Bone Speed of Sound and Physical Activity Levels of Overweight and Normal-Weight Girls and Adolescents

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Bone properties, reflected by speed of sound (SOS), and physical activity levels were examined in overweight (OW) girls ($n = 19$) and adolescents ($n = 22$), in comparison with normal-weight (NW) girls ($n = 21$) and adolescents ($n = 13$). Moderate-to-vigorous physical activity (MVPA) was higher in NW than in OW in both age groups. Tibial SOS was lower in OW compared with NW in both age groups. MVPA correlated with tibial SOS, once age was partialed out. The results suggest that overweight girls and adolescents are characterized by low tibial SOS, which may be partially attributed to lower physical activity levels.

Childhood obesity is a growing concern as its prevalence remains relatively high and contributes to many health problems. In adults, bone mineral density (BMD) is positively associated with adiposity, suggesting that obesity has positive effects on bone strength (8). Excess adiposity also has a protective effect against osteoporotic fractures in the elderly, suggesting stronger bones with increasing adiposity (1). However, it is unclear whether the positive association between bone strength and adiposity is apparent in childhood and adolescence.

The relationship between fracture incidence and age is bimodal. Although the elderly are most prone to fractures, children are at a high risk for fractures as well, especially obese children (10). Davidson et al. (10) demonstrated that despite softer impact surfaces in obese children, they were still at a 1.7 higher risk of fracture...
compared with nonobese children. As suggested by Falkner et al. (16), the highest vulnerability to fracture during the growing years is around the age of puberty.

Dual-energy X-ray absorptiometry (DXA) has been the most widely used method to assess bone strength in overweight/obese and normal-weight children and adolescents. However, the results among studies are conflicting, with some studies demonstrating similar BMD (11,26), some demonstrating lower BMD (19,20,33), and some reporting higher BMD (24) in overweight compared with normal-weight children and adolescents. In view of DXA’s two-dimensional measurements of BMD (a three-dimensional parameter), the discrepant results may be attributed to the different methods used to correct BMD for body size.

Transaxial quantitative ultrasound (QUS) is a relatively new technique used to assess bone properties in the general population, as well as in children and adolescents. Transaxial QUS measures the speed of sound (SOS) that travels along the bone, rather than through the bone, and so, unlike DXA, the measurement is not directly affected by bone size, allowing for easy comparisons between children of different sizes. SOS has been shown to predict fractures independent of BMD, suggesting that it is measuring some aspect of bone strength (27). Indeed, SOS is reflective of BMD, as well as elasticity and microarchitecture of bone (5).

Eliakim et al. (13) found that 6–17 year old obese children had lower radial and tibial SOS compared with the manufacturer’s reference database. Falk et al. (14) recently reported that 9–12 year old overweight prepubertal boys had lower tibial but not radial SOS than normal-weight controls. The authors hypothesized that reduced weight-bearing physical activity would explain the reduced lower extremity bone strength in the overweight boys.

It is generally accepted that weight-bearing high-impact sports participation positively influences bone strength parameters (15). Recently it has been shown that general physical activity confers benefits to bone strength as well (4,21). Therefore, in the overweight subjects, for whom physical activity levels are characteristically low (38), perhaps small changes in physical activity may have significant effects on bone strength. The purpose of the study was to compare radial and tibial SOS, as assessed with transaxial QUS, along with habitual physical activity levels and nutritional intake in overweight and obese girls with their normal-weight counterparts, of similar chronological age and sexual maturity.

Participants

All subjects were of Caucasian ethnicity and included girls (8–11 years old and premenarcheal) and adolescents (14–16 years old and postmenarcheal). Groups were categorized by degree of adiposity: normal-weight (NW, body fat ≤25%), and overweight and obese (OW, body fat ≥28%). Subjects were recruited from the Golden Horseshoe area (Ontario, Canada) through physician clinics, obesity programs, newspaper ads, flyers and information packages. All participants were nonathletic, with minimal involvement in structured physical activities (≤2 hr/wk). Those who had prior experiences that could affect bone properties (i.e., use of steroid medication, growth delay, previous and/or current fracture) were excluded from the study. Adolescents having irregular menstrual cycles or on oral contraceptives were also excluded.
Methods

All testing was reviewed and received clearance from the Brock University Research Ethics Board (REB; 04–284). Before commencing any assessment, the participants and parents (or legal guardians) were given an explanation of the purpose of the study and measurement procedures, and informed consent was obtained. All questionnaires were completed with the same investigator throughout the study. Pubertal stage was self-assessed according to secondary sexual characteristics (pubic hair), as described by Tanner (36).

With the subjects wearing light clothing and barefoot, height, and body mass were measured using an Ellard Instrumentation board length stadiometer (Monroe, WA, USA) and a Zenith digital scale, respectively. Relative body fat (%BF), lean mass and fat mass were then assessed using the Biospace Inbody520 bioelectrical impedance analysis system (BIA; Beverly Hills, CA, USA). Subjects had abstained from exercising, consuming alcohol and eating/drinking for at least four hours, before arrival. To ensure that the subjects were hydrated, they were given approximately 500 ml of water to drink at least 45 min before their body composition assessment and were asked to void just before the BIA body composition assessment. The Inbody520 BIA device passes different mild electrical currents with multiple frequencies (5–500 kHz) through the subject’s body via electrodes situated on the palms and feet. The body’s resistance and reactance to the current is related to total body water, which in turn, is highly correlated with fat-free mass. This BIA system was recently found to be an accurate predictor of body composition in children of a wide range of adiposity (23). In addition, BIA was reported to be valid and reliable in estimating body fat in overweight and obese children (18).

Each subject was asked which hand she preferred to write with and what leg she preferred to kick with, to determine the dominant limb. Bone SOS of the distal one-third radius and midshaft tibia was assessed bilaterally using Sunlight Medical Ltd.’s Sunlight Omnisense model 7000P (Tel Aviv, Israel). The area of measurement for the radius was determined as the midpoint between the olecranon process and the tip of the third phalanx. The midshaft tibia was determined as the midpoint between the calcaneus and the top of the knee while the subject was seated (knee and ankle at 90°). To measure radial SOS, 140° scans were performed around the radius. To measure tibial SOS, scans from the tibial crest to the medial end were performed. All measurements consist of at least three consistent measurement cycles. A system quality verification of the QUS was performed with a Perspex phantom before the first test of each day. All measurements were performed by the same investigator. The intraoperator coefficient of variation of the QUS measurements in 10 children was 0.98 for the radius and 0.94 for the tibia.

Daily physical activity was assessed using Actigraph GT1M accelerometers (Pensacola, FL, USA). The accelerometers were programmed to record activity counts at 10-s epochs, to measure vertical acceleration from 0.05 to 2.00 G, at a frequency from 0.25 to 2.50 Hz. During their visit to the laboratory, participants were instructed on the proper usage of the accelerometers. Using an adjustable elastic belt, the subjects secured the accelerometers snugly on the right side of the hip, against the skin, throughout the waking hours for seven consecutive days. Because the accelerometer is not waterproof, the subjects were asked to remove the accelerometer while swimming or bathing. At the same time, the subjects were
provided with a log sheet in which they were asked to record the times when the accelerometers were removed and the time and type of structured activities that were performed throughout the day. The accelerometers were programmed to commence data collection the following early morning (0500). A researcher phoned the participant or guardian during the data collection week to facilitate compliance. Output for the accelerometry consisted of counts/10-s and a Visual Basic data reduction program was used to quantify total time spent performing moderate, vigorous, and very vigorous physical activity according to age-appropriate cutoff thresholds (38). Although seven days of monitoring was expected of the subjects, a minimum of three weekdays and one weekend day of full data (≥10 hr/day) were required to be included in data analysis (30).

For nutritional analysis, each subject was interviewed regarding the previous day’s dietary intake (24-hr recall), to estimate daily energy, vitamin D and calcium intake. Subjects were asked if the previous day was typical and if not, subjects were asked to recall a typical weekday. The 24-hr recall method has been shown to be valid in children (39). Axxya System’s Nutritionist Pro Diet Analysis (Stafford, TX, USA) was used to analyze the 24-hr recall questionnaires to quantify total energy intake, calcium and vitamin D intake.

**Statistical Analysis**

Two-way ANOVAs were used to assess differences in SOS, nutritional intake, physical characteristics and physical activity between the adiposity and age groups. A Chi square ($\chi^2$) analysis was used to compare the pubertal stage distributions. Pearson Product Moment correlations were used to determine the correlations between SOS and possible influencing factors, such as physical activity. When significant correlations were found between SOS and possible influencing factors, the latter were used as covariates in an ANCOVA analysis. Data were analyzed using SPSS ver. 16.0 (SPSS, Chicago, IL) and is presented as means ± SD with significance set at $p \leq .05$.

**Results**

The physical characteristics of the subjects are displayed in Table 1. Adolescents were older, taller and more sexually mature than girls, with no significant differences in age, height and maturity between adiposity groups. There was an age-by-adiposity interaction for height reflecting the fact that among the girls, OW were taller than NW, while among the adolescents, the pattern was reversed. Adolescents were significantly heavier, had greater fat mass, as well as greater lean mass than girls. This was also the case when comparing OW with NW. There was an age-by-adiposity interaction for weight and fat mass, reflecting the fact that the absolute difference between NW and OW groups was much greater in the adolescents compared with the girls. Body fat percentage was similar in the younger and older NW. However, among the OW groups, body fat was higher in the older compared with the younger group.

There were no significant differences between age or adiposity groups in total energy intake or in calcium and vitamin D intake (Table 2). All groups had calcium intakes that were only 69–80% of the recommended daily intake of 1300 mg (35).
All groups had vitamin D intakes that were 75–120% of the recommended daily vitamin D intake of 200 IU (~4 mg) (35), with a tendency of OW to consume less vitamin D than NW, although this difference was not significant.

The SOS of the dominant and nondominant radii and tibiae were highly correlated \(r = .97\) in upper and lower limbs and there were no significant differences between the nondominant and dominant limbs. Thus, only data for the nondominant

### Table 1  Physical Characteristics of the Overweight and Normal-Weight Girls and Adolescents

<table>
<thead>
<tr>
<th></th>
<th>Girls</th>
<th>Adolescents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal-weight</td>
<td>Overweight</td>
</tr>
<tr>
<td></td>
<td>((n = 21))</td>
<td>((n = 19))</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>10.0 ± 1.1 *</td>
<td>10.3 ± 1.1 §</td>
</tr>
<tr>
<td>Tanner Stage</td>
<td>16,3,2,0,0 *</td>
<td>11,7,1,0,0 §</td>
</tr>
<tr>
<td>(I,II,III,IV,V)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
<td>139.8 ± 8.4 *</td>
<td>146.3 ± 10.6 §</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>33.0 ± 7.2 *</td>
<td>51.5 ± 11.8 §</td>
</tr>
<tr>
<td>Fat Mass (kg)</td>
<td>6.2 ± 1.8 *</td>
<td>18.7 ± 6.7 §</td>
</tr>
<tr>
<td>Fat-free Mass</td>
<td>28.0 ± 4.9 *</td>
<td>32.8 ± 6.1 §</td>
</tr>
<tr>
<td>(kg)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Body Fat</td>
<td>18.0 ± 3.1 #</td>
<td>35.4 ± 5.9 §</td>
</tr>
<tr>
<td>Percentage (%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values are means ± SD

# significantly different from overweight girls \((p < 0.05)\).

* significantly different from normal-weight adolescents \((p < 0.05)\).

§ significantly different from overweight adolescents \((p < 0.05)\).

All groups had vitamin D intakes that were 75–120% of the recommended daily vitamin D intake of 200 IU (~4 mg) (35), with a tendency of OW to consume less vitamin D than NW, although this difference was not significant.

The SOS of the dominant and nondominant radii and tibiae were highly correlated \((r = .97)\) in upper and lower limbs and there were no significant differences between the nondominant and dominant limbs. Thus, only data for the nondominant

### Table 2  Nutritional Intake of the Overweight and Normal-Weight Girls and Adolescents

<table>
<thead>
<tr>
<th></th>
<th>Girls</th>
<th>Adolescents</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Normal-weight</td>
<td>Overweight</td>
</tr>
<tr>
<td></td>
<td>((n = 21))</td>
<td>((n = 19))</td>
</tr>
<tr>
<td>Total Energy Intake (kcal)</td>
<td>1651 ± 404</td>
<td>1630 ± 205</td>
</tr>
<tr>
<td>Calcium Intake (mg)</td>
<td>1000 ± 537</td>
<td>914 ± 393</td>
</tr>
<tr>
<td>Vitamin D intake (mg)</td>
<td>5.6 ± 4.6</td>
<td>3.3 ± 2.6</td>
</tr>
</tbody>
</table>

Values are means ± SD; There were no significant differences between groups.
limbs are presented below. Adolescents had significantly higher radial SOS than girls. However, there were no differences in radial SOS between adiposity groups (Figure 1). Adolescents had significantly higher tibial SOS than girls (Figure 2). In both age groups, NW had significantly higher tibial SOS than OW.

Moderate-to-very-vigorous physical activity (MVPA) was significantly higher in girls compared with adolescents, with no differences between adiposity groups (Table 3). When physical activity was expressed in absolute minutes of moderate, vigorous and very vigorous activities, as well as the MVPA, adolescents were significantly less active than girls. Likewise, OW were significantly less active than NW (Table 3).

Figure 1 — Nondominant radial SOS of the overweight and normal-weight girls and adolescents. Values are means ± SD (*p < .01 between age groups).

Figure 2 — Nondominant tibial SOS of the overweight and normal-weight girls and adolescents. Values are means ± SD (*p < .01 between age and between adiposity groups).
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Tibial SOS, but not radial SOS, was negatively correlated with relative body fat ($r = -0.25; p \leq 0.05$), especially in the adolescent OW group ($r = -0.57; p \leq 0.05$). Physical activity decreased with an increase in age while bone SOS increased with an increase in age. Therefore, to examine the correlation between bone SOS and physical activity, age was partialed out. When age was partialed out, tibial SOS was positively correlated with the absolute number of minutes spent at moderate-to-very vigorous activity per day ($r = 0.33–0.38, p < 0.05$).

To examine whether fat-free mass or MVPA explained the difference in tibial SOS between groups, both were entered as covariates in the analysis. However, neither covariate was statistically significant and the differences in tibial SOS between adiposity groups for each age group persisted. Although total moderate, vigorous and very vigorous physical activities were differences between age and adiposity groups, none of these variables was a significant covariate.

**Discussion**

The objective of this study was to compare bone properties, as assessed by transaxial QUS, along with physical activity levels and nutritional intake, between normal-weight and overweight girls and adolescents. Our main finding is that overweight girls had lower tibial SOS than normal-weight girls and adolescents, despite the fact that within each age group, adiposity groups were similar in sexual maturity,
menarcheal status, body height, and nutritional intake. This finding extends an earlier report of lower tibial SOS in prepubertal boys (14) to females, and more importantly, to adolescents. Relative body fat correlated inversely with tibial SOS, especially in the adolescent overweight girls. An important finding, however, is that although physical activity also correlated with tibial SOS, it did not explain the difference in SOS between adiposity groups.

Bone properties may be affected by a number of factors, including nutrition, physical activity and hormonal status. No differences in nutritional intake were observed between any of the age or adiposity groups in our study (Table 2). Overweight females tend to underreport nutritional intake on a recall questionnaire (28). If this was the case in the current study, the overweight subjects may have had higher calcium intake, which is associated with enhanced bone quality (17). However, despite the possible higher nutritional intake, the overweight girls and adolescents still had significantly lower tibial SOS than the normal-weight girls and adolescents. Thus, it is unlikely that any difference in calcium intake could explain the differences in tibial SOS between adiposity groups.

Vitamin D intake can also affect bone strength throughout the growing years (7). In adults, adiposity is negatively associated with serum vitamin D levels (3), possibly due to its sequestering in fat cells (25). Thus, vitamin D deficiency, or reduced bioavailability, is common in obese adults (40). It is unclear if this is the case in youths. In the current study, vitamin D intake appeared to be lower in the overweight groups, although the differences were not statistically significant (Table 2). Serum levels of 25-hydroxyvitamin D are a better indicator of vitamin status. While we did not measure serum vitamin D levels in our subjects, it is possible that the overweight individuals had lower bioavailability of vitamin D in circulation, potentially explaining, at least in part, their lower tibial SOS.

Obesity is often accompanied by a greater amount of lean body mass. Indeed, the overweight subjects in this study had a higher fat-free mass compared with the normal-weight groups (Table 1). It is argued that increased lean mass is associated with increased muscle force, which may enhance bone quality (6). In fact, El Hage et al. (12) recently reported a positive relationship between lean mass and BMD in adolescent boys and girls. However, in the current study, despite the greater fat-free mass in the overweight groups, their tibial SOS was lower.

There are several hormones associated with adipose tissue, such as leptin, adiponectin and growth hormone, which may partially explain the reduced bone strength of overweight individuals (9,31,32). Nonetheless, hormonal influences are likely to have systemic effects on the skeleton, inconsistent with our finding that overweight girls and adolescents in the current study had low tibial but not radial SOS.

The finding that the overweight subjects had low tibial but not radial SOS suggests that the explanatory factor(s) are site-specific rather than systemic, (i.e., adiposity-related). For example, weight-bearing physical activity would specifically affect the tibiae rather than the radii. Our findings revealed that the overweight girls accumulated significantly less MVPA per day than the normal-weight girls. This is in agreement with previous studies which demonstrated that obese children, especially girls, are 20–36% less active than nonobese girls (29,37,38). In the current study, when age was partialed out, physical activity was moderately correlated with tibial SOS, reflecting the well-accepted view that weight-bearing physical activity
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is beneficial to bone (4,21). Nevertheless, MVPA was not a significant covariate of the tibial SOS difference between groups. Thus, it is possible that an interaction of nutrition, low physical activity levels and different hormonal status, contribute to the compromised bone properties of overweight and obese children and adolescents.

It should be noted that accelerometry is regarded as an objective measure of physical activity. It reflects physical activity habits over a relatively short period of time. That is, it cannot measure past physical activity. On the other hand, bone properties reflect past, as well as present, physical activity. Therefore, future longitudinal follow up studies should clarify the possible effect of past, as opposed to present physical activity and adiposity on bone strength in overweight or obese children and adolescents. In addition, although QUS is recommended for assessment of bone status in children (5), it still has its limitations when assessing bone strength. QUS cannot measure bone geometry, which is an important factor that governs strength. For example, the bending strength of a bone is proportional to the fourth power of its radius (34) and change in a long bone’s diameter can account for up to 55% of the variability in bone strength (2). Thus, future studies should use a combination of methods (e.g., QUS and pQCT) to evaluate bone quality.

Fat tissue may be argued to compromise the accuracy of the SOS measurement (22). Previous studies using transaxial QUS argued that QUS measures bone quality independent of soft tissue (13,14). Ultrasound travels through cortical bone at approximately 4000 m/s and much slower through soft tissue, at approximately 1500 m/s. The ultrasound receiver detects the fastest signal that propagates along the tissue. Therefore, the SOS value obtained is that which reflects cortical bone and not soft tissue. In addition, differences between adiposity groups could be seen in the tibia but not radii, suggesting that soft tissue did not affect the QUS measurements. Nevertheless, it should be noted that adequate contact between the ultrasound probe and bone surface is necessary to obtain valid results. Thus, further validation studies for the use of QUS on overweight and obese individuals may be warranted.

In summary, overweight girls and adolescents are characterized by lower tibial but not radial SOS, compared with normal-weight girls and adolescents. The overweight girls and adolescents were significantly less active than normal-weight girls and adolescents, and both adiposity groups had physical activity levels that were lower in postpubertal than in prepubertal girls. Decreased physical activity levels may have contributed to the reduced tibial SOS of overweight girls and adolescents. Future research should examine levels of hormones and bone markers in relation to bone health in overweight and obese individuals to shed light on the reasons for the apparent reduced bone strength in these children and adolescents.

Acknowledgments

We would like to thank the many participants and their parents, who enthusiastically got involved in the project. In addition, we would like to thank Brianna Holmes for her technical assistance as well as Dr. Brian Timmons and his team at the Children’s Exercise & Nutrition Centre of McMaster University for their assistance with subject recruitment. The study was partially funded by the Social Sciences and Humanities Research Council (SSHRC) and the Natural Sciences and Engineering Research Council (NSERC) of Canada.
References


