Positive effects of vegetable and fruit consumption and calcium intake on bone mineral accrual in boys during growth from childhood to adolescence: the University of Saskatchewan Pediatric Bone Mineral Accrual Study\textsuperscript{1–3}

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ABSTRACT

Background: Nutrition is an important modifiable factor in the development of bone mass during adolescence. Recent studies of children and adolescents examined the effects of foods such as milk products and fruit and vegetables on bone growth; however, few studies included both boys and girls.

Objective: The purpose was to ascertain the role of consumption of milk products and vegetables and fruit in the accrual of total-body bone mineral content (TBBMC) in boys and girls from childhood to late adolescence.

Design: Seven-year longitudinal data were obtained from 85 boys and 67 girls aged 8–20 y. Biological maturity was defined by the number of years from the age at peak height velocity. Dietary intake was assessed by serial 24-h recalls. Anthropometric measurements and physical activity were assessed every 6 mo. TBBMC assessed with dual-energy X-ray absorptiometry in the fall of each year was the indicator of bone mass.

Results: Most boys (87.8%) met Canadian recommendations for milk product intake. Few subjects (<30%) consumed vegetables and fruit in recommended amounts. Using a multilevel modeling statistical approach containing important biological and environmental factors, we found that vegetable and fruit intakes, calcium intake, and physical activity were significant independent environmental predictors of TBBMC in boys but not in girls.

Conclusions: In addition to adequate dietary calcium intake, appropriate intakes of vegetables and fruit have a beneficial effect on TBBMC in boys aged 8–20 y. Underreporting of dietary intake by girls may explain why this effect was not apparent in girls. Am J Clin Nutr 2005;82:700–6.

KEY WORDS Milk products, vegetables and fruit, total-body bone mineral content, adolescence, age at peak height velocity

INTRODUCTION

Nutrition is an important modifiable factor in the development and maintenance of bone mass. Approximately 80–90% of bone mineral content (BMC) is composed of calcium and phosphorus (1); protein is another important component of bone. Other dietary components, such as magnesium, zinc, copper, iron, fluoride, and vitamins D, A, C, and K, are required for normal bone metabolism (2). These nutrients occur together in foods, and their intake can be detected by assessing dietary patterns and by measuring food group intake. We previously showed in a nonnation-ally representative study that, during adolescence, milk products were the principal source of dietary calcium (61%), and that grain products (9%), vegetables and fruit (7%), meat and alternatives (2%), and other foods (21%) contributed smaller proportions (3). Food groups that contribute to calcium intake may also contribute other important bone-forming nutrients; conversely, food groups other than those contributing calcium may be beneficial to bone growth for other reasons.

Although most studies have focused on the effect of calcium, the intake of milk products, or both on bone accrual (4–12), the role of dietary vegetables and fruit is emerging in the literature. Jones et al (13) first reported cross-sectional data that showed a positive link between the consumption of fruit and vegetables and bone mineral density (BMD) in 10-y-old girls. Tylavsky et al (14) found, in a study of 56 girls aged 8–13 y, a positive relation of fruit and vegetable consumption with bone area and BMD. Their analysis indicated that the relation between intakes of fruit and vegetables and total-body BMD in these girls remained significant after adjustment for age, body mass index (BMI; in kg/m\textsuperscript{2}), and physical activity. Recently, McGartland et al (15) examined whether usual intakes of fruit and vegetables influenced BMD in boys and girls aged 12 and 15 y. They found a significantly higher heel BMD only in 12-y-old girls who consumed high amounts of fruit. Although more studies are needed, these preliminary data suggest a positive link between the consumption of fruit and vegetables and bone health in girls, as has been seen in adults (16–20). No association in boys has been reported.

The dramatic increase in bone mass during childhood and adolescence, measured as either BMC or BMD, results from normal growth and biological maturation (21). Change in BMC is a useful indicator of calcium retention in children. Because...
areal BMD can misrepresent bone mass changes in the growing skeleton. BMC is considered to be a better indicator of bone accrual in growing children than is BMD (1). Children of the same chronological age may differ by several years in their biological maturity (22); therefore, assessment of biological maturity is critical to control for the effects of maturation on outcome variables in studies during adolescence. The age of attainment of peak height velocity (PHV), a measure of somatic maturity, is the most commonly used indicator of biological maturity in longitudinal studies (23). Hence, subjects in the present study were aligned on a biological maturity age range (ie, the number of years from their age at PHV). The purpose of this study was to ascertain the role of consumption of food groups, specifically milk products and vegetables and fruit, in the accrual of total-body BMC (TBBMC) in boys and girls from childhood to late adolescence.

SUBJECTS AND METHODS

Study participants and design

Subjects were participants in the University of Saskatchewan Pediatric Bone Mineral Accrual Study (PBMAS). PBMAS used a mixed-longitudinal study design that incorporated 8 age cohorts (aged 8–15 y at study entry). The initial phase of the study ran from 1991 to 1997, a time span during which the clustering of the age cohorts remained the same; because the cohorts overlapped, a developmental age range of 8–20 y was assessed. In 1991, 228 boys and girls entered the study. They were selected as a population-based sample of children in Saskatoon (23). Most of the children were white and were attending 2 public schools in a socioeconomically middle-class area of the city. Eligible children had no history of chronic disease or chronic medication use, and they had no medical conditions, allergies, or medication use known to influence bone metabolism or calcium balance.

Subjects and their parents provided written informed consent for the children’s participation in the study. Ethical approval was obtained from the University of Saskatchewan and the Royal University Hospital Advisory Committee on Ethics in Human Experimentation.

According to the study protocol, data collection included anthropometric and physical activity data every 6 mo, dietary data 2–4 times a year in different seasons, and annual bone scans with the use of dual-energy X-ray absorptiometry. In the current analysis, 7-y longitudinal data from 85 boys and 67 girls were used. The sample represents an age range of 8 to 20 y.

Dietary analysis

Intake was assessed by serial 24-h recalls conducted both at the participating schools and at the hospital at the time of the bone scans. All days of the week except Friday and Saturday were included. Food intake from the 24-h recalls was analyzed with the use of NUTS nutritional assessment software (version 3.7; Quilchena Consulting Ltd, Victoria, Canada), which used the 1988 Canadian Nutrient File information. This software categorized every food according to servings from the 1982 edition of Canada’s Food Guide, which, with the exception of names and recommended servings of the food groups and graphics to illustrate the food guide, was similar to the current version of Canada’s Food Guide (24). For foods categorized as “other foods,” 2 separate groups were used: 1) fats and oils and 2) sweets and desserts. Use of nutrient supplements was included in nutrient intake data when supplement use was considered consistent (3). The same person coded and checked all the forms and analyzed dietary intake data according to procedures described elsewhere (25). To obtain the usual intake for the subjects, intakes of food and nutrients from serial 24-h recalls were averaged for each year of study.

Bone measurements

Bone measurements were obtained in the fall of each year by using dual-energy X-ray absorptiometry (Hologic QDR 2000; Hologic, Waltham, MA) scans of the whole body, posterior-anterior lumbar spine, and proximal femur, performed by 1 of 2 experienced operators across 7 y. Array mode was used for bone mineral acquisition and enhanced global scanning software (version 7.10; Hologic) was used for analysis. To minimize operator-related variability, the same person analyzed all total-body scans with the use of analysis software (version 5.67A; Hologic). Short-term precision in vivo for TBBMC, expressed as CV (in %), was 0.60. An ion chamber survey meter (model 450p; Victoreen Inc, Cleveland, OH) measured entrance radiation dose. When this surface dose was corrected for body attenuation, subject age, and type and volume of tissue undergoing irradiation, the effective dose equivalent was <1 mrem. TBBMC data were used in this study (21, 24).

Anthropometric, physical activity, and maturity assessments

Height and weight were measured every 6 mo by trained study personnel who used the same scale and stadiometer. Subjects wore tee-shirts and shorts during measurement, and they had removed their shoes and jewelry. Height and weight were measured twice and recorded to the nearest 0.1 cm and 0.1 kg, respectively.

General levels of physical activity of subjects were assessed with the use of the Physical Activity Questionnaire for Older Children. Subjects rated their physical activity level during their spare time in the previous 7 d, resulting in a rating from 1 to 5. Higher scores suggest higher levels of physical activity. The questionnaire was modified for high school students by omitting the item about activity at recess.

Details about our derivation of PHV have been described elsewhere (26, 27). In brief, a cubic spline procedure fitted a curve to each individual’s velocity data (in cm/y), and the age at PHV was extrapolated from the curve. Biological maturity was calculated as measurement age minus age at PHV, and biological maturity at age of PHV was equal to 0. Biological maturity age before the age at PHV is measured in negative years, and that after the age at PHV is measured in positive years. Subjects were clustered into 1-y biological maturity age categories. By using this method, we fitted TBBMC distance curves at different food group intakes by biological maturity age in boys and in girls.

Statistical analysis

Values are reported as means ± SDs. Data analyses were conducted with the use of Microsoft EXCEL software (version 2000; Microsoft, Redmond, WA) and SPSS software (version 11.5; SPSS Inc, Chicago, IL). GraphPad PRISM (version 4.0; GraphPad Software, San Diego, CA) was used to produce the distance curves for TBBMC and for intakes of nutrients and food
TABLE 1
Characteristics of subjects at the age of peak height velocity (PHV)\(^1,2\)

<table>
<thead>
<tr>
<th></th>
<th>Boys (n = 85)</th>
<th>Girls (n = 67)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age of PHV (y)</td>
<td>13.5 ± 1.0</td>
<td>11.8 ± 0.9</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>164.1 ± 6.9</td>
<td>153.3 ± 7.7</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>52.31 ± 8.68</td>
<td>43.27 ± 9.72</td>
</tr>
<tr>
<td>BMI (kg/m(^2))</td>
<td>19.38 ± 2.64</td>
<td>18.26 ± 3.01</td>
</tr>
</tbody>
</table>

1 All values are \(\bar{x} \pm SD\).
2 Significantly different from boys (2-sided unpaired Student’s \(t\) test), \(P < 0.05\).

RESULTS

Age, height, weight, and BMI at the age at PHV (biological maturity = 0) are shown in Table 1. Chronological age corresponding to age at PHV was 11.8 y for girls and 13.5 y for boys, which does not differ significantly from that reported for smaller samples of this cohort (26). The height, weight, and BMI of girls at age at PHV were less than those of boys (\(P < 0.05\)). Food group intakes are shown in Table 2. Most subjects had an appropriate intake of milk products; however, girls consumed less milk product than did boys (\(P < 0.05\)). Sex difference could also be seen in the intakes of meat and alternatives (Table 2). In boys, the mean intakes of all food groups in the overall age span were significantly greater than those in girls (\(P < 0.001\); Table 2). Most boys and girls consumed less vegetables and fruit than the recommended amounts. In contrast, >40% of them consumed a high amount of sweets and desserts.

The TBBMC and calcium intake distance curve for boys and girls, aligned by biological age, is shown in Figure 1. As biological age increased, TBBMC increased in boys and girls. The greater magnitude of this increase in boys was related to their greater body size. Before the age at PHV, the intake of calcium did not differ significantly in boys and girls. After the age at PHV, a dramatic increase was observed in calcium intake in boys, whereas, in girls, the intake of calcium dipped. After the age at PHV, boys had significantly higher intakes of calcium than did girls (\(P < 0.05\); Table 2).

The results of the additive polynomial model described previously (equation 1) are shown in Table 3. Two models were fitted, one for boys and one for girls. By making the time variable (biological maturity) random at level 2, the variance of TBBMC accrual over increasing biological maturity was estimated in 2 parts. Level 1 variance was the variance associated with a subject’s regression line for TBBMC development on biological maturity. Level 2 variance was the variance representing the deviation of each subject’s line from the average line for the whole group. The fixed effects in both models indicated that TBBMC increased with each successive year of biological maturity (boys: 114.8 ± 10.7 g; girls: 80.4 ± 7.1 g). The power functions for biological maturity were included to shape the curves and essentially forced a sigmoidal shape to a linear model. In boys, a 1-cm increase in stature predicted a 22.6-g accrual of

TABLE 2
Mean intake of nutrient and food groups at the age of peak height velocity (PHV) and overall in boys and girls\(^1,2\)

<table>
<thead>
<tr>
<th>Intake groups</th>
<th>Boys (n = 85)</th>
<th>Girls (n = 67)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Age of PHV</td>
<td>Age of PHV</td>
</tr>
<tr>
<td></td>
<td>(age 8–20 y)</td>
<td>(age 8–20 y)</td>
</tr>
<tr>
<td>Milk products (servings/d)</td>
<td>3.1 ± 1.8</td>
<td>2.6 ± 1.1(^3)</td>
</tr>
<tr>
<td>Grain products (servings/d)</td>
<td>3.9 ± 2.2</td>
<td>5.5 ± 1.6(^4)</td>
</tr>
<tr>
<td>Meat and alternatives (servings/d)</td>
<td>2.3 ± 1.0</td>
<td>1.7 ± 0.7(^3)</td>
</tr>
<tr>
<td>Fat and oils (servings/d)</td>
<td>3.2 ± 3.7</td>
<td>4.2 ± 2.9(^4)</td>
</tr>
<tr>
<td>Vegetables and fruit (servings/d)</td>
<td>4.1 ± 2.7</td>
<td>3.8 ± 2.0(^4)</td>
</tr>
<tr>
<td>Sweets and desserts (servings/d)</td>
<td>3.3 ± 2.1</td>
<td>3.1 ± 1.6(^4)</td>
</tr>
<tr>
<td>Calcium (mg/d)</td>
<td>1199 ± 569</td>
<td>1030 ± 360(^4)</td>
</tr>
</tbody>
</table>

1 All values are \(\bar{x} \pm SD\).
2 The intake in the subjects was compared with the lower value in the range.
3 Significantly different from boys (n = 67) at age of PHV, \(P < 0.05\).
4 Significantly different from boys at overall age span (2-sided unpaired Student’s \(t\) test), \(P < 0.001\).
TBBMC, whereas, in girls, it predicted an 18.9-g accrual of TBBMC. For body mass, the coefficients were 4.3 and 7.3 for boys and girls, respectively. Once the confounding effects of growth and biological maturity were controlled for, the effects of physical activity, intake of calcium, and intakes of vegetables and fruit were shown to be sex specific. In girls, physical activity, intake of calcium, and intakes of vegetables and fruit were not significant independent predictors of TBBMC ($P < 0.05$).

![Figure 1](https://academic.oup.com/ajcn/article-abstract/82/3/700/4863030)

**FIGURE 1.** Mean (±SEM) total-body bone mineral content (TBBMC; – – –) and calcium intake (—) distance curves (cubic spline procedure) by biological maturity [age at peak height velocity (PHV) as a reference] in boys (A; $n = 85$) and girls (B; $n = 67$). After the age of PHV, calcium intake and TBBMC accrual differed significantly between the boys and the girls, $P < 0.05$ for both.

**TABLE 3**
Multilevel regression analysis of total-body bone mineral content (TBBMC) aligned on biological maturity, adjusted for height, body mass, physical activity, intake of calcium, and intakes of vegetables and fruit

<table>
<thead>
<tr>
<th></th>
<th>TBBMC</th>
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<tbody>
<tr>
<td></td>
<td>Boys ($n = 85$)</td>
</tr>
<tr>
<td><strong>Fixed effects</strong></td>
<td>$g$</td>
</tr>
<tr>
<td>Constant</td>
<td>$-2306.6 \pm 233.4^2$</td>
</tr>
<tr>
<td>Biological maturity by year</td>
<td>$114.8 \pm 10.7^2$</td>
</tr>
<tr>
<td>Biological maturity (2nd polynomial)</td>
<td>$12.8 \pm 0.8^2$</td>
</tr>
<tr>
<td>Biological maturity (3rd polynomial)</td>
<td>$-2.3 \pm 0.2^2$</td>
</tr>
<tr>
<td>Height by cm</td>
<td>$22.6 \pm 1.5^2$</td>
</tr>
<tr>
<td>Body mass by kg</td>
<td>$4.3 \pm 0.8$</td>
</tr>
<tr>
<td>Physical activity score$^4$</td>
<td>$22.2 \pm 9.0^2$</td>
</tr>
<tr>
<td>Calcium intake by mg/d$^5$</td>
<td>$0.017 \pm 0.008^2$</td>
</tr>
<tr>
<td>Vegetable and fruit intakes by servings/d$^6$</td>
<td>$5.4 \pm 1.3^2$</td>
</tr>
</tbody>
</table>

| **Random effects**       |             |
| Level 1 (within-subjects) constant  | $4330.8 \pm 316.8^2$ | $2204.7 \pm 156.5^2$ |
| Level 2 (between-subjects) variance of constant | $36 851.0 \pm 5175.5^2$ | $20 204.9 \pm 2798.0^2$ |
| Covariance of constant with biological maturity | $4186.3 \pm 806.1^2$ | $1650.1 \pm 112.6^2$ |
| Variance of biological maturity | $1026.6 \pm 188.3^2$ | $669.2 \pm 112.6^2$ |

$^1$ Values are estimated $\bar{x}$ coefficients $\pm$ SEE (TBBMC; in g).
$^2$ $P < 0.05$ if estimate $\geq 2 \times$ SEE for all values unless NS.
$^3$ Biological maturity is the number of years from the age at peak height velocity.
$^4$ Low = 1, high = 5.
$^5$ Significant only in boys.
$^6$ Values are estimated $\bar{x}$ variance $\pm$ SEE (TBBMC; in g).
However, in boys, a score of 1 on the physical activity scale [range: 1 (low)–5 (high)] predicted a 22.2-g accrual of TBBMC. For every additional 1 mg calcium consumed, 0.017 g TBBMC was accrued, and, for every additional serving of vegetables and fruit, 5.4 g TBBMC was accrued. The coefficient can also be used to predict the percentage of TBBMC accrued at any particular time point. For example, in boys at PHV (biological maturity = 0), height accounted for 91.6% and body mass accounted for 5.7% of predicted TBBMC. Physical activity, intake of calcium, and intakes of vegetables and fruit accounted for 1.7%, 0.5%, and 0.5%, respectively, of predicted TBBMC in boys. In girls, the percentages of contribution of covariates were 89.3% for height, 9.8% for body mass, 0.8% for physical activity level, 0.09% for intake of calcium, and 0.009% for intake of vegetables and fruit (Table 4). Intakes of energy and other food groups, including grain products, meat and alternatives, fat and oils, and sweets and desserts, were not significant predictors of TBBMC in boys or girls and thus were not included in the final models.

**DISCUSSION**

The unique aspect of the design of this study is the alignment of subjects along an axis related to age at attainment of PHV. Age at PHV is a useful indicator of biological maturity because the timing and tempo of bone accrual can be expressed against this maturity landmark, so that comparisons by sex can be made (22). As we described previously, the magnitude of TBBMC accrual in girls was significantly less than that in boys (Figure 1), and this sex difference in accrual can be explained by anthropometric differences (26).

Although our subjects had better food group intakes than did those in other published studies, they did not all meet the recommendations (29, 30). The percentage of subjects in our cohort who met the guidelines for each of the food groups ranged from ≈18% for meat and alternatives (girls) to ≈90% for milk products (boys). A marked sex difference was observed in food choices, and the high intake by boys increased from childhood to adolescence in almost all food groups.

Despite the fact that milk products were the main source of calcium for these subjects (3), our current results do not show a greater specific effect of milk product intake than of calcium intake on TBBMC accrual. Most subjects in our cohort met the recommendation for servings of milk products. We showed previously that calcium intake was a significant predictor of TBBMC in boys (31), and thus the current findings suggest that calcium intake from other sources was important. Our derivation of the number of servings of milk products was not as precise as finding milligrams of calcium, and this may have reduced our power to detect a significantly greater effect of milk products than of calcium.

Intakes of vegetables and fruit had a significant independent effect on TBBMC development in boys. For subjects of the same biological maturity age, height, body mass, physical activity, and calcium intake, TBBMC would be 48.6 g higher in the subject with an intake of 10 servings of vegetables and fruit per day than in the subject with an intake of 1 serving/d. Bone mineral acts as a buffering base, and a lifetime of buffering the acid load from the ingestion of Western-type diets is believed to lead to bone loss (19). Fruit and vegetables provide organic salts of potassium and magnesium that have such a buffering effect. Another component found in vegetables is vitamin K, which is an essential cofactor for osteoblastic activity (32). Lower BMD and higher numbers of hip fractures have been reported in patients with low concentrations of vitamin K (32). Natural antioxidants and phytoestrogen compounds in some vegetables may also have bone-protective effects (33). However, an inhibitory effect on bone resorption has been reported for some vegetables, such as onion (34).

Most research on the effect of fruit and vegetables on bone health has been conducted in perimenopausal women (16–20, 32–34). Three cross-sectional studies in children and adolescents found a positive relation between the intake of vegetables or fruit (or both) and bone mass markers in girls (13–15). We showed that vegetables and fruit were a significant predictor of TBBMC in boys aged 8–20 y. Overall, these studies support the concept of a lifetime beneficial effect on bone health of the intakes of vegetables and fruit.

Studies by others showed a positive relation between moderate physical activity and BMC accrual (35–37), as did our previous analysis (27). In our final model, physical activity was a significant predictor of TBBMC in the presence of the intakes of calcium and of vegetables and fruit. However, no interaction between those factors was observed. The concept of a threshold intake of calcium during childhood or adolescence (or both) that optimizes the effect of physical activity on adult bone status was supported by several studies (38–40).

We could not show effects of physical activity, intake of calcium, and intakes of vegetables and fruit on TBBMC in girls. We previously showed, by using data from the first year of our study, that underreporting the consumption of foods and beverages was greater in girls than in boys and that older girls underreported more than did younger girls (8). This pattern of underreporting can be seen as a lower-than-expected calcium intake after the age at PHV compared with that before the age at PHV, as plotted in Figure 1. Our data are in agreement with data on energy intake and energy expenditure in girls measured longitudinally at ages 10, 12, and 15 y by Bandini et al (41), who found that, as the age of girls increased, they tended to report energy intake less accurately. Those researchers concluded that the use of self-reported energy intake data in adolescent girls will result in substantial underestimation of energy intake. In our cohort, the decline of calcium intake in girls from the age at PHV to 4 y after the age at PHV (Figure 1) had a pattern comparable to that of their energy intake, in which the energy intake declined from 1778 kcal at the age at PHV to 1467 kcal in year 4 after the age at PHV.

**TABLE 4** Percentage of contribution of each variable (from Table 3) in the prediction of total-body bone mineral content (TBBMC) at the age of biological maturity in boys and girls

<table>
<thead>
<tr>
<th></th>
<th>Boys (n = 85)</th>
<th>Girls (n = 67)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>91.6%</td>
<td>89.3%</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>5.7%</td>
<td>9.8%</td>
</tr>
<tr>
<td>Physical activity (score)</td>
<td>1.7%</td>
<td>0.8%</td>
</tr>
<tr>
<td>Calcium intake (mg/d)</td>
<td>0.5%</td>
<td>0.091%</td>
</tr>
<tr>
<td>Vegetable and fruit intakes (servings/d)</td>
<td>0.5%</td>
<td>0.009%</td>
</tr>
</tbody>
</table>

1 The biological maturity age was defined as the age at peak height velocity (PHV = 0).
2 Low = 1, high = 5.
The current study has some limitations. The subjects were not drawn from a nationally representative sample. Dietary intakes were self-reported, which can lead to underestimation because of underreporting. Physical activity was also self-reported and was determined as the frequency of various activities, which was subject to underreporting or overreporting. The longitudinal nature of the study and the determination of biological maturity age, however, are unique features of the study. Use of the multilevel modeling method specifically developed for the analysis of growth data permitted the determination of factors that affect TBBMC during biological maturation.

Important biological, psychological, social, and cognitive changes occur during adolescence. These changes can affect the nutritional needs of teenagers (42). Although biological factors play the most important role in bone mineral accrual during those critical years, nutrition and physical activity are important factors in the accrual of genetically designed potential peak bone mass. The beneficial effect of the intake of vegetables and fruit on bone mass in boys, measured as TBBMC in boys aged 8–20 y, adds to previous published reports of this effect in girls. Appropriate intakes of vegetables and fruit, as well as of the dairy products that are the main sources of dietary calcium, are beneficial to bone health from childhood to late adolescence.

HV performed the statistical data analyses and wrote the manuscript. SJW, DAB, and RAF were involved in developing the Pediatric Bone Mineral Accrual Study protocol and conducting the study. SJW was involved in the critical revision of the manuscript for intellectual content and interpretation of results. ABI, the current director of the longitudinal study of the Pediatric Bone Mineral Accrual Study, developed the specific model for analyzing growth data and supervised the data analysis. All authors contributed to revisions of the manuscript. None of the authors had a personal or financial conflict of interest.

REFERENCES