Disturbances of calcium metabolism, including increased urinary calcium excretion, may accompany primary hypertension (PH) and osteoporosis.\textsuperscript{1,2} Hypercalciuria, as a function of blood pressure, was observed in normotensive children in the Dutch Hypertension and Offspring Study and also in normotensive children of hypertensive parents.\textsuperscript{3,4} On the other hand, PH is strictly related to sedentary behavior and nutritional habits with high-sodium and low-calcium intake, and both PH and decreased bone mass are among the main problems of elderly persons.\textsuperscript{2,5} Calcium, vitamin D metabolites, proper nutrition, and physical activity (PA) are crucial determinants of peak bone mass.\textsuperscript{6–13} It was shown recently that low serum vitamin D levels correlate with higher blood pressure.\textsuperscript{14} Therefore, PH, through its possible associations with calcium and vitamin D metabolism, as well as behavioral factors including nutritional habits and low PA, may alter skeletal status and body composition. Bone mass accrual is highly influenced by mechanical stimulation from skeletal muscles, and the proper muscle-bone interactions during growth are key determinants of skeletal adaptation toward changing loads.\textsuperscript{11–13,15,16} Low PA, excessive sodium intake, and calcium loss are among the risk factors common not only for osteoporosis but also for PH.\textsuperscript{16,17} Because exposure to similar risk factors for both osteoporosis and PH takes place already in childhood, it seems interesting to evaluate the musculoskeletal system at an early stage of PH.

The method of choice for the evaluation of both skeletal status and body composition is dual-energy x-ray absorptiometry (DXA).\textsuperscript{6–10,18–22} DXA offers accurate and precise measurements of total body bone mineral density (TBMD), total body bone mineral content (TBBMC), lean body mass (LBm; predominantly muscle mass), fat mass (FM), and its fraction of whole body mass.\textsuperscript{18–22} Recently, DXA-derived TBBMC and LBm were implemented as the parameters
feasible for the estimation of bone adaptation to muscle demands, with the assumption that when LBM is abnormally low for body height (BH), TBBMC may also be decreased. At the same time, the TBBMC:LBM ratio as a Relative Bone Strength Index (RBS) was implemented as a marker of imbalance between bone and muscle, as well as fracture risk. This study was aimed to investigate the relationships among muscle, bone, and fat tissues in newly diagnosed juveniles with PH.

Methods

Healthy Control Subjects
The reference population consisted of 562 healthy white subjects of Polish origin aged 5 to 18 years including 278 girls (12.0±3.9 years) and 284 boys (12.1±3.7 years) who underwent a complete medical examination before the study. The exclusion criteria for healthy control subjects were a history of any chronic diseases and treatment affecting bone metabolism and orthopedic problems that could affect bone and muscle. The anthropometric and densitometric characteristics of the reference population have been described previously in detail.

Patients
The study population was composed of 94 newly diagnosed and as-yet-untreated white subjects of Polish origin aged 6 to 18 years, including 21 girls (22.3%; 15.3±1.3 years) and 73 boys (77.7%; 15.1±2.5 years), admitted consecutively because of a diagnosis of elevated blood pressure and in whom prehypertension or PH was ultimately diagnosed. In all of the case subjects, elevated blood pressure was diagnosed during routine school checkup and/or during clinical workup of other complaints. Arterial hypertension was diagnosed when elevated blood pressure was found on ≥3 blood pressure measurements on 3 different occasions according to recent guidelines. Time from diagnosis of elevated blood pressure to clinic referral was 4 to 8 weeks. PH was diagnosed during a hospital stay after thorough examination excluding known causes of secondary hypertension according to the fourth Task Force Report guidelines. In all of the case subjects, hypertension was confirmed by 24-hour ambulatory blood pressure monitoring. In all of the patients, irrespective of the stage of hypertension, urinalysis, plasma biochemistry including determination of renal function, ion concentrations, plasma renin activity, plasma aldosterone, urinary steroid profile, and microalbuminuria were evaluated. Imaging studies including Doppler ultrasonography and renal scintigraphy were performed in all of the patients.

Assessment of Skeletal Status and Body Composition
DXA (DPX-L, GE Lunar) was used to assess skeletal status and body composition. PH patients were measured at the time of diagnosis of PH. BH (in centimeters) and body weight (BW; in kilograms) were assessed on the day of the DXA scan, and the body mass index (BMI; in kilograms per meter squared) was calculated. TBBMC (in grams), TBBMD (in grams per centimeter squared), LBM (in grams), and FM (in grams) were evaluated on the basis of total body scan data. To ensure high accuracy of DXA measures, a daily quality control procedure and anthropometric spine phantom (Hologic) scans were performed. The coefficient of variation for repeated DXA measures of the Hologic spine phantom (L1 to L4) was 0.56%. The coefficient of variation percentage for TBBMC measurements of the Hologic spine phantom (L1 to L4) was 0.1%. The coefficient of variation for TBBMC:LBM ratio was 1.33% and 1.94% for LBM and FM, as assessed by the root mean square method.

Evaluation of PA and Sedentary Behavior
A modified method based on the International Physical Activity Questionnaire was used to estimate the PA level. Specifically, all of the patients were asked to fill in the modified International Physical Activity Questionnaire evaluating PA, sedentary behavior, and markers of stress. Patients gave subjective information on a “usual” number of hours of PA weekly at school and at home and a usual number of hours daily playing computer games and/or working with a computer within the last 6 months. The weekly amount of hours of PA organized and supervised at school was regarded as objective information of the real time of PA weekly. Reported hours of sleep daily were regarded as a nonspecific marker of stress.

Statistical Analysis
BH, BW, BMI, TBBMC, TBBMD, LBM, FM, and the ratios of LBM:BW, FM:BW, FM:LBM, and TBBMC:LBM were analyzed for possible differences between the PH groups with respect to gender and were compared with data obtained in the reference population. To assess the magnitude of expected bone and body composition disturbances resulting from hypertension, the Z scores, SD scores, and SDs scores were calculated to express the disturbances in units of standard deviation from the value of 0 (expected in healthy control subjects).

The Z scores were used for evaluation of disturbances in relation to age- and gender-matched values established previously in healthy control subjects and were calculated using the following formula:

\[ Z = \frac{\text{test result for a subject} - \text{(age- and gender-matched mean in control subjects)}}{\text{(age- and gender-matched SD in control subjects)}} \]

The SD scores were used to limit the potential influence of differences in body stature on DXA results and were calculated according to BH- and gender-matched values of healthy control subjects using the respective formula:

\[ SD = \frac{\text{(test result for a subject) - (BH- and gender-matched mean in control subjects)}}{\text{(BH- and gender-matched SD in control subjects)}} \]

Finally, absolute densitometric data were also expressed as SDs scores calculated according to BW- and gender-matched control subjects to evaluate how far and in what direction PH impacts skeletal status and body composition in relation to controls with the same BW. SDs scores were calculated using the following formula:

\[ SDs = \frac{\text{(test result for a subject) - (BW- and gender-matched mean in control subjects)}}{\text{(BW- and gender-matched SD in control subjects)}} \]

The normal distribution of the distribution of analyzed data was controlled by Kolmogorov-Smirnov and Shapiro-Wilk tests. For the evaluation of differences between the consecutive study groups, nonparametric Kruskal-Wallis ANOVA rank test and Mann-Whitney U test were performed. Calculated Z scores, SD scores, and SDs scores were also compared with the hypothetical value of 0 to assess whether a studied disturbance is significant from data expected in healthy control subjects. The comparison of the percentage distribution of patients at risk of bone fracture was calculated using the chi² test. The Spearman correlation test was performed for the evaluation of relationships between the PA level and DXA parameters. All of the Ps<0.05 were considered significant. Results are presented as mean±SD unless otherwise stated.

Ethics
The study was granted by the ethical committee of the Children’s Memorial Health Institute. All of the children or their caregivers gave their informed consent before the study.
### Results

#### General Clinical and Anthropometric Characteristics of PH Patients

Prehypertension was diagnosed in 11 patients (11.7%), stage 1 hypertension in 65 patients (69.1%), and stage 2 hypertension in 18 (19.1%). Prehypertensive patients had the greatest absolute BMI and BMI Z score in comparison with stage 1 and stage 2 patients (P<0.05). The mean difference between BH values observed in PH girls and boys was 9.8 cm (P<0.01; Table 1). PH boys had slightly but significantly increased BH Z scores when compared with control subjects (P<0.01) and PH girls (P<0.05). When compared with control subjects, markedly increased BW Z scores of +2.32±2.45 (P<0.001) and +1.63±1.74 (P<0.0001), as well as BMI Z scores of +2.56±2.48 (P<0.001) and +1.76±1.81 (P<0.0001), were noted in PH girls and boys, respectively (Table 1).

#### Skeletal Status and Body Composition in PH Patients

PH girls had significantly lower TBBMC (P<0.01) and LBM (P<0.0001), but not TBBMD, when compared with PH boys.

Furthermore, the LBM fraction of the body, as assessed by the LBM:BW ratio, was lower in girls compared with boys (P<0.0001). Moreover, PH girls had higher absolute FM (P<0.05) and its fraction in the whole body (FM:BW; P<0.0001), as well as FM:LBM ratio values (P<0.0001), when compared with PH boys (Table 1).

#### Skeletal Status and Body Composition of PH Patients in Relation to Age- and Gender-Matched Healthy Control Subjects

Hypertensive case subjects, when compared with control subjects, had markedly increased FM and FM:BW ratio Z scores of +2.53±2.49 (P<0.001) and +1.60±1.34 (P<0.0001) in girls and +1.66±2.02 (P<0.0001) and +1.15±1.39 (P<0.0001) in boys, respectively (Figure 1). In both genders, LBM Z scores trended to be slightly higher than in control subjects, but this observation was significant in boys (P<0.0001). In contrast, markedly reduced LBM:BW Z scores of −1.89±1.47 (P<0.0001) and −1.24±1.38 (P<0.0001) were noted in girls and boys compared with control subjects. Moreover, LBM:BW ratio Z scores trended to be lower in PH girls than in boys (P=0.0553). Compared with control subjects, both girls and boys had markedly disturbed relationships between FM and LBM as assessed by FM:LBM ratio Z scores of +1.89±1.76 (P=0.0001) and +1.29±1.76 (P<0.0001), respectively (Figure 1).

#### Skeletal Status and Body Composition of PH Patients in Relation to BH- and Gender-Matched Healthy Control Subjects

The SD score values showed that, in PH patients, TBBMD and TBBMC were both slightly higher when compared with BH-matched control subjects; however, the difference from control subjects was significant in girls for TBBMD (P<0.0001), whereas it was significant in boys for TBBMC (P<0.0001). PH girls had mean SD scores of +1.21±1.09 and +1.06±0.94 for TBBMD and TBBMC, respectively, that were higher than the respective values of +0.57±0.89

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### Table 1. Anthropometry, Physical Activity Level, and DXA Parameters in Girls and Boys With Primary Hypertension

<table>
<thead>
<tr>
<th>Variable</th>
<th>Girls (n=21)</th>
<th>Boys (n=73)</th>
<th>P, Mann-Whitney Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Anthropometry</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age, y</td>
<td>15.3±1.3</td>
<td>15.1±2.5</td>
<td>ns</td>
</tr>
<tr>
<td>BH, cm</td>
<td>164.6±7.5</td>
<td>174.4±13.3</td>
<td>0.002</td>
</tr>
<tr>
<td>BW, kg</td>
<td>73.1±20.3</td>
<td>77.9±20.6</td>
<td></td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>26.8±6.6</td>
<td>25.3±5.3</td>
<td></td>
</tr>
<tr>
<td>BH Z score</td>
<td>−0.22±1.09</td>
<td>+0.26±0.75</td>
<td>0.027</td>
</tr>
<tr>
<td>BW Z score</td>
<td>+2.32±2.45</td>
<td>+1.63±1.74</td>
<td></td>
</tr>
<tr>
<td>BMI Z score</td>
<td>+2.56±2.48</td>
<td>+1.76±1.81</td>
<td></td>
</tr>
<tr>
<td><strong>Physical activity level</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Personal computer, h/d</td>
<td>2.6±1.7</td>
<td>3.0±1.7</td>
<td>ns</td>
</tr>
<tr>
<td>Physical education, h/wk</td>
<td>2.7±1.7</td>
<td>2.8±1.5</td>
<td>ns</td>
</tr>
<tr>
<td>Total physical activity, h/wk</td>
<td>11.4±5.2</td>
<td>15.4±9.5</td>
<td></td>
</tr>
<tr>
<td>Seating, h/d</td>
<td>9.3±2.7</td>
<td>9.8±2.6</td>
<td>ns</td>
</tr>
<tr>
<td>Sleep, h/24 h</td>
<td>7.2±1.4</td>
<td>8.1±1.2</td>
<td>0.039</td>
</tr>
<tr>
<td><strong>DXA parameters</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TBBMD, g/cm²</td>
<td>1.146±0.066</td>
<td>1.157±0.119</td>
<td>ns</td>
</tr>
<tr>
<td>TBBMC, g</td>
<td>2481±396</td>
<td>2852±672</td>
<td>0.002</td>
</tr>
<tr>
<td>FM, kg</td>
<td>29.2±13.3</td>
<td>21.9±13.4</td>
<td>0.016</td>
</tr>
<tr>
<td>FM:BW ratio</td>
<td>0.38±0.09</td>
<td>0.26±0.11</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>LBM, kg</td>
<td>39.2±7.5</td>
<td>51.5±11.2</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>LBM:BW ratio</td>
<td>0.55±0.08</td>
<td>0.68±0.11</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>FM:LBM ratio</td>
<td>0.73±0.26</td>
<td>0.43±0.26</td>
<td>&lt;0.0001</td>
</tr>
<tr>
<td>TBBMC:LBM ratio, g/g</td>
<td>0.064±0.006</td>
<td>0.055±0.005</td>
<td>&lt;0.0001</td>
</tr>
</tbody>
</table>

*P* value indicates significance of differences between girls and boys; ns, not significant.
and SD scores trended to be higher than in control subjects (Table 2). In contrast, when increased BW was controlled for, all 3 of the groups trended to have both TBBMD and TBBMC SDs scores lower than those in control subjects. Prehypertensive patients had the greatest amount of FM expressed as FM, FM:BW, FM:LBM Z scores and SD scores, and FM SDs scores compared with patients with stage 1 and stage 2 hypertension (Table 2). Although prehypertensive subjects had greater LBM SD scores compared with stage 1 hypertensive subjects (P<0.05), they also had the lowest LBM:BW SD scores (P<0.05).

**Assessment of Muscle-Bone Interaction by DXA**

When musculoskeletal interactions were evaluated by the TBBMC:LBM ratio, Z score, SD score, and SDs score values were not different in girls and boys (Figure 4) or in prehypertensive, stage 1, and stage 2 hypertensive subjects (Table 2). Of note, in both girls and boys TBBMC:LBM Z scores of +0.05±0.98 and +0.23±1.35, as well as TBBMC:LBM SD scores of +0.50±1.00 and +0.19±1.21, were close to the values of control subjects. The same pattern was observed in prehypertensive, stage 1, and stage 2 hypertensive subjects (Table 2). In contrast, the BW adjustment, using the SDs score approach, revealed that TBBMC:LBM values were in some cases markedly below the value of weight- and gender-matched control subjects, and it was more evident in girls. In the latter group, a TBBMC:LBM ratio SDs score of −2.14 tended to be lower than in control subjects (P=0.05). The similar tendency was observed in boys (−2.22±0.96; P=0.0541). Among the groups analyzed according to the stage of disease, the lowest SDs score for TBBMC:LBM was observed in prehypertensive subjects; however, only stage 1 hypertensive subjects had SDs scores significantly lower compared with control subjects (P<0.01). Interestingly, 28.6% of PH girls had TBBMC:LBM ratio SDs scores markedly below the lowest limit of the acceptable range of physiological values, ie, below the value of −2.00. In contrast, among the 73 hypertensive boys, only 1 (1.4%) had

**Skeletal Status and Body Composition in Relation to Stage of Hypertension**

In prehypertensive subjects, as well as in stage 1 and stage 2 hypertensive subjects, both TBBMD and TBBMC Z scores
The absolute amount of hours spent weekly on PA organized
Correlations Among PA, Sedentary Behavior, and
scores

<table>
<thead>
<tr>
<th>Variable</th>
<th>Prehypertensive, Mean±SD (n=11)</th>
<th>Stage 1 Hypertension, Mean±SD (n=65)</th>
<th>Stage 2 Hypertension, Mean±SD (n=16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z scores</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TBBMD</td>
<td>+0.78±0.69</td>
<td>+0.45±1.07</td>
<td>+0.54±0.86</td>
</tr>
<tr>
<td>TBBMC</td>
<td>+0.63±1.09</td>
<td>+0.49±1.07</td>
<td>+0.49±0.88</td>
</tr>
<tr>
<td>LBM</td>
<td>+0.88±2.18</td>
<td>+0.58±1.28</td>
<td>+0.60±1.00</td>
</tr>
<tr>
<td>FM</td>
<td>+2.79±1.95†</td>
<td>+1.31±1.66</td>
<td>+1.05±1.79</td>
</tr>
<tr>
<td>LBM:BW</td>
<td>-2.22±1.13</td>
<td>-1.32±1.45</td>
<td>-1.09±1.26</td>
</tr>
<tr>
<td>FM:BW</td>
<td>+2.28±1.23†</td>
<td>+1.20±1.33</td>
<td>+0.95±1.51</td>
</tr>
<tr>
<td>FM:LBM</td>
<td>+2.86±1.87†</td>
<td>+1.33±1.66</td>
<td>+1.05±1.79</td>
</tr>
<tr>
<td>TBBMC:LBM</td>
<td>+0.17±1.29</td>
<td>+0.15±1.28</td>
<td>+0.32±1.29</td>
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<tr>
<td>SD scores</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TBBMD</td>
<td>+1.25±1.41</td>
<td>+0.61±0.91</td>
<td>+0.76±0.83</td>
</tr>
<tr>
<td>TBBMC</td>
<td>+1.23±1.19</td>
<td>+0.60±1.05</td>
<td>+0.85±0.85</td>
</tr>
<tr>
<td>LBM</td>
<td>+1.96±2.82*</td>
<td>+0.63±1.26</td>
<td>+0.99±1.03</td>
</tr>
<tr>
<td>FM</td>
<td>+3.99±3.49†</td>
<td>+1.47±1.80</td>
<td>+1.80±2.52</td>
</tr>
<tr>
<td>LBM:BW</td>
<td>-2.00±1.45†</td>
<td>-0.98±1.20</td>
<td>-0.78±1.25</td>
</tr>
<tr>
<td>FM:BW</td>
<td>+2.30±1.65†</td>
<td>+0.98±1.18</td>
<td>+1.16±1.81</td>
</tr>
<tr>
<td>FM:LBM</td>
<td>+3.10±2.75†</td>
<td>+1.13±1.52</td>
<td>+1.40±2.24</td>
</tr>
<tr>
<td>TBBMC:LBM</td>
<td>+0.42±1.27</td>
<td>+0.24±1.19</td>
<td>+0.27±1.11</td>
</tr>
<tr>
<td>SDs scores</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TBBMD</td>
<td>-0.16±1.08</td>
<td>-0.14±1.14</td>
<td>-0.13±0.96</td>
</tr>
<tr>
<td>TBBMC</td>
<td>-1.61±2.74</td>
<td>-0.60±1.46</td>
<td>-0.85±2.46</td>
</tr>
<tr>
<td>LBM</td>
<td>+0.97±1.14</td>
<td>+0.37±0.97</td>
<td>+0.29±1.14</td>
</tr>
<tr>
<td>FM</td>
<td>+1.80±2.69†</td>
<td>+0.49±1.26</td>
<td>+0.33±1.28</td>
</tr>
<tr>
<td>LBM:BW</td>
<td>-0.92±0.86</td>
<td>-0.29±1.00</td>
<td>-0.37±1.00</td>
</tr>
<tr>
<td>FM:BW</td>
<td>+0.97±1.14</td>
<td>+0.37±0.97</td>
<td>+0.29±1.14</td>
</tr>
<tr>
<td>FM:LBM</td>
<td>+1.16±1.49</td>
<td>+0.43±1.12</td>
<td>+0.31±1.25</td>
</tr>
<tr>
<td>TBBMC:LBM</td>
<td>-0.66±2.06</td>
<td>-0.43±1.26</td>
<td>-0.01±1.08</td>
</tr>
</tbody>
</table>

*Prehypertensive vs stage 1; P<0.05.
†Prehypertensive vs stage 1 and stage 2; P<0.05.

a TBBMC:LBM SDs score lower than −2.00 (−2.58%), which is significantly lower when compared with PH girls (P=0.001; χ²=19.58). Among the groups analyzed according to stage of hypertension, the prevalence of subjects with TBBMC:LBM SDs scores below the value of −2.00 did not differ (P=0.4). Nonetheless, 18.2% of prehypertensive case subjects and 7.7% of case subjects with stage 1 hypertension had SDs scores below the value of −2.00.

Correlations Among PA, Sedentary Behavior, and Sleep Duration and Markers of Body Composition
The absolute amount of hours spent weekly on PA organized
and supervised at school, when analyzed in the 94 PH case subjects, positively correlated with the LBM:BW Z scores (r=0.28; P<0.05), LBM:BW SD scores (r=0.31; P<0.05), and LBM:BW SDs scores (r=0.29; P<0.05) and negatively with FM Z scores (r=−0.35; P<0.05), FM SD scores

\( r = -0.32; P < 0.05 \), FM:BW SDs scores \( r = -0.28; P < 0.01 \), and FM:BW SDs scores \( r = -0.32; P < 0.05 \). There was also significant negative correlation between the number of hours of sleep daily and the FM:BW SD scores \( r = -0.36; P < 0.01 \) and FM:BW SDs scores \( r = -0.31; P < 0.05 \). Moreover, a magnitude of disturbance between FM and LBM, as assessed by FM:LBM ratio SDs scores and SDs scores, was negatively correlated with the number of hours of sleep daily \( r = -0.27 \) and \( r = -0.32 \), respectively; \( P < 0.05 \).

Discussion
To our knowledge, this study is the first providing the complex analyses of skeletal status and body composition of children newly diagnosed with PH and prehypertension. The study was focused on a noninvasive evaluation of the fat, muscle, and bone tissues using DXA. Of note, DXA is prone to body size–related pitfalls leading to false interpretation of results obtained in individuals with unusual body sizes. 6–10,19–22. Thus, because of more completely linked DXA data with anthropometric variables, absolute values of DXA-assessed parameters characterizing fat, bone, and muscle tissues of our hypertensive case subjects were analyzed according to chronological age-, BH-, and BW-dependent data, obtained previously in the group of 562 healthy control subjects. 21

Our main findings are that, regardless of gender, hypertensive and prehypertensive subjects had TBBMD and TBBMC within physiological ranges for their chronological age 21,25 and that in PH subjects muscular and fat status, although more or less disturbed, were both a function of the PA level. The third finding is that, at least in prehypertensive and stage 1 hypertensive subjects, and especially in girls, the whole skeleton seems to be proper for muscle loads but still may be
at increased risk for fracture because of markedly increased BW-related loads.

Our age-dependent findings based on Z scores for TBBMD and TBBMC are, at least in part, in contrast with the observations reported by Afghani and Goran,26 who showed that hypertensive children had significantly lower TBBMD and TBBMC values compared with normotensive counterparts. In our approach, TBBMC appeared to be reduced only when BW was adjusted, but TBBMD was still close to control subjects. This observation relates to our previous finding that BW is a stronger predictor of TBBMC than TBBMD,21 which is also in agreement with Afghani and Goran.26

The new aspect of our study is the complex analysis of body composition of hypertensive children, including the evaluation of interrelations between fat and muscle tissues. We found that our hypertensive subjects had markedly increased fat stores compared with control subjects, but girls appeared to be more affected. Interestingly, girls compared with boys had slightly higher Z scores and SD scores for LBM (predominantly muscle mass), which probably reflects the adaptation to increased BW bearing. However, LBM in girls appeared to be still lower for their weight when compared with control subjects. Finally, in both girls and boys, a disturbed interrelation between fat and muscles was revealed by an increased FM:LBM ratio. It is well known that fat accumulation is a risk factor for metabolic syndrome,27,28 but our results suggest that not only the absolute amount of fat but also the interrelationship between FM and LBM may be clinically relevant. A combination of markedly increased fat stores with lowered muscle mass may have a negative impact on health, leading to functional impairment, disabilities, and an increased fall rate. For that reason, nutritional and PA protocols used to manage both the PH and metabolic syndrome should be directed not only to reduce fat stores but also to reestablish the normal relationship of FM to LBM. It is underscored by an evidenced negative correlation between increased FM and PA levels and a positive correlation between PA and LBM. Interestingly, we did not find any relation between subjective self-reported PA and DXA results but with objective data on weekly hours of organized and supervised PA. It highlights the importance of structuralized preventive programs, including the school. In our approach, hours of sleep daily were chosen as a nonspecific marker of school and environmental stress. It was found that a magnitude of body composition disturbances, as analyzed by FM:BW and FM:LBM ratios, correlated with hours of sleep daily. Sleep deprivation and chronic stress are known risk factors for obesity and sarcopenia in the general adult population.29

Another new aspect of our study was the analysis of muscle-bone interactions, thus far not reported in hypertensive children. We found that PH patients, irrespective of the stage of hypertension, had both the Z scores and SD scores for the RBS (TBBMC:LBM ratio) close to the values in healthy control subjects.21 It indicates that TBBMC of our patients was properly adapted to LBM.19–22 Surprisingly, when RBS values were adjusted to BW-dependent data, 28.6% of girls and only 1 boy, when analyzed as a whole PH group, as well as 18.2% of prehypertensive subjects and 7.7% subjects with stage 1 hypertension, had markedly reduced RBS values, as evidenced by SDs scores below the lowest limit of the acceptable range, ie, below the value of −2.0. In accordance with the mechanostat theory11–13,15,16 and recent reports, the markedly reduced RBS is a risk factor for fracture.19–22 For example, in the British children with fragility fractures, RBS Z score was −1.9±1.5, as reported by Crabtree et al.20 Furthermore, RBS Z scores of −2.9±1.1 and −2.6±1.5 were noted in girls and boys with fragility fractures resulting from idiopathic juvenile osteoporosis.22 These observations have led us to speculate that bone strength of our PH patients was properly adapted to muscle demands; however, especially in girls, the risk for fracture may be still increased because of increased BW.

Limitations of our study are related to the methodology and to study design. First, the study group was limited to white children; therefore, caution is advised when trying to generalize our finding for other ethnic groups. Furthermore, the numbers of PH girls and prehypertensive subjects were both significantly lower than the numbers of PH boys and stage 1 and 2 hypertensive subjects, respectively. Keeping this issue in mind, we still decided to split our study groups to elucidate the differences between genders and stages of disease, which otherwise could be hidden. Future studies are strongly needed to confirm our preliminary findings.

In conclusion, we found that hypertensive children had physiological values of DXA-assessed bone parameters for their chronological age and BH. Reduced TBBMC but not TBBMD coincided with increased BW. FM and the interrelationship between FM and LBM were disturbed especially in hypertensive girls. LBM appeared to be normal when age or BH adjusted but lowered when weight adjusted. RBS, as the marker of fracture risk, was decreased in 28.6% of girls compared with control subjects with similar BW. This indicates that PH with overweight may not only lead to well-known direct complications of hemodynamic and metabolic insult, but, at least in girls, may also be associated with increased risk for fracture.

**Perspectives**

Both PH and osteoporosis are public health challenges in developed and developing countries. Pathogenesis of both disorders is at least in part related to similar lifestyle and nutritional habits. Although osteoporosis is clinically evident in adulthood, low TBBMC is already present in adolescence. Increased PA as part of the nonpharmacological treatment of PH and prevention of cardiovascular disease may influence PH, bone disease, and metabolic complications. Moreover, low LBM in relation to BW can be a key point in the development of metabolic syndrome and the increase of cardiovascular risk. Thus, our results indicate that future studies evaluating metabolic abnormalities in PH should consider not only classic anthropometrical markers, such as BMI and fat tissue distribution, but also the muscle-fat unit. Finally, analysis of metabolic disturbances should include the evaluation of the relationship among sodium intake, calcium excretion, and body composition.
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References
Bone Mass and Body Composition in Children and Adolescents With Primary Hypertension: Preliminary Data

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