Food Insecurity Is Associated with Diet and Bone Mass Disparities in Early Adolescent Males but Not Females in the United States

Heather A. Eicher-Miller, April C. Mason, Connie M. Weaver, George P. McCabe, and Carol J. Boushey

Abstract

Food insecurity is associated with decreased nutrient intake and poor health and possibly low bone mass in children. The purpose of this study was to formally investigate the relationship of diet, bone mass, and food insecurity among children aged 8–19 y (n = 5270). The data used in this cross-sectional study were drawn from children participating in the NHANES 2001–2004. Data were collected from homes and NHANES mobile examination centers across the United States. Food security status was classified using the US Children’s Food Security Scale and the US Household Food Security Scale. Dietary measures were quantified by 24-h dietary recall and bone mineral content (BMC) was determined with whole body DXA. Results indicated that males 8–11 y from households with food insecurity among children were 2.5 times (OR = 2.5 [95% CI = 1.1–5.8]) more likely to have fewer than the USDA Food Guide recommended servings of dairy foods, 2.3 times (OR = 2.3 [95% CI = 1.3–4.0]) more likely to have less than the estimated average requirement for calcium intake, and more likely to have a significantly lower estimated total body (P = 0.04), trunk (P = 0.05), lumbar spine (P = 0.02), pelvis (P = 0.05), and left arm (P = 0.05) BMC compared with males 8–11 y old from households with food security among children. Calcium-related dietary factors and BMC did not differ among females by food security status. These results are evidence that health disparities persist among 8- to 11-y-old, food-insecure boys. Successful interventions to improve diet and bone health and reduce food insecurity among children are a continuing need in the United States. J. Nutr. 141: 1738–1745, 2011.

Introduction

Many U.S. children do not have ensured access to food. Food security is defined as “access by all people at all times to enough food for an active, healthy life” (1). Food-insecure children have “limited or uncertain availability of nutritionally adequate and safe foods or limited or uncertain ability to acquire acceptable food in socially acceptable ways” (1). Using data collected by the U.S. Census Bureau, Nord et al. (2) estimated that 17.2 million children (23.2%) lived in food-insecure households in 2009 (2). Food insecurity defines an experience broadly ranging from eating less desirable foods to skipping meals to not eating for an entire day (3). Children who are food insecure may consume a diet low in nutrients, including calcium (4), putting them at risk for undesirable health outcomes. Dairy foods were responsible for 62% of dietary calcium among children 2–18 y old in the Continuing Survey of Food Intakes by Individuals 1994–1996 and 1998 (5). Access to dairy foods may be limited for food-insecure children due to the associated expense. Preschool children in severely food-insecure households were significantly less likely to meet Food Guide Pyramid recommendations for the milk food group compared with children from food-secure and less severely food-insecure households (6).

Dairy source calcium intake compared with other food source calcium intake is most often associated with greater bone mass (7–10). Milk-avoiding children were found to have significantly less bone compared with nonavoiding children (11) and fracture rates were greater in milk avoiders compared with nonavoiders (12). In addition, young women recalling high milk consumption from early childhood to age 12 y had greater total body, spine, and radial peak bone mass compared with those recalling low milk consumption (9). A diet that is less likely to meet dairy food recommendations, such as the diets of food-insecure children, may be less likely to fulfill calcium needs for adequate bone mass accumulation.

Childhood and adolescence are a critical time for maximum bone accrual (13). Bone deposition is especially rapid during puberty, starting from 11 y in girls and 13 y in boys (14). Scant calcium intake during this time may result in low peak bone mass achievement and increased risk for osteoporosis and fracture (13). Even small differences in bone mass can affect
fracture risk, which was estimated to be 89% greater for a single
SD decrease in total body BMC in 9-y-old children. Heaney
et al. (15) estimated a 5–10% difference in adolescent peak bone
mass may be attributed to calcium nutrition and responsible for
a 25–50% difference in hip fracture rate in later adulthood (15).
Thus, disparities in calcium nutrition and bone status in child-
hood and adolescence hint at immediate and lifelong conse-
quences to bone health.

The research focusing on food and nutrient intake has been
narrow in coverage of food-insecure children (4,6,16,17) and
further limited for school-aged, food-insecure children (4,17).
 Dietary disparities, however, including less meat consumption
(18); fewer servings of fruits, vegetables, and grain products (4);
and lower intake of vitamins C, B-6, B-12, and folate and
potassium have been noted in food-insecure compared with
food-secure, school-aged children (4). Negative health outcomes
have also been found to be associated with food insecurity in
school-aged children, including iron deficiency anemia (19),
compromised psychosocial functioning (20), and poor develop-
mental trajectories (21,22).

The present investigation into the differences between the bone
status of food-secure groups is novel, as is analysis following a
hypothesized framework of how diet may be the mechanism fa-
cilitating the relationship of food insecurity to bone mass.
The purpose of this study was to determine the strength of the asso-
ciation of food security status and BMC among children 8–19 y
old from the NHANES 1999–2004. An investigation into the
relationship of food security and selected dietary indicators of
calcium intake, i.e. the USDA Food Guide for dairy intake and the
EAR for calcium, was also completed.

Methods

Survey design and study participants. NHANES 2001–2002 and
2003–2004 were nationally representative cross-sectional surveys con-
tinuously conducted by the NCHS, a program of the CDC. NHANES
participants were drawn from and representative of the noninstitution-
alized and civilian U.S. population. A complex multistage probability
sampling method was used to select participants on the basis of age, sex,
and race-ethnicity. Subpopulations, including non-Hispanic Black Amer-
icans, Mexican Americans, low-income white Americans, children 12–
19 y old, and individuals >60 y old (23), were oversampled to allow for
the generation of precise and reliable estimates for these groups.
NHANES participants completed an in-depth questionnaire assessing
diet, socioeconomic indicators, and health history in their homes and at
the NHANES MEC. In addition, a physician-conducted assessment of
medical, dental, and physiologic health indices, a 24-h dietary recall, and
whole-body DXA scan were completed during a visit to the MEC.

Children 8–11 y old reported with assistance from a parent or
guardian, whereas children 12 y and older completed portions of the
interview independently. Consent by a parent or guardian was required
for all participants younger than 18 y old. Consent was requested of
children ≥12 y (23). The NCHS Research Ethics Review Board reviewed
and approved NHANES protocol for all NHANES content (24). The
Purdue University Human Research Protection Program deemed the de-
defined data and research activities of this study as exempt.

Participants of this study included all nonpregnant children 8–19 y
old who successfully completed the household interview and partici-
pated in the MEC exam. DXA data were required for the bone status
analysis (n = 5576) and dietary data for the dietary analysis (n = 6024).
Exclusions were made for participants without Household Food Secu-

rity classification (n = 317), without Child Food Security classification
(8–15 y; n = 182), and taking drugs known to interfere with bone
metabolism (for bone analysis; n = 88). Inclusion in a particular analysis
required responses for all variables comprising the model. Individuals
numbered 4846 and 5270, respectively, for the bone and dietary analysis.

Family and sample person questionnaire. Characteristics queried in
the questionnaire portion of the survey were age, sex, race/ethnicity,
annual household income, household participation in the USDA Special
Supplemental Nutrition Program for WIC, presence of a smoker living in
the household, personal smoking, dietary supplement use in the past 30 d,
number of school meals eaten each week, menarche (females), mean level
of physical activity, and use of birth control at the time of the survey
(females 12–19 y old).

FSSM. The FSSM was administered during the household interview.
This questionnaire has been extensively evaluated for validity and re-
liability and shown to accurately quantify access to food (25–34). Par-
ticipants completing the 18-item FSSM were directed to consider food
eaten in their households over the past 12 mo (35) and to evaluate household,
individual, or child-specific food access. The food security of
household adults and children is classified in 1 of 4 ranges on the con-
tinuum of food security: 1) household full food security, where there are
no problems or anxieties for household members regarding food; 2) house-
hold marginal food security, when household members worry about attaining food or experience problems in attaining food, but
quality, variety, and quantity are not reduced; 3) household low food
security, when quality, variety, and desirability are reduced yet adequate
quantity remains; 4) household very low food security, a situation of
interrupted eating patterns and food quantity reduction due to inadequate
resources. Household full and marginal food security classifications are
often grouped and referred to as food secure, whereas low and very low
food security classifications are referred to as food insecure (3).

Eight child-specific questions in the FSSM were used to determine
food security among household children (36) with ranges defined sim-
ilarly to household classifications: “child food quality and quantity un-
affected” termed food security among household children; “child
reduced food quality or quantity,” termed marginal food security among
household children; “child reduced food quality and quantity,” termed
low food security among household children; and “child severely reduced
quality and quantity,” termed very low food security among household
children (23). Food security classifications for the household and child-
specific household were included in the NHANES data release.

Child-specific household food security was selected as the most direct
and reliable measure to quantify the experience of hunger and reduced
food intake among children aged 8–15 y (36–39). Children 18–19 y old,
an age group with an insufficient number of participants to be analyzed
collectively, were not provided child-specific household food security
classification. Consequently, the age range was expanded to include 16-
to 17-y-old children and household food security was chosen, because this
was the common food security measure among 16–
to 19-y-old children.

Bone status parameters. The total body DXA scan completed by
participants in the examination portion of the survey provided BMC (g)
assessment for the total body and subregions: trunk, pelvis, thoracic and
lumbar spine, and right and left arms and legs. The Hologic QDR 4500a
fan-beam densitometer (Hologic) was used to perform the DXA scans,
accompanied by Hologic software version 8.26a.3. Certified radiology
technologists positioned participants and administered the exams. Qual-
ity control was high, including monitoring of technologists, densitom-
eters, and completing rigorous phantom scanning schedules. The scans
were analyzed with Hologic Discovery software, version 12.1 at the
University of California, San Francisco, Department of Radiology. An
Auto WB application was incorporated in the software to improve bone
detection in very low-density bone of children. All scans were reviewed
by experts at the University of California, San Francisco to ensure cons-
istency and maintenance of specified standards. DXA method details are
extensively outlined elsewhere (40).

A nonrandom pattern of missing DXA data was apparent in partici-
pant distributions. The NCHS addressed this potential bias by creating 5
datasets with imputed values for missing participants who were not pregnant or limb amputees. Imputed values were determined using regression models that included several relevant predictor variables. A few sample participants with imputed DXA values had extremely variable data and were not included in this analysis. A detailed description of imputation methods and analysis strategies are available elsewhere (41).

Dietary assessment. The USDA’s Automated Multiple Pass Method (42) 24-h dietary recall was completed during the MEC examination. The dietary information was then linked to the USDA Food and Nutrient Database for Dietary Studies (43), a nutrient composition database. The Automated Multiple Pass Method computerized software system allows for direct coding of the reported foods, data editing and management, and nutrient analysis of the dietary data (42).

Total calcium intake (mg/d) was included in the NHANES data release. Calcium intakes were compared using the EAR for the specific gender and age group (44). Total servings of dairy foods consumed were determined by identifying dairy foods using the USDA food code then using the gram weight to calculate number of servings and summing for the total. Reference servings given in the USDA Food Guide (45) for moderately active children of each gender and age group were then compared with calculated servings.

Anthropometry. Height and weight were collected in the examination portion of the survey using a stadiometer for height and a Toledo scale for weight. BMI-for-age for each individual was calculated by linking the portion of the survey using a stadiometer for height and a Toledo scale for weight. Anthropometry.

Statistical analysis. All analyses were stratified by age (8–11, 12–15, and 16–19 y) and sex due to known biological differences between these groups regarding bone development, such as timing of peak bone mass accumulation and accelerated bone growth (48). Age groupings were also chosen to maintain consistency with NHANES multiple imputation datasets for bone measures and for other parameters. Race/ethnicity was identified as another important factor related to bone (49,50) and indicator variables were created as non-Hispanic white (reference group), non-Hispanic black, Mexican American, and a combined group of other Hispanic, other races, and multi racial participants that were too few to be classified separately. Although the participants of these groups are likely very diverse within themselves and between the other groups, the benefits of combining them outweighed the loss of power resulting from their exclusion or blending with other dominant groups. The poverty:income ratios included in the NHANES data were calculated as household income divided by the federal poverty guideline for household income and simplified to a range of 0–5 (51) and divided as: 0–0.99, 1.00–1.99, 2.00–2.99, and 3.00–5.00 (indicator variables) for this analysis.

Household participation in WIC was categorized as yes or no; presence of a smoker living in the household as yes or no; personal smoking as yes or no; use of a dietary supplement in the past 30 d as yes or no; number of school meals eaten per week as 0, 1–5, or 6–10 (indicator variables); physical activity of 8–11 y olds as <1 time/wk, 2–4 times/wk, 5–7 times/wk, or ≥8 times/wk (indicator variables); physical activity of 12–19 y olds as vigorous, moderate, or no activity per day (indicator variables); premenarche or postmenarche; birth control use at survey or not; and survey cycle year, 2001–2002, 2003–2004 (indicator variables).

Food security classifications were collapsed, because of the few participants classified for low and very low food security, into 2

### TABLE 1

<table>
<thead>
<tr>
<th>Item</th>
<th>Males (8–11 y) (n = 652)</th>
<th>Males (12–15 y) (n = 1073)</th>
<th>Males (16–19 y) (n = 812)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Food secure</td>
<td>Food insecure</td>
<td>β (SE)</td>
</tr>
<tr>
<td>Total body</td>
<td>1700 ± 12.4</td>
<td>1150 ± 28.5</td>
<td>−59.1 (2.6)</td>
</tr>
<tr>
<td></td>
<td>Food secure</td>
<td>Food insecure</td>
<td>β (SE)</td>
</tr>
<tr>
<td>Trunk</td>
<td>271 ± 3.2</td>
<td>263 ± 6.6</td>
<td>−13.9 (6.9)</td>
</tr>
<tr>
<td>Pelvis</td>
<td>112 ± 1.6</td>
<td>104 ± 3.4</td>
<td>−7.6 (3.7)</td>
</tr>
<tr>
<td>T spine</td>
<td>47.4 ± 0.6</td>
<td>46.5 ± 1.3</td>
<td>−1.8 (1.4)</td>
</tr>
<tr>
<td>L spine</td>
<td>24.2 ± 0.4</td>
<td>22.6 ± 1.0</td>
<td>−2.0 (0.8)</td>
</tr>
<tr>
<td>Left arm</td>
<td>71.3 ± 1.1</td>
<td>70.9 ± 2.2</td>
<td>−4.0 (1.9)</td>
</tr>
<tr>
<td>Right arm</td>
<td>75.1 ± 1.1</td>
<td>74.9 ± 2.4</td>
<td>−2.5 (2.1)</td>
</tr>
<tr>
<td>Left leg</td>
<td>215 ± 3.3</td>
<td>215 ± 6.9</td>
<td>−11.7 (7.2)</td>
</tr>
<tr>
<td>Right leg</td>
<td>219 ± 3.3</td>
<td>221 ± 6.2</td>
<td>−9.1 (7.3)</td>
</tr>
</tbody>
</table>

1 Values are mean ± SE. Differences were considered significant at P ≤ 0.05. All models are adjusted for clustering and stratification. Sample weights were appropriately constructed and applied to the analyses as directed by the National Center for Health Statistics. Weights were rescaled so that the sum of the weights matched the survey population at the midpoint of the 4 y covering 2001–2004.

2 Refers to the status of food security or food insecurity in the household.

3 Negative β indicates lower BMC in food insecure children compared with food secure children.

4 Adjusted for survey year, poverty:income ratio, race/ethnicity, BMI status, physical activity, and meals eaten at school per week.

5 Adjusted for survey year, poverty:income ratio, race/ethnicity, BMI status, physical activity, meals eaten at school per week, and personal smoking.

6 Thoracic.

7 Lumbar.

8 Downloaded from https://academic.oup.com/jn/article-abstract/141/9/1738/4630717 by guest on 26 November 2018
categories: full food security/marginal food security, or food secure, and low/very low food security, or food insecure (36). BMC values were included as continuous variables. Total calcium intake was defined as < EAR or ≥ EAR. Participant BMI was categorized as normal, or < 85th percentile; at risk for overweight, or ≥ 85th and ≤ 95th percentile; and overweight, or > 95th percentile (indicator variables) (52, 53). Distributions of the continuous BMC variables for total body, trunk, pelvis, left and right arm, and left and right leg did not deviate considerably from normality and were not transformed for analysis.

A t test was used to compare food-secure and food-insecure children of each age and gender group for individual quantitative variables and chi-square analysis was used to determine differences for individual categorical variables. Multiple linear regression and logistic regression were used to determine differences in BMC and dietary intake, respectively, for food-secure and food-insecure children. All analyses were adjusted for clustering and stratification. Sample weights were appropriately constructed and applied to each analysis as directed by the NCHS.

Multiple linear regression and logistic regression models were additionally adjusted for survey cycle year, race/ethnicity, poverty: income ratio (23), and variables (identified by chi-square analysis) that were unevenly distributed between food-secure and -insecure groups (Supplemental Tables 1 and 2). The potential confounders of presence of household smoking, use of a dietary supplement, and household WIC participation were considered and did not affect the significance of the independent variable and were not included in the final models. All other variables were considered in selection of the best model. Analyses were completed in SAS 9.1 and 9.2 using SAS Survey procedures to account for the complex NHANES survey design. Statistical measures to account for the multiple imputations of the BMC data were also employed in the calculation of all relevant tests. P ≤ 0.05 was considered significant.

### Results

The weighted and adjusted chi-square analyses indicated a significantly greater proportion of food-insecure compared with food-secure participants of all age groups living in households with an income:poverty ratio < 1.0, eating more meals at school among all males and females 8–11 y and 16–19 y old, smoking among males 16–19 y old, and postmenarche among females 12–15 y old (Supplemental Tables 1 and 2). Food-insecure participants as a group had a significantly different racial/ethnic distribution compared with food-secure participants; there was a greater proportion Mexican Americans and a smaller proportion non-Hispanic whites.

Adjusted and weighted multiple linear regression models showed less BMC in males 8–11 y old from households with food insecurity among children compared with males 8–11 y old from households with food security among children (Table 1). Food-insecure males had an estimated 59.1 ± 2.6 g lower total body BMC, 13.9 ± 6.9 g lower trunk BMC, 7.6 ± 3.7 g lower pelvis BMC, 2.0 ± 0.8 g lower lumbar spine BMC, and 4.0 ± 1.9 g lower left arm BMC compared with their food-secure peers. Females and males of other age groups did not significantly differ in BMC (Tables 1 and 2). Survey-adjusted univariate analysis revealed differences in calcium-related dietary proportions among food-secure and food insecure groups (Table 3).

### TABLE 2

<table>
<thead>
<tr>
<th>Item</th>
<th>Females (8–11 y) (n = 653)</th>
<th>Females (12–15 y) (n = 1037)</th>
<th>Females (16–19 y) (n = 685)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Food secure</td>
<td>Food insecure</td>
<td>β (SE)</td>
</tr>
<tr>
<td>Total body</td>
<td>1180 ± 17.0</td>
<td>1210 ± 33.1</td>
<td>6.0 (37.3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.87²</td>
</tr>
<tr>
<td>Trunk</td>
<td>286 ± 5.0</td>
<td>291 ± 9.2</td>
<td>1.3 (10.3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.92²</td>
</tr>
<tr>
<td>Pelvis</td>
<td>118 ± 2.3</td>
<td>117 ± 4.6</td>
<td>1.7 (5.5)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.76²</td>
</tr>
<tr>
<td>T spine⁶</td>
<td>52.2 ± 1.0</td>
<td>53.5 ± 2.1</td>
<td>1.6 (2.4)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.50²</td>
</tr>
<tr>
<td>L. spine⁶</td>
<td>26.6 ± 0.4</td>
<td>27.0 ± 1.1</td>
<td>0.4 (1.3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.75⁵</td>
</tr>
<tr>
<td>Left arm</td>
<td>73.1 ± 1.3</td>
<td>74.9 ± 2.4</td>
<td>0.6 (2.8)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.82⁴</td>
</tr>
<tr>
<td>Right arm</td>
<td>76.3 ± 1.3</td>
<td>78.7 ± 2.9</td>
<td>1.1 (3.1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.73⁶</td>
</tr>
<tr>
<td>Left leg</td>
<td>228 ± 4.1</td>
<td>233 ± 7.6</td>
<td>1.6 (8.3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.85⁷</td>
</tr>
<tr>
<td>Right leg</td>
<td>230 ± 4.2</td>
<td>238 ± 7.8</td>
<td>3.5 (8.6)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.69⁸</td>
</tr>
</tbody>
</table>

1 Values are mean ± SE. Differences were considered significant at P ≤ 0.05. All models are adjusted for clustering and stratification. Sample weights were appropriately constructed and applied to the analyses as directed by the National Center for Health Statistics. Weights were rescaled so that the sum of the weights matched the survey population at the midpoint of the 4 y covering 2001–2004.

2 Refers to the status of food security or food insecurity in the household.

3 Refers to the status of food security or food insecurity among children in the household.

4 Negative β indicates lower BMC in food-insecure children compared with food-secure children.

5 Adjusted for survey year, poverty/income ratio, race/ethnicity, BMI status, physical activity, and meals eaten at school per week.

6 Adjusted for survey year, poverty/income ratio, race/ethnicity, BMI status, physical activity, meals eaten at school per week, and menarche.

7 Adjusted for survey year, poverty/income ratio, race/ethnicity, BMI status, physical activity, meals eaten at school per week, and use of birth control.

8 Thoracic.

9 Lumbar.
However, when adjusted and weighted multiple logistic regression models were constructed, only males 8-11 y from households with food insecurity among children were found to differ from their food secure counterparts. These males were 2.5 times [OR = 2.5 (95% CI = 1.1–5.8)] more likely to report less than the USDA Food Guide recommendations for servings of dairy and 2.3 times [OR = 2.3 (95% CI = 1.3–4.0)] more likely to have a calcium intake less than the EAR compared with males from households with food security among children (Table 4).

### Discussion

This study is the first to our knowledge to document an association between food insecurity and BMC.

The additional finding of 2.3 times [OR = 2.3 (95% CI = 1.3–4.0)] greater odds for males 8-11 y old from households with food insecurity among children consuming less than the EAR for calcium and 2.5 times [OR = 2.5 (95% CI = 1.1–5.8)] greater odds for consuming less than the USDA Food Guide recommended servings of dairy foods compared with males from households with food security offers a mechanism for the disparity in BMC for food-insecure 8- to 11-y-old males. The association of food insecurity with dietary factors and food insecurity with bone mass among the same group of children strengthens the evidence of a pathway.

Dairy foods may be perceived to be more expensive compared with other foods and may be rarely available to young adolescent, food-insecure males. Milk supply has been documented to be significantly less in food-insecure compared with food-secure households (18). Younger males from households with food insecurity among children may be more dependent on a diet from the food-insecure household compared with older and more mobile adolescents from households with food insecurity among children (36). The findings are limited by the cross-sectional nature of the data, yet the idea that early adolescent, food-insecure males may be consuming few dairy foods leading to an unfulfilled calcium requirement and ultimately a low BMC is certainly suggested by the results. Low bone mass is significantly related to childhood fracture (54,55) and early pubertal boys have the highest fracture rates of any age group from infancy to 39 y old (56). Thus, low bone mass in food-insecure males suggests a threat to the health and well-being of these children. Health costs associated with fracture may put an additional and considerable financial burden on food-insecure families and may be difficult to address with adequate health care.

The suggested dietary mechanism for disparities in bone mass in early adolescent, food-insecure males is congruent with the bone sites where differences were noted: total body, trunk, lumbar spine, and pelvis. Total body and spine are the bone sites most affected by diet due to the repository of trabecular bone largely contained in the axial skeleton. The pelvis is also an area with sizable trabecular deposits (57). Trabecular bone may be particularly susceptible to situations of insufficient calcium due to a relatively high bone turnover rate (58). The observed disparities in left arm BMC may be explained by the concept of limb dominance and the varying factors, diet, and physical activity. Heightened physical activity in the dominant arm may overwhelmingly contribute to BMC, transcending differences affected by diet. Weaver et al. (10) have established dominant limb association with elevated BMC. A population exhibiting right arm dominance might display more conformity in right arm compared with left arm BMC among groups with dietary differences such as food insecurity. Lower physical activity associated with the left arm may leave bone vulnerable to the constrained nutrient environment of a food-insecure diet. The finding of no difference in leg BMC by food insecurity status may be attributable to the comparatively smaller discrepancy in dominant and nondominant leg physical activity (59).

Food insecurity was associated with neither diet nor BMC in older, 12- to 19-y-old males, suggesting bone mass compens-

### TABLE 3  
Univariate analysis of calcium related dietary proportions of male and female participants 8–19 y old by food security status (NHANES 2001–2004)  

<table>
<thead>
<tr>
<th>Dietary factors</th>
<th>Food secure, n ( % )</th>
<th>Food insecure, n ( % )</th>
<th>χ² P value</th>
<th>Food secure, n ( % )</th>
<th>Food insecure, n ( % )</th>
<th>χ² P value</th>
<th>Food secure, n ( % )</th>
<th>Food insecure, n ( % )</th>
<th>χ² P value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Males</strong> 8–11 y (n = 693)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calcium intake</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; EAR</td>
<td>323 (53)</td>
<td>89 (66)</td>
<td>0.03</td>
<td>336 (42)</td>
<td>70 (38)</td>
<td>0.17</td>
<td>197 (28)</td>
<td>46 (28)</td>
<td>0.98</td>
</tr>
<tr>
<td>≥ EAR</td>
<td>242 (47)</td>
<td>39 (34)</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Servings of dairy</td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>&lt; Recommended</td>
<td>451 (78)</td>
<td>114 (87)</td>
<td></td>
<td>677 (74)</td>
<td>156 (74)</td>
<td></td>
<td>536 (75)</td>
<td>197 (85)</td>
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</tr>
<tr>
<td>≥ Recommended</td>
<td>114 (22)</td>
<td>14 (13)</td>
<td>0.12</td>
<td>197 (28)</td>
<td>46 (28)</td>
<td>0.98</td>
<td>118 (25)</td>
<td>34 (15)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td><strong>Males</strong> 12–15 y (n = 1076)</td>
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<td></td>
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<tr>
<td>Calcium intake</td>
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<td></td>
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</tr>
<tr>
<td>&lt; EAR</td>
<td>359 (71)</td>
<td>77 (64)</td>
<td></td>
<td>720 (73)</td>
<td>173 (82)</td>
<td></td>
<td>448 (73)</td>
<td>151 (83)</td>
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<tr>
<td>≥ EAR</td>
<td>173 (29)</td>
<td>46 (36)</td>
<td>0.15</td>
<td>210 (27)</td>
<td>43 (18)</td>
<td>0.02</td>
<td>138 (27)</td>
<td>38 (18)</td>
<td>0.04</td>
</tr>
<tr>
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<tr>
<td>&lt; Recommended</td>
<td>510 (88)</td>
<td>104 (87)</td>
<td></td>
<td>802 (83)</td>
<td>193 (89)</td>
<td></td>
<td>538 (89)</td>
<td>176 (95)</td>
<td></td>
</tr>
<tr>
<td>≥ Recommended</td>
<td>62 (12)</td>
<td>19 (13)</td>
<td>0.77</td>
<td>128 (23)</td>
<td>23 (11)</td>
<td>0.07</td>
<td>48 (11)</td>
<td>13 (5)</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td><strong>Males</strong> 16–19 y (n = 885)</td>
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<tr>
<td>Calcium intake</td>
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<td></td>
</tr>
<tr>
<td>&lt; EAR</td>
<td>448 (73)</td>
<td>151 (83)</td>
<td></td>
<td>448 (73)</td>
<td>151 (83)</td>
<td></td>
<td>448 (73)</td>
<td>151 (83)</td>
<td></td>
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<tr>
<td>≥ EAR</td>
<td>138 (27)</td>
<td>38 (18)</td>
<td>0.04</td>
<td>138 (27)</td>
<td>38 (18)</td>
<td></td>
<td>138 (27)</td>
<td>38 (18)</td>
<td></td>
</tr>
</tbody>
</table>

1 Differences were considered significant at P ≤ 0.05. Chi-square analyses were adjusted for clustering and stratification. Sample weights were appropriately constructed and applied to the analyses as directed by the National Center for Health Statistics. Weights were rescaled so that the sum of the weights matched the survey population at the midpoint of the 4 y covering 2001–2004.

2 Total numbers do not always add to sample size due to missing values; percents do not always add to 100 due to rounding.

3 Refers to the status of food security or food insecurity among children in the household.

4 Refers to the status of food security or food insecurity in the household.

5 EAR, estimated average requirement, defined by sex and age.

6 USDA Food Guide recommendations by gender and age for moderately active children are given as 3 servings of dairy/ for males and females 8–11, 12–15, and 16–19 y old (45).

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tion by food-insecure, early adolescent males. Discrepancy in the relationship of food security groups by age is offered by the catch-up phenomenon (60). Demand for calcium during growth may be unmet by availability in early adolescent, food-insecure males who may receive little parental protection from the food-insecure household situation (36). Insufficient calcium intake contributes to bone deficits when deposition does not counter bone loss (58). High demand for calcium in early adolescent, food-insecure males may continue until fulfillment and taper off over time. As noted earlier, older, food-insecure adolescents may have improved opportunities for calcium intake as they experience greater mobility, dietary freedom, and less constraint of a diet originating from the food-insecure household, resulting in the equalization of bone mass in food-secure and -insecure groups for older adolescents. Bone accrual in 8- to 11-y-old, food-insecure compared with food-secure males may be decelerated, but peak bone mass achievement of late adolescence may remain the same (60,61).

The lack of significant differences among female participants was perplexing considering the significant results for males 8–11 y old. One factor contributing to these results might be a later onset of puberty in males. The rate of growth in male and female children aged 2–8 y slows down from the accelerated rate of infancy. Males who are 8–11 y old are still at least 1 y away from the start of peak adolescent height velocity, which starts at age 12 y and reaches a maximum at age 14 y. The group of males aged 8–11 y may be more homogeneous compared with females in respect to their stage of bone growth, because height velocity is at a lull during the years of 8–11 y. Bone equity among males may make the differences associated with food insecurity more noticeable for this age group. Females begin the time of accelerated height velocity growth at an earlier age of 10 y and peak at the age of 12 y, so the age group comprising 8–11 y is a comparatively heterogeneous group with respect to bone mass and stage of growth. The similar lull in bone velocity for females aged 8–9 y was not a large enough group of participants for a separate analysis. The results for 12- to 15-y-old males may similarly be attributable to the heterogeneity expected in a stage of peak velocity growth; hence, the lack of significant differences among food-insecure groups also can be explained (48). Consistency between genders was a secondary factor for the selection of the age groupings in the present study.

One limitation of this study was the lack of a chronic measure of food insecurity; extended retrospective evaluation of the food security scale is yet to be developed and validated. Health consequences of food insecurity may be dependent upon how long and how many years a child has experienced food insecurity. Future studies could also advance the findings presented here by stratifying analysis by race/ethnicity, an important factor influencing bone metabolism (49,50). Adjustment for race/ethnicity was performed in these analyses, homogenizing food-secure and -insecure groups with regard to race. Stratification, however, would allow the differences in bone metabolism by race to be maintained and observed while still comparing food-secure and -insecure adolescents within these groups. Participant numbers in the present analyses were not large enough to perform stratification for different racial/ethnic groups. A limitation to the dietary analyses was the availability of only one 24-h dietary recall for the full 6 y of dietary data and one dietary assessment method. Finally, adolescents as a group may be less concerned about accurately reporting their diets compared with adults (62,63), a reporting error universal to adolescents regardless of food security or economic status.

In summary, early adolescent males from households with food insecurity among children have less bone mass compared with food-secure, early adolescent males, suggesting the threat of greater fracture in this group. This study is evidence of the health disparities that continue to exist in food-insecure children despite U.S. policy and programs directed to this audience. Successful and ongoing interventions are required to improve food security among children and improve bone health and nutrient intake among food-insecure children.

### Acknowledgments
H.A.E-M., A.C.M., C.M.W., G.P.M., and C.J.B. designed research; H.A.E-M. conducted research; H.A.E-M. analyzed data; H.A.E-M. wrote the paper; and H.A.E-M. and C.J.B. had primary responsibility for final content. All authors read and approved the final manuscript.

### Literature Cited


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