Influence of calcium intake and growth indexes on vertebral bone mineral density in young females

Joan M Sentipal, Gordon M Wardlaw, John Mahan, and Velimir Matkovic

ABSTRACT This cross-sectional study examined the relationship between current calcium intake and vertebral bone mineral density (V-BMD) in 49 healthy Caucasian adolescent females aged 8–18 y. The ability of current calcium intake to account for the variance in V-BMD in this population was compared with that seen with weight, height, maturational age (determined by the Tanner Sexual Maturity Rating), chronological age, and total energy expenditure. Calcium intake was determined from the mean of 4-d, food-intake records. Average vertebral bone mineral density from L1–L4 was measured by dual x-ray absorptiometry. A multiple-regression model revealed that 81% of the variance in V-BMD was described by maturational age, chronological age, and calcium intake, with all representing significant predictors of bone mineral density (P < 0.0001, 0.005, 0.04, respectively). This study supports the hypothesis that better calcium nutrition during adolescence may optimize, within genetic boundaries, peak bone mass. Am J Clin Nutr 1991;54:425–8.

KEY WORDS Peak bone mass, calcium intake, adolescence, osteoporosis, sexual development, Tanner Sexual Maturity Rating

Introduction

Osteoporosis results in ≥ 1.2 million bone fractures each year, qualifying it as a major health concern in the United States (1). This disease is of particular concern for women because approximately one-third of women aged > 65 y suffer from vertebral osteoporosis. Over a lifetime, women may lose up to a total of 35% of cortical bone mass and 50% of trabecular bone whereas men may lose only two-thirds of these amounts (1). Because adult bone loss is so pervasive, we need to identify prophylactic measures that help optimize the peak bone density of early adulthood to aid in the maintenance of structural integrity throughout the life span.

Forty-five percent of the adult skeleton is built and enlarged during adolescence (2). The average daily accumulation of calcium in adolescent girls is ~ 2.87 mmol/d and increases to ~ 9.23 mmol/d during the peak growth spurt (3). Consequently, we and others have suggested that adolescence could be an important time to optimize bone density by consuming adequate dietary calcium (4–8). It follows that a low calcium intake during adolescence may be a major limiting factor in achieving peak adult bone density (5–7).

In this cross-sectional study we determined current calcium intake and vertebral bone mineral density (V-BMD) in female preadolescents and adolescents. We were particularly interested to see if current calcium intake would be a significant predictor of the variance in V-BMD values in this group of young girls when the influence of weight, height, chronological age, maturational age, and total energy expenditure were simultaneously accounted for.

Subjects and methods

Subjects

Healthy Caucasian female preadolescents and adolescents ranging in age from 8 to 18 y were recruited from the metropolitan area of Columbus, OH, through contacts with hospital employees and advertisements in suburban news publications. Potential subjects were excluded from the study on the basis of criteria listed in the Appendix. The study protocol was approved by The Human Subjects Review Committee at Children’s Hospital, Columbus, OH. This hospital also served as the clinical site for the study.

The final sample included 49 subjects. They were categorized in the various stages of pubertal development by using the Tanner Sexual Maturity Ratings (SMRs), which are based on breast development: SMR 1, n = 10; SMR 2, n = 9; SMR 3, n = 9; SMR 4, n = 10; SMR 5, n = 11. This method for setting SMRs is described in detail by Tanner (9). After subjects were categorized into a specific SMR by a registered nurse, height (± 0.1 cm) and weight (± 0.1 kg) were measured at the clinical site by using guidelines from the National Center for Health Statistics (10).

Diet and activity histories

Past calcium intake from dairy sources was assessed in consultation with each mother and child by using a retrospective

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to present food frequency form for the time periods: preschool, childhood, and adolescence (11, 12). Food models were used to estimate portion sizes.

Current total dietary intake was assessed by using complete 4-d diet records that included three weekdays and one weekend day (13). Nutrient intake was analyzed by using the Food Processor II computerized program for nutrient analysis (ESHA Research, Salem, OR). Mean daily calcium intake was then calculated.

Activity records were kept for the last 3 d of the diet-record interval. Total energy expenditure was calculated as outlined by Bouchard et al (14). Mean daily energy expenditure was then calculated. Directions for completing diet and activity records were reviewed with participants during a home visit by a registered dietitian (JMS). A twenty-dollar cash incentive was provided to each participant to encourage participation.

Vertebral bone mineral density

Vertebral bone mineral density (average of L1-L4) was measured by using a dual-energy radiographic absorptiometer (Hologic QDR 1000, Hologic Inc, Waltham, MA) according to protocol supplied by the manufacturer. A lumbar-spine phantom (Hologic) consisting of four simulated vertebrae with known amounts of calcium hydroxyapatite embedded in clear plastic was scanned daily for quality control. The CV (precision) for the phantom scans during the study was 0.21%. Kelly et al (15) reported a test-retest SD of 0.009 g/cm² for the Hologic instrument after evaluating 85 adults with a range of bone density values that essentially overlapped our population values.

Data analysis

The relative abilities of calcium intake, age, weight, height, total energy expenditure, and SMR to describe the variance seen in V-BMD were examined by multiple linear-regression analysis (General Linear Model procedure, Statistical Analysis System, SAS Institute, Cary, NC). A backward elimination technique was used. All the predictor variables and first-order interactions were included initially in the regression model. Then, one by one, the least nonsignificant predictor variable (largest P value) was deleted until only significant predictor variables remained. The goal of this regression analysis was to obtain a predictor model that contained relatively few significant predictor variables while still having a large coefficient of determination (r²).

Results

Table 1 summarizes subject characteristics, including height, weight, age, V-BMD, and total energy expenditure. The mean values for all variables increased as SMR increased.

Table 2 summarizes the subject's current dietary intakes based on a 4-d food record, including calcium, protein, phosphorus, energy, the ratio of calcium to phosphorus, and dietary fiber. For current intakes, 67% of the girls aged 8-10 y met the recommended dietary allowance (RDA) for calcium (800 mg) whereas 16% of the girls aged 11-18 y did so (1200 mg) (16). On the basis of each subject's retrospective food frequency analysis, dairy-product consumption in comparison with the Daily Food Guide recommendations for the appropriate age showed a gradual decline over the years (17). The percentage of girls meeting the recommended daily milk and cheese group servings decreased from 73% between the ages of 2 and 5 y to 52% between kindergarten through sixth grade. No girl met her recommended amount during adolescence.

Much variation in V-BMD existed within each SMR (Fig 1). Multiple regression was used to identify the contribution of individual variables and first-order interactions to the overall variance in V-BMD. An initial multiple-regression model, which included all predictor variables plus first-order interactions (ie, calcium intake, age, height, weight, SMR, total energy expenditure, calcium-by-age, calcium-by-height, calcium-by-weight, calcium-SMR, calcium-by-total energy expenditure, age-by-height, age-by-weight, age-by-SMR, age-by-total energy expenditure, height-by-weight, height-by-SMR, height-by-total energy expenditure, weight-by-SMR, weight-by-total energy expenditure, and SMR-by-total energy expenditure) accounted for 86% of the variance in V-BMD. When nonsignificant variables were removed, a multiple-regression model that accounted for 83% of the variance in V-BMD was obtained with the following

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<thead>
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<th>Table 1</th>
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<td><strong>Subject characteristics</strong></td>
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<tr>
<td>Tanner SMR</td>
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<tr>
<td>(8-11)</td>
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<td>2 (n = 9)</td>
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<td>3 (n = 9)</td>
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<tr>
<td>5 (n = 11)</td>
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<td>(13-18)</td>
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* x ± SEM, range in parentheses. SMR, Sexual Maturity Rating; V-BMD, vertebral bone mineral density.
variables: SMR ($P < 0.0001$), age ($P < 0.001$), calcium intake ($P < 0.013$), and age-by-calcium ($P < 0.034$).

To obtain the simplest model for predictive purposes, age-by-calcium was eliminated from the model. The new model then accounted for 81% of the variance in V-BMD and included SMR ($P < 0.001$), age ($P < 0.005$), and calcium intake ($P < 0.04$).

From this model, a prediction equation for V-BMD was computed:

$$\text{BMD} = 0.484 - (0.182 \times T1) - (0.132 \times T2) - (0.110 \times T3) + (0.063 \times T4) + (0.025 \times A) + (0.067 \times C)$$

where $A$ is Age (y) and $C$ is calcium intake (g/d).

**Discussion**

In this population of healthy Caucasian adolescent females, SMR, height, weight, and total energy expenditure will be highly intercorrelated, considering that all these variables increase with age. To identify the factors that best describe the wide variability of V-BMD in the population, multiple-regression models were generated. The variables SMR, age, and calcium intake significantly contributed to the best three-variable model and described 81% of the variance in V-BMD. Of these factors, increases in chronological age and SMR occur naturally. However, calcium, another significant contributor to V-BMD, represents a self-controlled variable. This is a key point because it potentially provides an opportunity to influence peak adult V-BMD and supports the recent emphasis on adequate dietary calcium in this age group (3, 16). Body weight also can have a significant influence on V-BMD. We possibly did not see this from our multiple regression because weight was kept within the 10th–90th height-related percentile to limit its confounding effect.

On the basis of summary of dietary intakes, minimal differences existed for our subjects in mean intakes of protein, phosphorus, and the ratio of calcium to phosphorus. In addition, dietary fiber intakes did not exceed adult recommendations. Thus, the potential for dietary variables listed other than calcium to influence V-BMD in any one Tanner stage more than in others can be discounted.

As suggested by other studies (5–8) and identified in our population, calcium intake can significantly describe part of the variance seen in V-BMD during preadolescence and adolescence. In some studies (18, 19) calcium intake was shown to be below the RDA for many young females in the United States. Our study confirms these observations; we noted a decrease in calcium consumption over the school-age years. Between ages 8 and 10 y, two of every three girls met the RDA for calcium whereas only one of every six girls met the RDA for calcium in adolescence (ages 11–18 y).

In summary, we found in a sample of 49 Caucasian females aged 8–18 y that 81% of the variance in V-BMD was described by SMR, age, and calcium intake; all represented significant predictors. As values for these variables increased, bone mineral...
density increased. If the predictive nature of calcium intake on the variance in V-BMD observed in this limited cross-sectional study can be substantiated in longitudinal studies, it will provide further evidence of the importance of calcium intake on the development of peak vertebral bone mass. This could then translate into higher bone density at menopause and thus potentially contribute to prophylaxis against subsequent spinal osteoporosis.

We thank the Clinical Studies Center staff at Children’s Hospital, Columbus, OH, and Ormand Berg for all of their time and work on the study. We are also indebted to Fei Fei Wei for her statistical advice and Linda Boone for her pediatric nutrition advice and editorial comments.

References


APPENDIX

Subject rejection criteria

Sex: Male
Race: Non-Caucasian
Desirable body weight:
Intake of glucocorticoids, anticonvulsants, aluminum-containing antacids, thiazide diuretics, or isoniazid
Prematurity:
History of or current medical problems, including thyroid problems, bone disease, physician indication of growth problem, bone fractures (more than one), persistent bone pain, liver disease, renal disease, kidney stones, pregnancy, diabetes

Vitamin A supplementation:
Intake of > 200 g ethanol/wk
Physical activity:
Present or past participation in a routine physical activity > 7 h/wk, weight lifting, or a competitive gymnastics program

TANNER Sexual Maturity Rating (SMR):

ERRATUM

Am J Clin Nutr 1989;50:1104–15. Two brackets were misplaced in equations 26–28. The equations should read as follows:

\[ D = (1.1315 + \{0.0018[\text{age (y)} - 2]\}) - \{0.0719 + 0.0006[\text{age (y)} - 2]\} \cdot \log \text{(skinfold thickness)} \]  \hspace{1cm} (26)

\[ D = (1.1315 + \{0.0004[\text{age (y)} - 2]\}) - \{0.0719 + 0.0003[\text{age (y)} - 2]\} \cdot \log \text{(skinfold thickness)} \]  \hspace{1cm} (27)

\[ D = (1.1350 + \{0.0031[\text{age (y)} - 10]\}) - \{0.0719 + 0.0003[\text{age (y)} - 2]\} \cdot \log \text{(skinfold thickness)} \]  \hspace{1cm} (28)