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Bone Densitometry in Canadian Children 8–17 Years of Age

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Abstract. Normative bone mineral density (BMD) and bone mineral content (BMC) values for the total body (TB), proximal femur (PF), and antero-posterior lumbar spine (LS) were obtained from a large cross-sectional sample of children and adolescents who were 8–17 years of age. There were 977 scans for the TB, 892 for the PF, and 666 for the LS; bone mineral values were obtained using a HOLOGIC QDR 2000 in array mode. Data are presented for the subregions of the PF (femoral neck, trochanter, intertrochanter, and the total region) and for the LS (L1–L4 and L3). Female and male values for the FN, LS (L1–L4), and the TB were compared across age groups using a two-way ANOVA. In addition, we compared the 17-year-old female values to a separate sample of young adult women (age 21). At all these sites, BMC and BMD increased significantly with age. There was no gender difference in TB BMC until age 14 or in TB BMD until age 16, when male values were significantly greater. Females had significantly greater LS BMC at ages 12 and 13, but by age 17 the male values were significantly greater. Females had significantly greater LS BMD across all age groups, however. Males had significantly greater FN BMC and BMD across all age groups. There were no significant differences in BMC or BMD at any sites between the 17- and 21-year-old women.

Key words: Bone mineral content — Bone mineral density — Children — DXA.

Although osteoporosis has traditionally been considered a disease of the elderly, there is increasing recognition of the importance of bone mineral acquisition during the growing years as an important preventative factor [1, 2]. Thus there is considerable interest in the assessment of bone mineral content (BMC) and bone mineral density (BMD) in children, and in identifying children, adolescents, and young adults with low BMC and BMD so that intervention programs can begin at an early age [3]. Dual-energy X-ray absorptiometry (DXA), because it allows rapid, highly reproducible assessment of bone mineral with low radiation dose, is now used extensively in studying children [4–6]. In order to assess children and adolescents who may be at risk for low bone mass, normative data based on large sample sizes are required. Several cross-sectional studies have presented normative data (using DXA) for children and adolescents at the proximal femur, lumbar spine, or total body [7–16], including previous data from our group [5]. Although all these data are useful, they are limited by relatively small sample sizes—especially at some age groups. The exception is the data from Argentina, which includes normative values based on 778 children who were 2–20 years of age, whose bone mass was measured on a Norland XR-26 densitometer [6].

In this article, we present normative (BMC and BMD) data for children and adolescents (ages 8–17) for the total body (TB), proximal femur (PF) regions (total region, trochanter, neck, intertrochanter), and at the antero-posterior lumbar spine at L1–L4 (LS). The values, depending on site, are based on 977 total body, 892 proximal femur, and 666 lumbar spine scans.

As a secondary analysis, we also compared BMC and BMD at the clinically important femoral neck (FN), LS, and TB between men and women. We also compared the BMD and BMC at these sites in the 17-year-old women to values from a sample of young adult women [17].

Methods

Subjects

Subjects are from an ongoing longitudinal study designed to assess the factors associated with bone mineralization in healthy growing children. Subjects were originally recruited from two elementary schools in middle-class neighborhoods in Saskatoon, Canada. Over 98% of the sample were caucasian. We have previously reported TB normative data for this group that were based on 110 boys and 124 girls [5]. This original sample has now been measured yearly for four years at the TB and PF sites, and for 3 years at the LS site. Over the 4-year period, some subjects dropped out of the study and others were added; thus the present cross-sectional database includes scans for all children who were measured one or more times. Age was determined precisely to the decimal age value. Age groups were then constructed that were based on the midpoint values (for example, the 8-year age group represents subjects who were 7.5–8.49 years of age).

We also include BMC and BMD data for a young adult female group ($n = 57$; age $= 21 \pm 2$ years; height $= 167 \pm 5$ cm; weight $= 62 \pm 7$ kg). This sample, from another cross-sectional study in our laboratory [17], was included in order to assess the relationship of BMC and BMD of the older adolescent female groups to values in young premenopausal women. We do not have comparative data for men of this age range.

Bone Scan Procedures

Testing procedures were approved by university and hospital ethics committees. Children and parents completed informed-consent

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Table 1. Height, weight, and BMC (g), BMD (g/cm^2), FT (g), and BFLT (g) for the total body by gender and age group (mean ± SD)

Groups	*n*	Age (yr)	Height (cm)	Weight (kg)	FT	BFLT	BMC	BMD
Female								
8	23	8.2 (0.2)	132.9 (6.4)	30.0 (6.9)	8340 (5060)	20328 (2533)	787 (161)	0.75 (0.04)
9	41	9.1 (0.2)	137.8 (8.0)	32.3 (8.1)	8899 (5207)	22241 (3778)	907 (236)	0.79 (0.05)
10	59	10.1 (0.3)	142.1 (7.9)	35.1 (8.8)	9700 (6244)	23826 (3986)	995 (224)	0.80 (0.05)
11	61	11.0 (0.3)	148.5 (8.5)	39.8 (10.7)	11048 (6841)	26831 (5030)	1151 (296)	0.82 (0.06)
12	63	12.0 (0.3)	154.6 (7.4)	44.2 (9.2)	12084 (5857)	29982 (4828)	1356 (302)	0.87 (0.07)
13	70	13.0 (0.3)	159.8 (6.8)	50.1 (10.1)	14175 (7009)	33815 (4721)	1598 (305)	0.92 (0.07)
14	65	14.0 (0.3)	162.8 (5.7)	55.1 (11.5)	16341 (8141)	36215 (4294)	1797 (271)	0.96 (0.06)
15	61	15.0 (0.3)	165.0 (5.9)	60.8 (11.2)	19718 (8331)	38282 (4242)	1993 (272)	1.00 (0.06)
16	37	15.9 (0.3)	166.2 (6.5)	64.6 (13.1)	22019 (9295)	39542 (5434)	2096 (315)	1.02 (0.07)
17	26	17.1 (0.4)	165.5 (5.3)	69.9 (16.7)	25972 (11128)	40272 (5478)	2173 (360)	1.04 (0.08)
Total	506							
Male								
8	18	8.1 (0.3)	132.3 (5.2)	27.4 (3.2)	4353 (2016)	21729 (2295)	809 (85)	0.79 (0.04)
9	27	9.1 (0.3)	137.7 (4.7)	31.7 (4.7)	6115 (3056)	23745 (2213)	900 (109)	0.80 (0.05)
10	44	10.1 (0.3)	143.8 (6.4)	35.8 (6.4)	8124 (4782)	26219 (2956)	1054 (164)	0.83 (0.04)
11	56	11.0 (0.3)	147.5 (6.4)	39.3 (7.5)	9351 (5831)	28272 (3495)	1176 (179)	0.84 (0.04)
12	79	12.0 (0.3)	153.0 (6.3)	43.2 (8.4)	9943 (5892)	31162 (4057)	1345 (221)	0.87 (0.05)
13	74	13.0 (0.3)	160.9 (7.6)	50.0 (9.3)	11059 (6401)	36588 (6037)	1594 (335)	0.91 (0.08)
14	66	14.0 (0.3)	168.9 (8.5)	57.5 (11.7)	10967 (6865)	43757 (7296)	1946 (424)	0.98 (0.09)
15	55	15.0 (0.3)	173.6 (7.7)	62.3 (10.7)	10289 (6583)	48985 (6913)	2224 (432)	1.03 (0.10)
16	34	15.9 (0.3)	177.4 (7.0)	67.7 (11.3)	11003 (6343)	52840 (6053)	2482 (442)	1.08 (0.10)
17	18	17.0 (0.4)	181.3 (6.7)	73.8 (13.5)	13254 (8357)	56733 (6887)	2766 (458)	1.13 (0.10)
Total	471							

forms prior to testing. All testing was done at the Royal University Hospital (Department of Nuclear Medicine) in Saskatoon. The BMC and BMD for each region were determined by DXA using a Hologic QDR-2000 in array mode. The scan times for the spine, proximal femur, and total body were 1.5, 2, and 5 min, respectively. All scans were acquired and analyzed by the same technician. Each subject removed all metal objects (jewelry, glasses, and so forth) and shoes before being scanned.

Total body scans were performed with the subject lying supine on the scanning table with the body positioned on the center line along the longitudinal axis of the table. The subject's hands were pronated and positioned within the global scan region boundary and the feet were taped together to immobilize the subject's lower extremities. Analysis was done using Hologic DXA software version 5.56A.

The LS scans were done with the subject in the supine position with a foam-filled block supporting the femora in as vertical position as possible. Analysis was done using Hologic DXA software version 4.42A.

For the proximal femur scan, the subject was supine on the scanning table with the leg slightly abducted and inverted about 20 degrees. The foot was secured with a nylon strap against a lucite positioning wedge to ensure a consistent view of the femoral neck. The narrowest point of the femoral neck was determined by the system software (version 4.55A) and was marked by the position of the femoral neck box (1.5 cm × 4.5 cm). The corners of the femoral neck box, covering only the femoral neck and the inferolateral border were positioned immediately adjacent to the medial aspect of the greater trochanter.

Short term reproducibility in vivo ranged from a coefficient of variation (CV) of 0.51% for the total body, 0.9% for the FN, and 1.03% for the LS.

Statistical Analyses

Means and standard deviations were calculated for each site according to gender and age. Gender comparisons of BMC and BMD across age groups were done for the three main sites: FN, LS (L1–L4), and FN. A two-way ANOVA (gender by age) was done to test for main effects and age-by-sex interaction. If there was a significant gender-by-age interaction, post-hoc comparisons were done at each age group to test for gender differences.

Results

The height, weight, and age, as well as lean body tissue and fat tissue masses, are displayed in Table 1. The gender-specific normative values for each site are shown in Tables 1–3. Results of the gender comparison for the TB, LS, and FN are shown in Figures 1–3. As expected, there was a significant age effect at all sites; both BMC and BMD increased with age. There was a significant age-by-gender interaction at the TB for both BMC and BMD. Post-hoc comparisons showed no gender differences until age 14 for BMC and age 16 for BMD, when the male values became significantly greater. There was a gender-by-age interaction for BMC at the LS (Fig. 2). Post-hoc comparison showed young women to have significantly greater LS BMC at ages 12 and 13, but by age 17 the male values were significantly greater. There was no age-by-sex interaction for LS BMD; women had significantly greater LS BMD across age groups. There was a significant age-by-gender interaction effect for BMC at the FN. Results of the post-hoc comparisons showed males to have significantly greater FN BMC beginning at age 14 (Fig. 3). There was no interaction effect for BMD at the FN; as shown, males had significantly greater FN BMD values across all age groups.

As also displayed in the figures, there was a distinct leveling off of the BMC and BMD curves in women between the ages of 16 and 21 and there was no significant difference in BMC or BMD at any of the sites between the ages of 17 and 21.

Table 2. BMC (g) and BMD (g/cm^2) for the proximal femur sites by gender and age group (mean ± SD)

		Total		Neck		Troch		Inter	
Groups	*n*	BMC	BMD	BMC	BMD	BMC	BMD	BMC	BMD
Females									
8	19	11.8 (3.0)	0.60 (0.08)	2.3 (0.4)	0.59 (0.08)	2.6 (0.8)	0.49 (0.08)	6.9 (2.1)	0.65 (0.09)
9	38	13.5 (3.7)	0.62 (0.08)	2.5 (0.5)	0.61 (0.07)	3.0 (1.0)	0.50 (0.07)	7.9 (2.6)	0.69 (0.10)
10	53	15.5 (4.1)	0.66 (0.09)	2.7 (0.5)	0.64 (0.07)	3.6 (1.3)	0.53 (0.08)	9.2 (2.6)	0.73 (0.11)
11	56	18.0 (4.5)	0.69 (0.11)	3.0 (0.6)	0.67 (0.09)	4.2 (1.4)	0.56 (0.09)	10.9 (2.8)	0.77 (0.13)
12	59	21.1 (4.9)	0.75 (0.11)	3.3 (0.6)	0.71 (0.10)	5.1 (1.6)	0.61 (0.10)	12.7 (2.8)	0.84 (0.14)
13	64	24.3 (4.6)	0.81 (0.11)	3.7 (0.6)	0.77 (0.10)	6.1 (1.6)	0.67 (0.10)	14.5 (3.0)	0.91 (0.12)
14	62	26.6 (4.0)	0.88 (0.10)	4.0 (0.5)	0.81 (0.10)	6.9 (1.5)	0.72 (0.09)	15.8 (2.5)	0.99 (0.12)
15	58	28.0 (4.0)	0.92 (0.10)	4.2 (0.6)	0.86 (0.10)	7.2 (1.3)	0.74 (0.09)	16.5 (2.9)	1.05 (0.11)
16	34	29.3 (4.9)	0.94 (0.10)	4.4 (0.6)	0.88 (0.11)	7.6 (1.2)	0.75 (0.09)	17.3 (3.5)	1.08 (0.12)
17	24	30.0 (5.0)	0.97 (0.11)	4.6 (0.7)	0.92 (0.12)	7.9 (1.5)	0.78 (0.10)	17.5 (3.2)	1.12 (0.13)
Total	467								
Males									
8	8	11.5 (1.3)	0.66 (0.04)	2.5 (0.4)	0.66 (0.05)	2.9 (0.6)	0.58 (0.03)	6.0 (0.9)	0.70 (0.05)
9	21	13.9 (2.1)	0.68 (0.07)	2.8 (0.3)	0.68 (0.07)	3.3 (0.9)	0.57 (0.06)	7.8 (1.6)	0.75 (0.08)
10	35	15.9 (2.8)	0.71 (0.06)	3.0 (0.3)	0.70 (0.06)	3.7 (1.0)	0.59 (0.06)	9.1 (2.0)	0.78 (0.08)
11	51	18.3 (3.2)	0.74 (0.07)	3.2 (0.4)	0.72 (0.06)	4.3 (1.1)	0.60 (0.07)	10.7 (2.4)	0.82 (0.09)
12	69	21.5 (3.8)	0.78 (0.09)	3.5 (0.4)	0.75 (0.08)	5.3 (1.3)	0.64 (0.08)	12.8 (2.7)	0.87 (0.10)
13	72	26.2 (6.5)	0.82 (0.11)	3.8 (0.6)	0.78 (0.10)	6.6 (1.9)	0.68 (0.10)	15.8 (4.4)	0.91 (0.13)
14	64	32.1 (7.3)	0.90 (0.12)	4.5 (0.7)	0.85 (0.11)	8.3 (2.0)	0.76 (0.10)	19.4 (5.1)	1.00 (0.13)
15	52	37.5 (8.0)	0.98 (0.14)	4.9 (0.7)	0.90 (0.12)	9.5 (2.4)	0.82 (0.12)	22.7 (5.8)	1.08 (0.16)
16	34	40.2 (7.8)	1.01 (0.14)	5.3 (0.8)	0.93 (0.13)	10.5 (2.1)	0.84 (0.12)	24.5 (5.4)	1.12 (0.15)
17	19	43.9 (8.8)	1.05 (0.15)	5.6 (0.8)	0.98 (0.14)	11.4 (2.4)	0.86 (0.13)	26.9 (6.0)	1.18 (0.16)
Total	425								

Discussion

The principal purpose of this article was to present normative BMC and BMD for children and adolescents for the TB, PF, and LS sites. These norms, which are based on the most comprehensive children's data to date, can be used as reference values in children and adolescents based on chronological age using the Hologic 2000 in array mode. To test the generalizability of our sample, we compared the heights and weights of our sample to two large population databases from the United States [18] (caucasian data) and Canada [19]. The 50th percentile values of our subjects were nearly identical to these other population survey data, with the exception of the older age groups where our subjects appeared to be slightly taller and heavier, thus our data, in general, appear to be representative of North American caucasian children.

Our data are consistent with previous studies showing that bone mineralization increases progressively in early childhood [9, 20–21] and then accelerates during adolescence [6, 9–11, 22–24]. In our data, total body BMC increased nearly threefold in females and more than tripled in males between 8 and 17 years of age. As noted by others, depending on site, at least 90% and probably more of the adult BMC is deposited by the end of adolescence [13, 25–29]; adolescence is clearly a critical time for bone mineral accrual [14]. Results of the gender comparisons are consistent with previous studies showing small differences in BMC or BMD at axial or appendicular sites between girls and boys during childhood, but showing gender differences becoming more apparent during the pubertal growth period [9, 11, 15, 30–32]. For example, in our data total body BMC and BMD is similar in boys and girls until about age 14,

Table 3. BMC (g) and BMD (g/cm^2) for the anteroposterior spine sites ([L1–L4] and L3) by gender and age group (mean ± SD)

		L1–L4	
Group	*n*	BMC	BMD
Female			
8	12	20.0 (4.0)	0.58 (0.07)
9	22	21.9 (5.4)	0.60 (0.08)
10	38	24.7 (6.6)	0.63 (0.03)
11	43	28.4 (8.2)	0.68 (0.10)
12	41	33.7 (9.5)	0.74 (0.11)
13	45	42.2 (9.1)	0.83 (0.10)
14	45	48.6 (8.5)	0.90 (0.09)
15	50	52.9 (9.3)	0.95 (0.11)
16	34	54.1 (9.5)	0.96 (0.11)
17	24	55.3 (8.8)	0.98 (0.11)
Total	354		
Male			
8	5	17.6 (3.4)	0.56 (0.04)
9	8	21.3 (4.0)	0.58 (0.06)
10	18	24.0 (3.9)	0.61 (0.05)
11	34	26.1 (4.6)	0.63 (0.06)
12	49	30.4 (5.7)	0.67 (0.08)
13	53	36.0 (8.1)	0.73 (0.10)
14	45	46.2 (11.3)	0.81 (0.12)
15	46	53.0 (11.3)	0.87 (0.11)
16	35	59.1 (11.7)	0.91 (0.12)
17	19	65.8 (12.8)	0.96 (0.13)
Total	312		

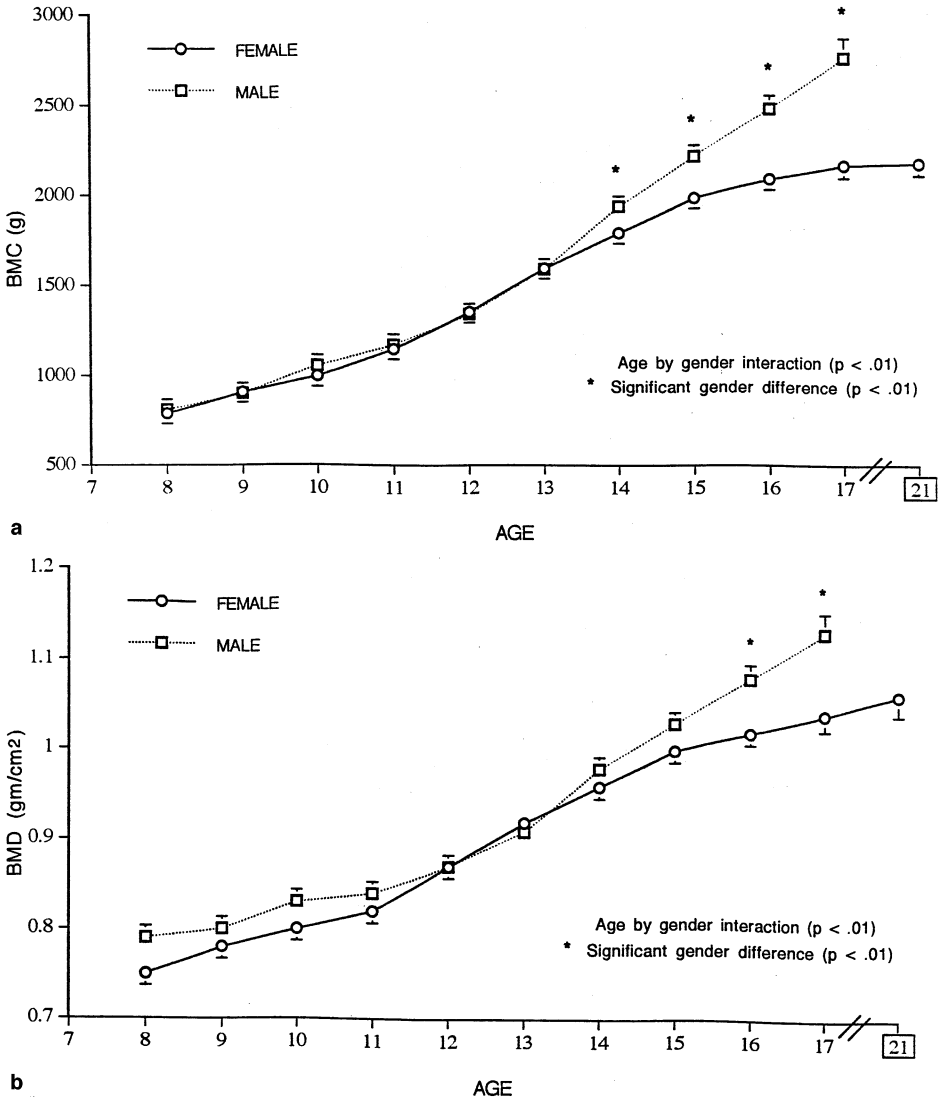

Fig. 1. Total body BMC **(a)** and BMD **(b)** for females and males by age showing results of the gender comparison (mean ± SE).

when BMC increases in boys become greater and girls' gains begin to level off. These data are consistent with others who have reported no differences in radial or TB BMC values in prepubertal boys and girls, but show boys to have a relatively greater increase in BMC during puberty, resulting in greater values at skeletal maturity [6, 15, 31, 34–35]. Although we did not report maturational-based values in these data, it is clear that BMC accelerated in women about two years earlier than men—reflecting the earlier onset of puberty in women. Others have demonstrated that the gains in BMC during adolescence are more a function of pubertal stage than chronological age [8, 15, 36].

We found males to have greater BMC and BMD at the FN at all ages. This result is consistent with previous studies that reported greater values in males at least at some stage during growth, or undoubtedly by late adolescence [21, 23, 27, 28, 37]. Others have found a trend (although not statistically significant) of greater FN BMD or BMC in males [36, 38–39], but these studies had low power to detect differences. The greater FN BMC and BMD in boys may be a factor of genetic disposition or may reflect greater or different physical activity patterns in boys throughout growth. For example, it may be that boys are more involved in physical activities such as running and jumping that require more mechanical loading of the proximal femur.

There is less consistency in the literature with regard to comparisons of LS BMC and BMD. Some have reported no gender differences during childhood or adolescence [8, 36, 38, 40], but others have reported females to have greater values until late adolescence when males catch up and surpass female values [6, 9, 10, 31]. The greater values in females prior to age 17 in our study most likely reflects earlier maturation in girls. For example, shifting the male curve about two years to the left (which would approximately align the males and females on a maturity status) would negate any gender differences in childhood. Others (controlling for maturity) have reported no significant gender differences at the LS until late puberty when males have greater BMD and BMC [11, 23]. The greater LS BMC or BMD reported in males at skeletal maturity has been demonstrated (in studies using QCT) to be a function of their larger vertebral bodies [41].

Although there is still some controversy as to the age when peak bone mineral content is attained, there appears to be little evidence to suggest any significant gains in BMD or BMC beyond the age of 30 [28–29, 42]. Data in our female sample supports this conjecture since we found no significant differences in BMC and BMC at the TB, FN, and LS between 17 and 21 years of age. These results should be accepted with some caution, however, since, because of

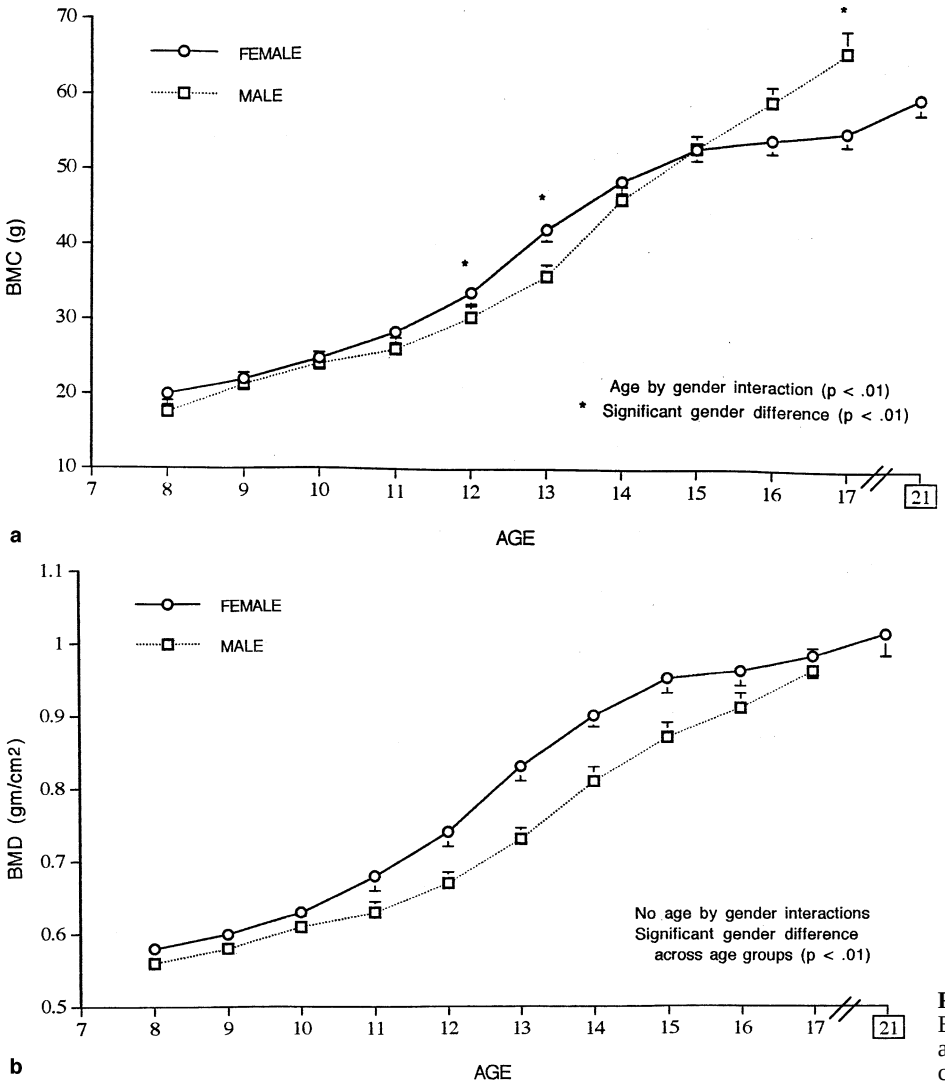

Fig. 2. Lumbar spine BMC **(a)** and BMD **(b)** for females and males by age showing results of the gender comparison (mean ± SE).

small sample sizes, the statistical power to detect differences in these age groups was relatively low.

In this article we have presented normative data for BMC and BMD for children and adolescents 8–17 years of age. The merits and difficulties of expressing the mineral component of bone as BMC or BMD has been discussed [43]. It is important, however, to understand the disparity between these two measurements and the problems that arise in using BMD in growing children. BMC provides quantitative information about the skeleton, whereas BMD yields more qualitative assessment of bone by attempting to control for size differences. However, photon absorption techniques, such as DXA, scan in only two directions (length and width) and yield an areal density value. This areal density provides an incomplete correction for size because it fails to account for bone depth [44]. This is particularly problematic in children and has led to some confusion about the magnitude of change in BMD during the growing years. These difficulties have been discussed previously and the difficulties have led to attempts to adjust BMC by an estimated volume, derived from mathematical principle; based on assumptions about bone geometry [37, 44]. For example, Katzman et al. [44], using this approach, found 99% of the change in TB and 50% of the change in LS BMC was caused by bone expansion rather than increases in BMC per unit volume. Volumetric BMD measurements have been applied in the clinical assessment of pediatric populations [45]. As a post-hoc procedure, we estimated volumetric BMD at the FN, based on the procedure used previously by Kroger et al. [37]. These results are shown in Figure 4. As depicted, there was no significant change in the estimated volumetric BMD with age, nor was there any significant gender difference. These results are consistent with previous work showing estimated volumetric BMD at the FN not to be influenced by age [37]. The fact that we found no gender difference in the estimated volumetric BMD suggests that bone dimension differences account for the gender differences in areal BMD at the FN. Other studies using QCT also have demonstrated that LS BMD (corrected for a true volume) does not increase to the same degree with age as areal BMD values [41].

In summary, the normative values presented in this article can be used to assess skeletal status in growing children and can be used as comparative standards for research articles. Although we report both BMC and BMD, the BMD values should be used with caution since this measurement

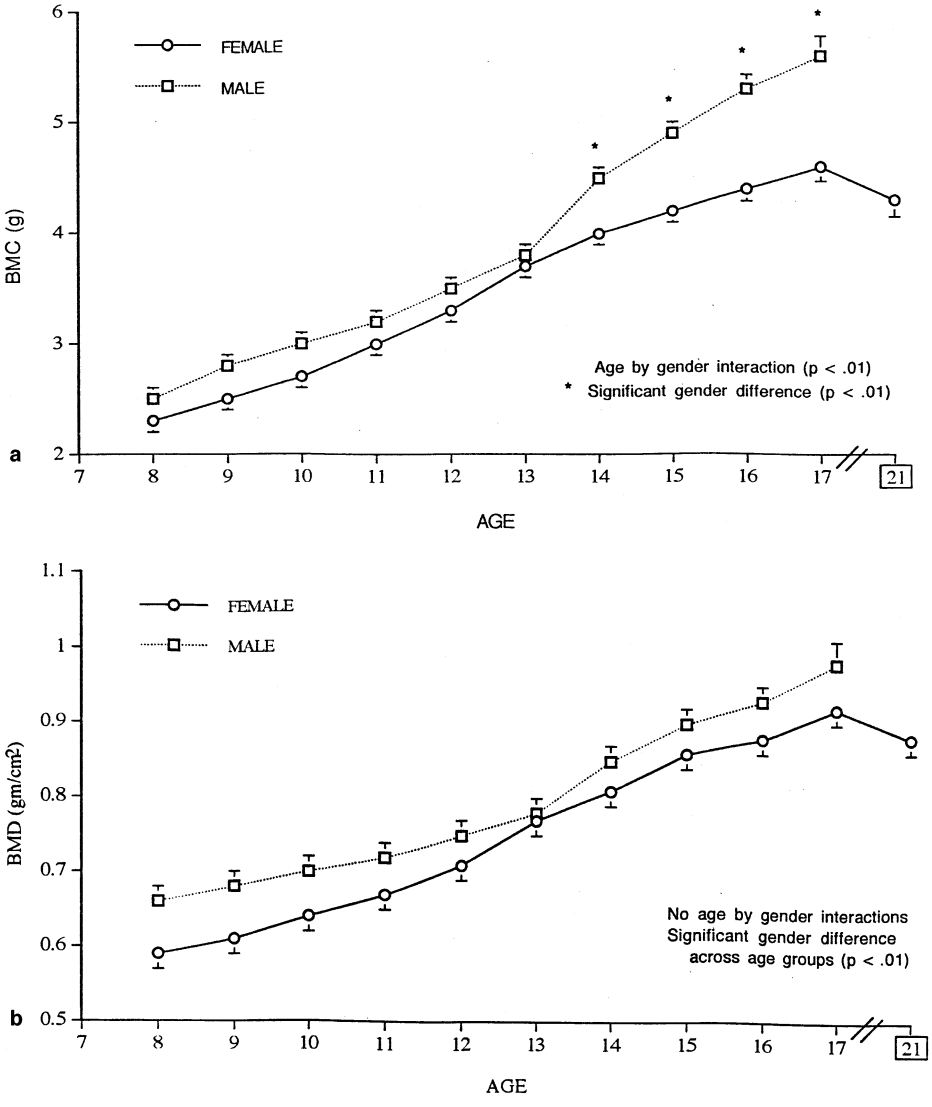

Fig. 3. Femoral neck BMC **(a)** and BMD **(b)** for females and males by age showing results of the gender comparison (mean ± SE).

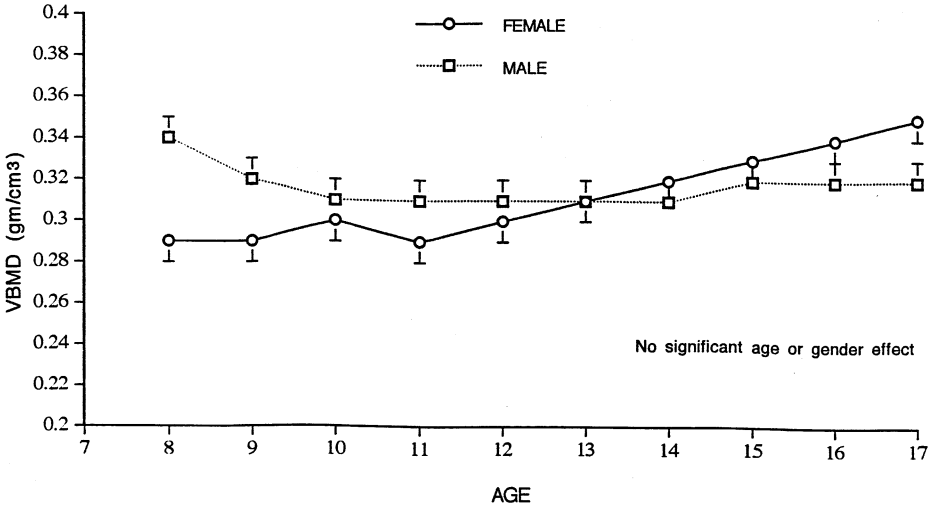

Fig. 4. Estimated volumetric BMD for females and males by age showing results of the gender comparison (mean ± SE).

does not fully adjust for size differences in growing children. Finally, although this data is based on large numbers of scans, the data are reported cross-sectionally and they are based on a sample of convenience; thus care should be used in interpreting the data across age groups and in extrapolating the results to the general population.

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