 ± 0.04	0.79 ± 0.1	0.82 ± 0.09	0.87 ± 0.10	0.88 ± 0.08	0.98 ± 0.16	0.86 ± 0.11	1.03 ± 0.07
	L	0.58 ± 0.07	0.71 ± 0.13	0.71 ± 0.08	0.77 ± 0.09	0.78 ± 0.08	0.79 ± 0.09	0.83 ± 0.12	0.97 ± 0.1	0.81	1.02 ± 0.10
Femoral Neck BMAD	H	0.15 ± 0.02	0.17 ± 0.04	0.14 ± 0.01	0.16 ± 0.02	0.16 ± 0.02	0.17 ± 0.04	0.17 ± 0.02	0.17 ± 0.02	0.16 ± 0.02	0.17 ± 0.01
	L	0.15 ± 0.02	0.15 ± 0.03	0.15 ± 0.02	0.16 ± 0.02	0.15 ± 0.02	0.15 ± 0.02	0.16 ± 0.03	0.16 ± 0.02	0.15	0.16 ± 0.02
Trochanter BMD	H	0.52 ± 0.06	0.58 ± 0.16	0.52 ± 0.04	0.61 ± 0.06	0.64 ± 0.07	0.70 ± 0.08	0.69 ± 0.06	0.77 ± 0.13	0.65 ± 0.08	0.80 ± 0.07
	L	0.45 ± 0.05	0.57 ± 0.10	0.56 ± 0.07	0.63 ± 0.080	0.62 ± 0.07	0.64 ± 0.08	0.64 ± 0.10	0.78 ± 0.08	0.60	0.79 ± 0.08

Values are mean ± SD; H = High socioeconomic status, L = Low socioeconomic status.

Table 4 shows the mean ± SD values of BMD and BMAD in boys and girls according to Tanner stage and SES. In general, children of high SES tended to have higher areal BMD values than those of lower SES of the same gender. Statistics were not reported, owing to the low numbers in each subgroup.

Discussion

This study provided gender-specific BMC and BMD values, expressed in discrete age and Tanner stage subgroups. The well-described pubertal increments in areal BMD, as well as the gender differences in BMD/BMC at the lumbar spine and hip sites, were observed. In general, children of high socioeconomic status had higher BMD at all skeletal sites in boys and at most skeletal sites in girls, as compared to children of low socioeconomic status.

Age effect

There was a significant increase in BMC/BMD at all skeletal sites with age. After adjustment for bone size using BMAD, this effect persisted at the lumbar spine but not at the femoral neck in both genders, as previously reported [10,27,28]. Because BMD values measured by DXA are area-dependent and do not take into account bone size and depth, it was previously assumed that the increase in BMD with age/puberty is a reflection of periostal expansion and bone growth rather than a true increase in density/mineralization [11]. In our study, there was an effect of age on the lumbar spine BMAD, precluding that the increase in BMD was only the result of increase in skeletal size. However, the calculation of the BMAD was based on geometrical assumption, and probably the combination of postero-anterior and lateral DXA scans would have provided better assessment of the lumbar spine [28]. Other studies have reported an increase of areal BMC/BMD with age [7,10,16,29–31].

Effect of puberty

The substantial impact of puberty on areal BMD/BMC is very well described in both boys and girls [4,30–33]. Bailey et al. [7] reported in a longitudinal study that approximately 26% of final adult bone mineral status is accrued during the two adolescent years surrounding peak BMC. Sabatier et al. [32] reported a gain of 30% in spine BMD between Tanner I and menarche, with smaller increments thereafter. Others reported an increase of up to 60% in bone mass at all skeletal sites between Tanner stages II and IV [33]. In our study, the difference in lumbar spine BMD was 43% between pre- and post-pubertal boys and 66% between pre- and post-pubertal girls. This difference was lower at the cortical sites, indicating that the effect of sex steroids may be more pronounced on trabecular bone. Although body fat and variability in breast dimensions might influence determination of Tanner stages by breast exam, we elected to present the results by Tanner staging of breast/genitalia, as this method was more consistently used in the literature [4,11,31,32]. However, we obtained similar results when using Tanner staging of genitalia/breast or Tanner staging of pubic hair. It is generally accepted that changes in areal BMD at cortical sites with puberty are, in part, secondary to changes in bone size, as we have described in the subgroup of boys and as reported [28,34,35]. The picture may be different at the lumbar spine, as detailed below.

Gender differences

In our study, boys had higher mean BMD values at cortical sites, including subtotal body BMC, whereas at the lumbar spine girls had higher mean values, even after adjustment for bone size using BMAD. Furthermore, mean lumbar spine bone area was similar in girls and boys in the overall group (Table 1) and in the subgroups by Tanner stages, precluding the possibility that differences in bone size explained the gender differences in BMD at the spine. Some studies have reported spine BMD to be higher in girls than in boys [16,30,31,36] until late adolescence; and it has been suggested that ultimately these gender differences during adolescence at the spine disappear as boys catch up with puberty and growth [7,37]. In our study, the gender differences between males and females persisted in the subgroup of adolescents who had achieved their pubertal development (Tanner V). McCormick et al. [38] reported that female adolescents accumulated spinal bone mineral more rapidly than boys, whereas longitudinal studies did not find gender differences in peak BMC and in 2-year bone mineral accrual at the spine [7], or demonstrated that gender has no significant independent effect on the rate of lumbar spine gain once the confounders of growth and biological age had been accounted for [37]. In view of these results, one may conclude that the accepted explanation attributing the gender differences in bone density in adolescents to the differences in bone size only is unlikely, and that the mechanisms underlying this effect may possibly be different at cortical and trabecular sites. At the trabecular sites, such as the lumbar spine, gender differences in areal and size-adjusted BMD may be explained by the earlier attainment of puberty in girls [16,38]; whereas, at the cortical sites, they may be explained by other factors, such as size, muscle mass, and the difference in the level of physical activity [16,28,34–36]. Bailey et al. [7] showed that the amount of bone mineral accumulated during adolescence correlates with physical activity. Indeed, in our group, boys exercised more frequently than girls. Studies in animals suggested the existence of sex-linked genes mediating the gender difference in BMD [39].

Relationships with lean mass

One previous report suggested that when BMC is corrected for lean mass in adolescents, there is a faster increase in girls than in boys because in females estrogen

reduces the remodeling-dependent bone losses [40]. In our group, lumbar spine BMD and subtotal body BMC adjusted for lean mass were higher in girls than in boys. Despite the literature stressing the importance of lean mass on BMD in general [31,41,42] and in children in particular [43,25], we are aware of only one additional study outlying sexual dimorphism in mineral accretion when expressing BMD as a function of lean mass [44]. In a recent report, Järvinen et al. [45] re-analyzed old data and suggested that these gender differences persist through adulthood and taper off after menopause. They underscored the evidence that has accumulated, both in animals and humans, supporting estrogen-driven extra-packing of bone mineral in the female skeleton at puberty, as a "safety deposit" of bone mineral needed during the reproductive cycle [45].

Ethnic differences

We found our pediatric population to have lower BMD values than Canadian children. These results were expected. There is an established ethnic difference in BMD [10–13]; and we have previously shown that, compared to Americans, Lebanese subjects have slightly lower peak bone mineral density BMD [8]. Ethnic differences may be explained, in part, by the differences in lifestyle or in anthropometric measurements [46]. Indeed, in our group, the time spent on sports per week was, on the average, 2 h less than the average time spent by Western pediatric populations [30]. Moreover, we and others have shown that even in the sunny country of Lebanon, vitamin D insufficiency is common among the country's healthy young people and schoolchildren, and more so among subjects of lower socioeconomic status [9,47]. Children with low vitamin D may be at high risk for reduced bone acquisition during growth, and it has been suggested that pubertal girls with hypovitaminosis D may be at risk of failure to achieve maximum peak bone mass [48]. This, however, has not been proven.

Our study suggests an impact of SES on both bone mineral content and bone density in both genders. This effect may be attributed to environmental and lifestyle factors [34,49–51], both of which are largely determined by the SES and have been reported to influence bone mass. Studies on adults have found that, in both genders, people of higher SES have higher spine BMD than those of lower SES [52,53], and that people of advanced age from the low SES group cross the fracture threshold earlier than others [52]. This pattern has not been consistent [54], and to our knowledge, has not been investigated in children and adolescents. The independent impact of socioeconomic status needs to be further investigated in a larger study, which may at least partially explain differences in BMD between various ethnic subgroups, as has been reported in the NHANES study [55].

There is still debate on whether the use of BMC, areal BMD or BMAD adjusted for growth parameters (i.e., size) is the correct method to assess bone mass in the growing skeleton [56–58]. We therefore elected to report all three measurements in the current study.

Although not population-based, this is the first study of its kind, providing, as it does, a large sample size and equal representation by gender and socioeconomic status of healthy schoolchildren from the Middle East. Because the BMD values in adult Lebanese are comparable to the BMD values of other countries in the Middle East [9,59–61], the data included in this study can serve as a valuable reference database enabling the calculation of specific Z scores for children and adolescents in the region, as well as in Lebanon. BMD in children varies with pubertal development. Therefore, values adjusted for Tanner stages and for lean mass will be of particular significance in the evaluation of children with pubertal or growth disorders.

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