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# Normative Data for Lumbar Spine Bone Mineral Content in Children: Influence of Age, Height, Weight, and Pubertal Stage

J. De Schepper, M. P. Derde, M. Van den Broeck, A. Piepsz, and M. H. Jonckheer

*Departments of Pediatrics, Biostatistics, and Nuclear Medicine, Akademisch Ziekenhuis, Vrije Universiteit Brussel, Brussels, Belgium*

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In 136 normal growing children between the ages of 1 and 18 yr, bone mineral content (BMC) at the level of the lumbar spine (L2-L4) was determined with a commercial dual-photon absorptiometer. BMC was calculated as BML (BMC per unit length) and BMD (BMC per unit surface). The mean lumbar spine BML of the studied children ( $2.53 \pm 0.86$  gHA/cm) was significantly lower than the spinal mineral content of adults ( $4.26 \pm 0.57$  gHA/cm). No sex difference existed in lumbar spine BMC. BML as well as BMD were highly dependent on age, body height, and body weight. During the prepubertal years, BML and BMD increased in a fairly rectilinear pattern. During puberty, BMC increased more rapidly: 40% for BMD and 77% for BML. For the entire group, the increase in BMC with age, height, and weight was best predicted by an exponential regression line analysis.

**J Nucl Med 1991; 32:216-220**

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**D**ual-photon absorptiometry, which in vitro is as accurate as single-photon absorptiometry, gives a slightly higher radiation dose than the single-photon technique, but offers the possibility of axial skeleton (lumbar spine) density measurements (1).

In a preliminary study, lumbar spine bone mineral content (BMC) has been measured with a commercial dual-photon absorptiometer in a rather limited number of children less than 16 yr old (2). A close relationship was found between lumbar spine BMC (expressed in grams of hydroxyapatite/cm) and age, body height, and body weight. The purpose of this study was to establish in a larger age group (up to 18 yr) normal values for lumbar spine BMC, calculated per unit length (BML), as well as per unit surface (BMD), versus age, weight, height, and pubertal stage.

## METHODS

Included in the study were 136 normal growing subjects (78 girls and 58 boys), between the ages of 1 and 18 yr (mean age:  $9.9 \pm 4.1$  yr). Informed consent of the parents and of children more than 12 yr of age was obtained. BMC evaluation was made in 78 subjects with a recent fracture of the peripheral skeleton (Group 1), in 25 children before treatment with glucocorticoids (Group 2), and in 33 cases with a minor orthopedic problem (Group 3). All studied children had a normal birth weight and were not taking any drugs.

BMC determination was made at the L2-L4 level of the spine with a Novo Industry BMC-Lab 22 densitometer. This equipment has a gadolinium-153 source emitting photon beams of 44 and 100 keV, respectively, which are detected by a NaI detector. A HP 85 computer was used for the calculation of BMC based upon scan image. Bone edges and baseline determination were operator adjusted. All images were processed by the same operator. With this technique, the precision varies in adults between 1.4% and 2.6% and the accuracy lies in vitro around 1% (3). The radiation dose at the skin level of the lumbar spine, measured by thermoluminescent dosimetry, amounts to 10 mrad (1).

BMC was expressed as total BMC minus BMC calculated within the L2-L4 region (gHA) as BML (BMC per unit length minus total BMC divided by the height of L2-L4 (gHA/cm) and as BMD (BMC per unit surface minus total BMC divided by the surface of the scanned L2-L4 region (gHA/cm<sup>2</sup>). Mean lumbar spine BML in young adults, measured with the same equipment, is  $4.33 \pm 0.78$  gHA/cm for men and  $4.21 \pm 0.69$  gHA/cm for women (4). Body weight and height were determined with an electronic scale and with a wall-mounted stadiometer, respectively. Pubertal development was assessed following the standards of Tanner and Marshall (5,6). Statistical analyses were carried out with the SPSS/PC program.

The tests were all performed two-sided at the 5% level of significance. The relation between continuous variables was evaluated by means of the Pearson's correlation coefficient and by means of linear regression. Multiple regression analysis was performed in order to evaluate the impact of the combination of several parameters on the BML and BMD values. Evaluation of sex difference was made by ANOVA techniques. For the comparison of two independent series of measurements (e.g., mean BMC in children and in adults), the Student's t-test was used. The comparison of the BMC values between the different pubertal stages and the young adults

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Received Mar. 7, 1990; revision accepted Jul. 19, 1990.  
For reprints contact: Dr. J. De Schepper, Akademisch Ziekenhuis Kinderen, Laarbeeklaan 101, 1090 Brussel.

was investigated using a one-way analysis of variance. For the subsequent comparison of BMC values in the different pubertal stages, the Student Newman-Keuls test was applied.

## RESULTS

The characteristics of the studied population are presented in Table 1. No difference in total BMC, BMC/cm, and BMC/cm<sup>2</sup> was found by analysis of variance between children with fractures and the two other groups. For further analysis, data of the three groups were pooled. Only BMC/cm and BMC/cm<sup>2</sup> were further analyzed, since these parameters had a lower variation than total BMC (CV: 33% and 23%, respectively versus 49%). The mean lumbar spine BMC/cm (2.53 ± 0.86 gHA/cm) of the studied children was significantly lower ( $p < 0.001$ ) than the mineral content of the spine of young adults.

As shown in Tables 2 and 3, there was no sex difference in BMC at the level of the lumbar spine during the prepubertal as well as during the pubertal period. For girls as well as boys, a regular increase in BML and BMD values in the different age groups (1-4; 4-8; 8-12; 12-16; 16-18 yr) was found. In all age groups, an important variation of the BMC/cm and the BMC/cm<sup>2</sup> values was found. The lowest variation was present in the age group 16-18 yr for BMC/cm (5%) as well as for BMC/cm<sup>2</sup> (6%).

The effect of age on the increase in BMC is more clearly depicted in a scatter graph (Fig. 1). During the prepubertal period (age range 1-12.9 yr), the BML increased by a factor of more than two following a fairly rectilinear pattern ( $\text{BMC/cm} = 0.92 \pm 0.15 \text{ age}$ ,  $r^2 = 0.75$ ). In prepubertal children, a linear increase in the BMD values with age was also present ( $\text{BMC/cm}^2 = 0.382 \pm 0.022 \text{ age (yr)}$ ,  $r^2 = 0.55$ ), but the increase (by a factor 1.4) was smaller than the BML values. After the age of 10 yr, not only the increase, but also the spread of the BMC/cm and BMC/cm<sup>2</sup> values became more important. For BML as well as for BMD, values of young adults were attained after the age of 16 yr. For the total group of children, the increase in BML and BMD with age could best be described by the following exponential functions: for BML:  $\text{BMC/cm} = 1.06 \times$

**TABLE 2**  
BMC/cm, Relative Increase (RI), and Coefficients of Variation (CV) of BMC/cm in the Different Age Groups

BMC/cm (gHA/ cm)	Boys		Girls		All children	
	(mean ± s.d.)		(mean ± s.d.)		(mean ± s.d.) No. CV (%)	
1-4 yr	1.18 ± 0.41	1.31 ± 0.24	1.25 ± 0.32	11	25%	
RI	(-)	(-)	(-)			
4-8 yr	1.85 ± 0.35	1.73 ± 0.28	1.79 ± 0.32	33	18%	
RI	(+57%)	(+32%)	(+43%)			
8-12 yr	2.58 ± 0.29	2.39 ± 0.45	2.46 ± 0.40	39	16%	
RI	(+39%)	(+38%)	(+38%)			
12-16 yr	3.11 ± 0.48	3.30 ± 0.71	3.22 ± 0.63	47	19%	
RI	(+21%)	(+38%)	(+31%)			
16-18 yr	4.05 ± 0.15	3.93 ± 0.24	3.99 ± 0.19	6	5%	
RI	(+30%)	(+19%)	(+24%)			

$e^{0.082 \text{ age}}$ ;  $r^2 = 0.82$ ; and for BMD:  $\text{BMC/cm}^2 = 0.38 \times e^{0.0475 \text{ age}}$ ;  $r^2 = 0.72$ ).

BMC, expressed as BMC/cm and BMC/cm<sup>2</sup>, was also significantly correlated to body weight and body height. Higher Pearson's correlation coefficients of BML with age ( $r = 0.87$ ;  $p < 0.0001$ ), body weight ( $r = 0.84$ ;  $p < 0.0001$ ) and height ( $r = 0.88$ ;  $p < 0.0001$ ) were found in the prepubertal children. In the pubertal children ( $n = 51$ ), the correlation factors were lower: 0.57 ( $p < 0.0001$ ), 0.48 ( $p < 0.0001$ ), and 0.61 ( $p < 0.0001$ ), respectively. In comparison with the BML results, the BMD values showed lower Pearson's correlation factors with age, body weight, and height, especially in the pubertal period:  $r = 0.50$  ( $p < 0.0001$ ) for age,  $r = 0.18$  ( $p < 0.0001$ ) for weight, and  $r = 0.38$  ( $p < 0.0001$ ) for height. For the whole population of children, the increases in BML as well as in BMD with body weight and height were best described by exponential functions. For BML,  $\text{BMC/cm} = 1.18 \times e^{0.019 \text{ weight}}$  ( $r^2 = 0.74$ ) and  $\text{BMC/cm} = 0.38 \times e^{0.014 \text{ height}}$  ( $r^2 = 0.84$ ). For BMD,  $\text{BMC/cm}^2 = 0.41 \times e^{0.01 \text{ weight}}$  ( $r^2 = 0.56$ ) and  $\text{BMC/cm}^2 = 0.20 \times e^{0.007 \text{ height}}$  ( $r^2 = 0.68$ ).

Using stepwise multiple regression analysis, the impact of these different growth parameters on BML and BMD were evaluated. If for the ln (BMD) results, age was held constant, no significant partial correlation coefficients for height ( $r = 0.15$ ;  $p = 0.09$ ) and weight

**TABLE 1**  
Age, Weight, Height, BMC, BMC/cm, and BMC/cm<sup>2</sup> in the Three Groups of Subjects

	Group 1 n = 78 (mean ± s.d.)	Group 2 n = 25 (mean ± s.d.)	Group 3 n = 33 (mean ± s.d.)	Total n = 136 (mean ± s.d.)
Age (yr)	10.0 ± 3.7	9.6 ± 4.4	9.9 ± 4.7	9.9 ± 4.1
Weight (kg)	36.7 ± 15.0	37.2 ± 18.9	40.4 ± 19.7	37.7 ± 16.9
Height (cm)	138.7 ± 21.2	138.2 ± 28.6	137 ± 27.6	138.2 ± 24.2
BMC total (gHA)	20.26 ± 9.21	20.46 ± 11.85	21.30 ± 11.61	20.55 ± 10.27
BMC/cm (gHA/cm)	2.53 ± 0.79	2.44 ± 0.86	2.61 ± 1.03	2.53 ± 0.86
BMC/cm <sup>2</sup> (gHA/cm <sup>2</sup> )	0.63 ± 0.12	0.62 ± 0.13	0.62 ± 0.18	0.62 ± 0.14

**TABLE 3**  
BMC/cm<sup>2</sup>, Relative Increase (RI), and Coefficients of Variation (CV) of BMC/cm<sup>2</sup> in the Different Age Groups

BMC/cm <sup>2</sup> (gHA/ cm <sup>2</sup> )	Boys (mean ± s.d.)	Girls (mean ± s.d.)	All children	
			(mean ± s.d.)	No. CV (%)
1-4 yr	0.41 ± 0.08	0.42 ± 0.07	0.42 ± 0.07	11 16%
RI	(-)	(-)	(-)	
4-8 yr	0.53 ± 0.07	0.52 ± 0.06	0.53 ± 0.06	33 11%
RI	(+29%)	(+23%)	(+26%)	
8-12 yr	0.60 ± 0.07	0.61 ± 0.08	0.61 ± 0.08	39 13%
RI	(+13%)	(+17%)	(+15%)	
12-16 yr	0.69 ± 0.07	0.75 ± 0.13	0.72 ± 0.11	47 15%
RI	(+15%)	(+22%)	(+18%)	
16-18 yr	0.86 ± 0.04	0.88 ± 0.08	0.87 ± 0.06	6 6%
RI	(+24%)	(+17%)	(+20%)	

( $r = 0.03$ ;  $p = 0.69$ ) were found. BMD values can, thus, be predicted by the exponential regression line of BMC/cm<sup>2</sup> for age:  $BMC/cm^2 = 0.38 \times e^{0.0745 \text{ age}(\text{yr})}$ . Ln (BML) could best be described by a linear combination of age and height, while the inclusion of weight did not deliver a significant improvement in the prediction. The equation of the exponential regression line for the prediction of BML is

$$BMC/cm = 0.52 \times e^{0.008 \text{ height}(\text{cm})} \times e^{0.034 \text{ age}(\text{yr})}$$

For pubertal children, the BMC values, expressed per cm and cm<sup>2</sup>, in relation to their pubertal stage, are presented in Tables 4 and 5. BML values increased significantly ( $p < 0.05$ ) at each pubertal stage, except at Stage 5. For the BMD values, however, only at Stage 4 was there a significant increase. For the children ( $n = 9$ ) with a completed pubertal development (Stage 5), the bone mass was already in the adult range.

## DISCUSSION

Normative data on BMC in children between 1 and 16 yr so far have been determined at the level of the forearm by single-photon absorptiometry (7-9). In nor-

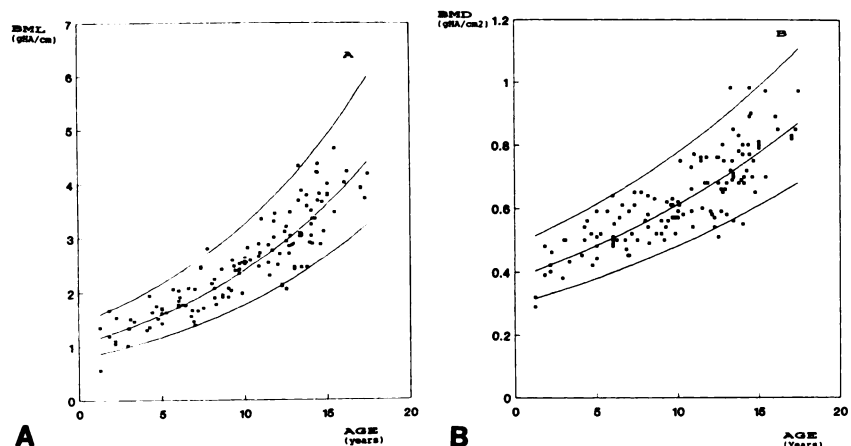
mal adults, BMC determined locally at the level of the forearm as well as at the level of the lumbar spine shows a close relationship with the BMC of the whole skeleton (10,11). However, in several diseases associated with osteoporosis, determination of forearm BMC is not appropriate for estimating changes in the axial skeleton (11,12). Lumbar spine BMC is clearly a more sensitive means of assessing trabecular bone turnover, as the response to disease and treatment is more rapid in this type of bone (13). Another advantage of a BMC determination at the level of the lumbar spine in children is the possibility to perform serial measurements at precisely the same localization (L2-L4). This is not so obvious for longitudinal studies using the monophoton technique (14).

To our knowledge, normative data on lumbar spine BMC in children have not been established. In the present study, BMC determination in normal children (without any pathology) could not be performed for ethical reasons, but the studied population of children might be considered as representative for the development and the presence of a normal lumbar spine bone mass.

In the first group of children, BMC determinations were made within 3 days after the fracture, thus, before the effect of immobilization could be present. None of the children had experienced a fracture before and in all cases a violent trauma was responsible for the fracture, which was always localized at the peripheral skeleton. In the second group of children with a minor orthopedic anomaly at the level of the peripheral skeleton, attention was paid not to include children whose skeletal anomaly might have led to a lesser degree of physical activities.

The third group included children in whom a corticosteroid treatment was indicated for an acute non-skeletal disease. In those children, the BMC values included in the present study were all obtained before the treatment was started. No difference in BMC results were found between these three groups. However, if the

**FIGURE 1**  
(A) Ninety-five percent confidence limits of BML in relation to age. (B) Ninety-five percent confidence limits of BMD in relation to age.



**TABLE 4**  
BMC/cm According to Pubertal Stage

Puberty stage	No. patients	Mean $\pm$ s.d. (gHA/cm)	Approximate 95% confidence interval for mean
Stage G2	16	2.82 $\pm$ 0.37	2.62–3.02
Stage G3	13	3.26 $\pm$ 0.33	3.06–3.46
Stage G4	13	3.77 $\pm$ 0.42	3.52–4.02
Stage G5	9	4.03 $\pm$ 0.33	3.78–4.28

selection of these subjects for a BMC evaluation might have biased the results, we suspect that this population is rather biased downward from the normal population.

In this study, lumbar spine BMC has been expressed in BMC/cm and BMC/cm<sup>2</sup>. In adults, a recent report suggests that the reproducibility of BMC measurements is better when the results are expressed in BMC/cm<sup>2</sup> (15). In children, one has to consider that the lower bone mass (and absorption) has a negative effect on a precise vertebral bone edge determination, which is a critical point in getting a precise lumbar spine absorption measurement. Since, for the calculation of the results per surface unit, the inaccuracies on height and on width determinations of the vertebrae are taken into account, the results might be less precise than if only the vertebral height is considered. However, for longitudinal measurements, BMD has to be preferred since a better correction for the vertebral growth is made. In this cross-sectional study of lumbar spine bone mass, BMD values were clearly less dependent on body height than the BML measurements. This may also explain the lower variations in BMD in the different age groups studied. High interindividual variations were found, especially in the age groups 1–4 yr and 12–16 yr. These age groups are characterized by the greatest alterations in sitting height-growth velocity, and, thus, also in vertebral growth. However, even after correcting spinal BMC for the height and width of the vertebra (BMC/cm<sup>2</sup>), these variations remained important. In the age group 16–18 yr, a very low CV (6%) was found. This is in accordance with the low variation in estimated total-body calcium after the age of 17 yr reported in a group of normal children (16). The fact that after the age of 16 yr, most children have completed their skeletal

**TABLE 5**  
BMC/cm<sup>2</sup> According to Pubertal Stage

Puberty stage	No. patients	Mean $\pm$ s.d. (gHA/cm <sup>2</sup> )	Approximate 95% confidence interval for mean
Stage G2	16	0.68 $\pm$ 0.08	0.63–0.71
Stage G3	13	0.70 $\pm$ 0.06	0.66–0.73
Stage G4	13	0.83 $\pm$ 0.09	0.78–0.88
Stage G5	9	0.86 $\pm$ 0.06	0.81–0.92

growth may perhaps explain the low variation in this age group.

To reduce the great variation of BMC in adolescence, some authors have suggested normalizing BMC to pubertal stage rather than to chronologic age (17,18). In our study, the correlation coefficients for lumbar spine BML and BMD versus age, weight, and height were much lower in pubertal than in prepubertal children, suggesting that, especially during puberty, factors other than growth influence bone mineralization. During puberty, the total increase in BML (1.87 gHA/cm) and BMD (0.25 gHA/cm<sup>2</sup>) was higher than that during the preceding 10 yr. These values represent a 40% increase for BMD and a 77% increase for BML. The most important increase in lumbar spine BMD and BML was found in pubertal Stage 4 for both sexes. It is during this stage of puberty that the deceleration of the growth spurt occurs and adult levels of sex steroids can be attained. Adult BMC values were found in the nine subjects with adult (Stage 5) pubertal development. However, this does not mean that these BMC values represent the peak bone mass, which is generally attained around the age of 30 yr (19).

#### ACKNOWLEDGMENTS

This investigation was supported by grant no. 3.0075.85 from NFWO. We wish to thank Mrs. H. Vindevoghel and Mrs. R. Vindevoghel for preparing the manuscript.

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