Influence of body composition on bone mineral content in children and adolescents

Paola Manzoni, Paolo Brambilla, Angelo Pietrobelli, Luciano Beccaria, Anna Bianchessi, Stefano Mora, and Giuseppe Chiumello

ABSTRACT Excess fat and fat-free mass have been extensively described in obese children, whereas few data about bone mineral content (BMC) variations are available in children. Dual-energy X-ray absorptiometry (DXA) allows a direct and accurate measurement of three body compartments (fat, lean, and BMC), subdivided into three regions (arms, trunk, and legs). The aim of our study was to evaluate the influence of body compartments on total BMC (TBMC) and regional BMC (RBMC) in obese and normal-weight subjects. Sixty-five obese and 50 normal-weight children and adolescents (age range: 5–18 years) had BMC measured by DXA. Subjects were subdivided into three categories (arms: lean, fat, and BMC; trunk: lean, fat, and BMC; legs: lean, fat, and BMC). We found no significant correlation between TBMC and BMC in any region. Multiple-regression analysis confirmed lean mass as the major determinant of TBMC and RBMC in children. Differences in TBMC and RBMC were no longer present after correction for age, sex, and body-composition variables. There were no differences in TBMC and RBMC between obese and normal-weight children after correction for the confounding variables age and sex.

KEY WORDS Body composition, bone mass, lean mass, bone mineral content, childhood, obesity, dual-energy X-ray absorptiometry

INTRODUCTION

Body-composition studies in obese children and adolescents are available because new methods have been validated in the past few years (1–4). The majority of these techniques are based on a two-compartment model measuring body fat and fat-free mass. It has been shown that obese children have increased fat mass and moderately increased fat-free mass (5, 6). Bone mineral mass was not included until recently in body-composition research. Few studies have measured bone mineral mass. Of those that have, all measured bone density at different skeletal sites. Obese adults showed increased bone density of the forearm (7) and femoral neck (8). The latter study showed that increased weight and increased lean mass exert the major influence on bone density. Contradictory data are available concerning bone density of obese children: one study showed reduced bone density at the radius (9), whereas another showed spinal bone densities within normal limits (10).

Bone mineral mass of obese subjects could be influenced by increased weight. In fact, weight load stimulates bone formation as described previously in animals (11) and humans (12). Furthermore, obese subjects show a moderate increase in lean mass and therefore in muscle mass, which is another important determinant of bone mass (13, 14). These influences on bone mineral mass could be even stronger in growing children and adolescents, in whom modifications of body compartments occur constantly and rapidly.

Dual-energy X-ray absorptiometry (DXA) is a scanning technique that measures the differential attenuation of two discrete energies as they pass through the body. It distinguishes total bone mineral content (TBMC) from soft tissue and subsequently divides the latter into fat and lean tissue (15). Thus, the three-compartment body-composition analysis performed by DXA introduces new indexes into body-composition studies, such as TBMC (16–18) and regional bone mineral content (RBMC).

The aims of our study were to measure TBMC in obese children and adolescents and to evaluate whether body weight and body compartments (lean and fat) influence TBMC and RBMC.

SUBJECTS AND METHODS

Subjects

A total of 115 healthy subjects aged 5–18 years were included in our study. According to their relative body weight (RBW) calculated with Tanner growth charts (19), they were subdivided into obese (n = 65; RBW > 120%) and normal-weight (n = 50; RBW = 80–120%) groups. None had a history of endocrine, nutritional, growth, or renal problems; the obese subjects had never received dietetic treatment. Clinical charac-

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teristics of the study population are shown in Table 1. Informed consent was obtained from parents and children and ethical approval for the study was granted by the Ethical Committee of the Scientific Institute Hospital San Raffaele.

Methods

Weight of subjects wearing minimal clothing was measured with an electric scale. Height was measured to the nearest millimeter by using a Harpenden stadiometer (Holtain Ltd, Crymych, United Kingdom). Body mass index (BMI) was calculated as weight (kg)/height(m)^2. Pubertal stages were assessed according to Tanner (19). Children in stage 1 were defined as prepubertal, whereas children in stages 2–5 were defined as pubertal.

DXA total-body analysis was performed with a Lunar DPX-L scanner (Lunar Corp, Madison, WI) equipped with pediatric software (version 1.5 e). Scans were performed with subjects in the supine position; the children did not require sedation. The entire body of each subject was scanned, beginning at the top of the head. A different scan mode was chosen with respect to each subject’s body size, as suggested by the manufacturer’s operator manual. Obese subjects were scanned with the “slow” scan mode (scan speed of 38.4 mm/s with a sample size of 4.8 mm × 9.6 mm, sample interval of 0.125 s, and source collimation of 1.68 mm); normal-weight subjects were scanned with the “medium” scan mode (scan speed of 76.8 mm/s with a sample size of 4.8 mm × 9.6 mm, sample interval of 0.062 s, and source collimation of 1.68 mm) or with the “fast” scan mode (scan speed of 153.6 mm/s with a sample size of 4.8 mm × 9.6 mm, sample interval of 0.03 s, and source collimation of 1.68 mm) according to their size. Mean measurement time was 20 min; radiation exposure was < 8 μSv. Body fat was expressed in kilograms and as a percentage of body weight; lean mass was measured in kilograms; BMC was expressed as both total mass (g) and as a percentage of body weight.

For regional analysis several regions of the body were taken into account. Three-compartment analyses were performed in the arms, trunk, and legs. The arms were defined by the line passing through the humeroscapular joint. The trunk region was delineated by an upper horizontal border below the chin, vertical borders lateral to the ribs, and a lower border formed by oblique lines passing through the femoral necks. The leg region was defined as the tissue below the oblique lines passing through the femoral necks (20).

Daily quality-assurance tests were performed according to the manufacturer’s directions. All scans were performed and analyzed by the same operator. The precision of the instrument was calculated as 0.7% for fat, 0.9% for lean, and 1.5% for TBMC in normal-weight subjects of pediatric and adult age (our data). Anthropometry and DXA analysis were performed on the same day.

Statistical analysis

Differences between normal-weight and obese subjects were analyzed by using Student’s t test for unpaired samples. Simple-regression analyses were carried out between TBMC and fat mass and between TBMC and lean mass. Multiple-linear-regression analysis was used to assess the influence of auxologic and body-composition variables on the dependent variables TBMC and RBMC (21, 22); sex was introduced in the regression model as an independent dichotomous variable, with boys assigned a value of 0 and girls a value of 1. Obesity was considered a dichotomous variable with normal-weight subjects assigned a value of 0 and obese subjects a value of 1. Age was closely related to both height and lean mass (r = 0.83 and r = 0.75, respectively) and therefore it was excluded from the analysis of TBMC. Significance levels were based on a two-tailed t test; the 5% significance level was chosen.

RESULTS

In Table 1 we reported body-composition data concerning fat and lean mass. Obese subjects had larger fat and lean compartments (P < 0.0001) and P < 0.001, respectively) than the normal-weight subjects. Fat content was also greater when expressed as a percentage of body weight (P < 0.0001). Obese children had significantly higher TBMC values than normal-weight children (1930 ± 670 g compared with 1480 ± 490 g, P < 0.0001). The influence of puberty on TBMC is shown in Table 2. Both obese and normal-weight prepubertal children had significantly lower values than pubertal children (P < 0.0001). TBMC showed a significant direct correlation with lean mass in obese as well as in normal-weight children (r = 0.91 and 0.94, respectively; TBMC = 0.059x + 0.023 for obese and TBMC = 0.06x − 0.125 for normal-weight children, where x is lean mass). Fat mass was also directly correlated with TBMC in the two groups (r = 0.68 and 0.54 for obese and normal-weight children, respectively). When multiple-regression analyses were performed, differences in TBMC between the two groups disappeared (P = 0.22) and the strongest determinants of TBMC were height and lean mass (Table 3).

Results of regional analyses of body composition are shown in Table 4. Each region’s weight as well as each regional compartment (fat, lean, and BMC) were significantly greater in the obese than in the normal-weight children.

Results of multiple-regression analyses for each region examined are shown in Table 5; differences between obese and

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**TABLE 1**

<table>
<thead>
<tr>
<th>Obese (n = 30 M, 35 F)</th>
<th>Normal weight (n = 28 M, 22 F)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Age (y)</strong></td>
<td>11.1 ± 2.9</td>
</tr>
<tr>
<td><strong>Weight (kg)</strong></td>
<td>63.9 ± 20.6</td>
</tr>
<tr>
<td><strong>Height (cm)</strong></td>
<td>148.0 ± 15.5</td>
</tr>
<tr>
<td><strong>RBW (%)^1</strong></td>
<td>160 ± 23</td>
</tr>
<tr>
<td><strong>BMI (kg/m^2)</strong></td>
<td>28.5 ± 4.8</td>
</tr>
<tr>
<td><strong>Fat</strong></td>
<td></td>
</tr>
<tr>
<td>(kg)</td>
<td>29.3 ± 12.2</td>
</tr>
<tr>
<td>(%)</td>
<td>44.7 ± 7.3</td>
</tr>
<tr>
<td><strong>Lean tissue (kg)</strong></td>
<td>32.8 ± 10.3</td>
</tr>
<tr>
<td><strong>TBMC (g)^5</strong></td>
<td>1927 ± 670</td>
</tr>
</tbody>
</table>

^1 Relative body weight (19).

^2 Total bone mineral content.
normal-weight subjects were no longer present. Age \((P < 0.002)\), sex \((P < 0.003)\), and lean mass \((P < 0.0001)\) appeared to be the most important factors influencing the BMC of the arms. On trunk BMC, lean mass \((P < 0.003)\) had the greater effect together with age \((P < 0.01)\). The BMC of the legs varied by sex \((P < 0.03)\), leg weight \((P < 0.001)\), and lean mass \((P < 0.002)\).

**DISCUSSION**

Obesity is characterized by increased body weight with excess body fat and a relative increase of the lean compartment. BMC is quite a new compartment for body-composition studies, and was only recently detected by using DXA. This method, which provides a negligible radiation exposure, gives a direct and accurate measure of bone and soft tissue as validated in adults and children \((18, 23)\). Bone mineral mass and its relation with body compartments in obese children may be of clinical importance because any therapeutic intervention that modifies body composition may affect BMC. This is of great interest, especially during linear growth when many exogenous factors affect peak bone mass, which decreases progressively with age after early adulthood.

Bone mineralization of obese children was evaluated by measurement of bone density. Studies with single-photon absorptiometry at the radius showed that obese children had reduced mineral density in comparison with normal-weight peers \((9)\). Contrasting results were described more recently using DXA: obese children showed higher \((24)\) or normal \((10)\) spine bone density with respect to normal-weight children. Similar contradictory data have been reported for obese adults \((25, 26)\).

**TABLE 2**

Total bone mineral content obtained with dual-energy X-ray absorptiometry: differences for pubertal development in both sexes in obese and normal-weight children \(^{6}\)

<table>
<thead>
<tr>
<th></th>
<th>Boys</th>
<th>Girls</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Prepubertal ((9.5 \pm 2.0 \text{ y}))</td>
<td>Pubertal ((13.6 \pm 1.0 \text{ y}))</td>
</tr>
<tr>
<td>Normal weight</td>
<td>(1187 \pm 294 \text{ [15]})</td>
<td>(1708 \pm 475 \text{ [13]}^{2})</td>
</tr>
<tr>
<td>Obese</td>
<td>(1586 \pm 487 \text{ [20]})</td>
<td>(2757 \pm 379 \text{ [10]}^{2})</td>
</tr>
</tbody>
</table>

\(^{1} \pm SD; \ n \ \text{in brackets.} \)

\(^{2} \text{Significantly different from prepubertal, } P < 0.0001. \)

The degree of obesity of our sample population ranged from moderate to severe. The obese children were comparable with the normal-weight children for age, height, sex, and pubertal stage. Body-composition analysis by DXA in obese subjects confirmed previous data \((27)\): they had significantly greater fat as well as lean compartments, both total and by region. Obese children had higher TBMC and RBMC values than normal-weight children. These findings are similar to those described in obese adults \((8)\). As described previously for bone density \((28-30)\), puberty exerts a significant influence on TBMC; higher TBMC values were found during puberty.

To evaluate the influence of body composition on TBMC in children and adolescents, we looked at the correlation with fat and lean mass. Lean mass had a higher correlation with TBMC in both obese and normal-weight children. Multiple-regression analysis confirmed the strongest influence of lean mass on TBMC as well as on each region examined. When corrected for all the confounding variables \(\text{(age, sex, weight, and lean and fat mass)}\), TBMC and RBMC did not differ significantly between obese and normal-weight children.

Sex seems to be an important determinant of limb BMC, probably because of the different muscle mass in boys and girls at these sites \((P < 0.004 \text{ at arms and legs}); this hypothesis is supported by the lack of effect at the level of the trunk, where lean mass is represented by muscles and abdominal viscera.

**TABLE 3**

Results of multiple-regression analysis of the influence of several variables on total bone mineral content in obese and normal-weight children

<table>
<thead>
<tr>
<th>Variable</th>
<th>(\beta^{1})</th>
<th>SE</th>
<th>(P)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>-79.71</td>
<td>42.56</td>
<td>0.06</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>-4.91</td>
<td>11.24</td>
<td>0.66</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>13.22</td>
<td>3.22</td>
<td>0.0001</td>
</tr>
<tr>
<td>Lean mass (kg)</td>
<td>0.04</td>
<td>0.01</td>
<td>0.0001</td>
</tr>
<tr>
<td>Fat mass (kg)</td>
<td>8.61</td>
<td>11.04</td>
<td>0.44</td>
</tr>
<tr>
<td>Obese or normal weight</td>
<td>-81.91</td>
<td>67.24</td>
<td>0.22</td>
</tr>
</tbody>
</table>

\(^{1} \text{Represents the difference in total bone mineral content \(g\) between dichotomous variables \(\text{(sex, obesity)}\) or per unit of continuous variables \(\text{(weight, height, lean mass, fat mass)}\).} \)

\(^{2} \text{Significantly different from obese \(\text{(Student's t test)}\); } P = 0.0001. \)

\(^{3} \text{Significantly different from obese \(\text{(Student's t test)}\); } P = 0.0002. \)
Lean mass and weight affected BMC of the legs in both obese boys and girls. This peculiar finding (apparently regional weight does not have an effect on arms and trunk BMC) seems to suggest the influence of weight load and muscle strength on bone formation. Mechanical loading stresses the skeleton, especially the long bones of the lower limbs. This finding agrees with previous studies that showed mechanical loading to be an important factor in the regulation of bone mass in animals (11) and humans (12).

The effect of exercise training on bone mass has been studied extensively. Sports exerting loads on the lower extremities and weight-bearing activities result in higher bone mass in the lower limbs (31), whereas typical non-weight-bearing exercises, such as swimming and cycling, condition a reduced bone mass in the legs (32–34).

Another important factor affecting regional bone mass is muscle mass and strength (13, 14). In obese women, the bone mass of the femur directly and linearly correlates with tertile of muscle mass (7). In our obese population lean mass was increased in the legs to the same extent as other regions. We did not perform muscle strength tests, but increased muscle mass may play an additional role in BMC (34).

In conclusion, our data suggest that obese children have an altered body composition characterized by increased body compartments: fat, lean, and BMC. However, when BMC was corrected for size- and body composition–related variables, it was comparable with that of normal-weight children. Moreover, TBMC seems to be influenced by lean mass; therefore, TBMC must be evaluated together with lean mass in body-composition studies. Contradictory data in obese subjects described in the literature could then be explained by the different methodology but also because TBMC was not assessed together with the other body compartments, whose influence has to be considered.

No data are available about changes in BMC during a dietary regimen in children and adolescents. Further studies are required to analyze the effect of long-term energy restriction with or without physical activity on TBMC and RBMC.

REFERENCES


