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Fruit and vegetable consumption and bone mineral density: the Northern Ireland Young Hearts Project¹⁻³

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ABSTRACT

Background: Studies examining the relation between bone mineral density (BMD) and fruit and vegetable consumption during adolescence are rare.

Objective: Our objective was to determine whether usual fruit and vegetable intakes reported by adolescents have any influence on BMD.

Design: BMD was measured by dual-energy X-ray absorptiometry at the nondominant forearm and dominant heel in a random sample of 12-y-old boys ($n = 324$), 12-y-old girls ($n = 378$), 15-y-old boys ($n = 274$), and 15-y-old girls ($n = 369$). Usual fruit and vegetable consumption was assessed by an interviewer-administered diet history method. Relations between BMD and fruit and vegetable intake were assessed by using regression modeling.

Results: Using multiple linear regression to adjust for the potential confounding influence of physical and lifestyle factors, we observed that 12-y-old girls consuming high amounts of fruit had significantly higher heel BMD ($\beta = 0.037$; 95% CI: 0.017, 0.056) than did the moderate fruit consumers. No other associations were observed.

Conclusion: High intakes of fruit may be important for bone health in girls. It is possible that fruit's alkaline-forming properties mediate the body's acid-base balance. However, intervention studies are required to confirm the findings of this observational study. *Am J Clin Nutr* 2004;80:1019-23.

KEY WORDS Fruit, vegetables, bone mineral density, adolescence, bone health, dietary intake

INTRODUCTION

Osteoporosis and related fractures are major public health problems that are growing in importance as populations age (1). Augmenting bone mass during youth has been suggested as a strategy to prevent osteoporosis, because adolescence may represent the final opportunity for substantially increasing bone mass before skeletal consolidation. Bone mineral density (BMD) is affected by genetic, endocrine, mechanical, and nutritional factors, with extensive interactions between these factors (2). Nutritional factors are considered to be of particular importance to bone health because they are potentially modifiable. One aspect of diet that has received relatively little attention to date is the potential it has to influence the body's acid-base balance. Humans generally consume a diet that generates metabolic acids, leading to a reduction in the concentration of systemic bicarbonate and a fall in pH (3). This fall in pH is thought to directly stimulate osteoclasts to resorb bone.

Consumption of alkaline-forming foods may be important in buffering the fixed acid load imposed by the ingestion of foods with the potential to form acid in the body (3). Nutrients found in abundance in fruit and vegetables may be protective for bone health, possibly because of their alkaline-forming properties. Positive links have been reported between fruit and vegetable consumption and bone health in older adults (4, 5), and, recently, fruit and vegetable intake was beneficially linked with bone size in girls (6). However, the relation between BMD and fruit and vegetable consumption during adolescence remains to be investigated in a large, representative population. Thus, the central aim of the present study was to examine the relation between reported intakes of fruit and vegetables and BMD of the nondominant forearm and dominant heel in a large, representative sample of apparently healthy 12- and 15-y-old girls and boys.

SUBJECTS AND METHODS

Young Hearts Study

The Young Hearts 2000 (YH2000) survey is the second in a series of large cross-sectional epidemiologic studies performed in a representative sample of Northern Irish adolescents. The primary aims of YH2000 were as follows: 1) to identify the prevalence of risk factors for coronary heart disease already present in adolescents aged 12 and 15 y and 2) to identify modifiable lifestyle factors associated with BMD in adolescents aged 12 and 15 y.

Subject recruitment

The sample selection was undertaken as follows. First, all postprimary schools in Northern Ireland ($n = 237$) were stratified

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by education area board ($n = 5$) and by school selection policy. In Northern Ireland, children aged 11 y take a transfer test in the last year of their primary education, the results of which determine whether they are eligible to attend a grammar (selective) or a nongrammar (nonselective) school. Currently, the top 25% of those who take the test attend grammar schools, whereas the remainder attend nongrammar schools. After stratification by board and school selection policy, 36 schools were identified, with the probability of identification proportional to school size. From within each of these schools, adolescents were randomly selected from the appropriate age and sex groups. With the use of this approach, 3147 adolescents were identified, and 2017 participated in the main study. For the purposes of the current study, data were available for 1345 subjects (12-y-old boys, $n = 324$; 12-y-old girls, $n = 378$; 15-y-old boys, $n = 274$; 15-y-old girls, $n = 369$). Ethical approval was obtained from the Research Ethics Committee of the Queen's University of Belfast, and written informed consent was obtained from each subject and from each subject's parent or guardian before participation.

Assessment of bone mineral density

BMD of the nondominant forearm (distal radius) and dominant heel (os calcis) was measured by dual-energy X-ray absorptiometry with a Norland Lunar PIXI (peripheral instantaneous X-ray imager) bone densitometer (Lunar Corporation, Madison, WI). Before each scan, the densitometer was calibrated by using quasi-anthropomorphic phantoms according to the manufacturer's recommendations. The results of the scan were expressed as BMD in g of calcium hydroxyapatite/cm².

Dietary intake assessment

Dietary data were collected by using a nutritionist-administered diet history method (7), the aim of which was to ascertain the habitual food and beverage intakes of each subject, including alcohol consumption. In the age groups under study, this open-ended interview approach has been shown to produce more valid estimates of energy intake at the group level than do weighed-food records (8). In brief, the dietary interview with each subject took ≈ 1 h to complete. Reported foods and drinks were quantified by using a variety of methods, including the use of a photographic food atlas (170 photographs) of known portion sizes, measuring spoons, and other household measures. In addition, several different sized bowls and glasses were provided, and the subjects were asked to measure out a typical serving of a beverage or a particular breakfast cereal if consumed. Similarly, the subjects were asked to spread their usual amount of spreading fat on a slice of bread. All breakfast cereals, beverages, and spreads were then weighed to the nearest gram. School canteens and confectioneries were also visited, and items reported to have been consumed by subjects were purchased and weighed. Manufacturer's data and average portion weight data were also used when necessary (9). If, for example, a subject consumed stew or a curry, further enquiries were made as to the various vegetables these included, and they were coded separately when the data were entered. Although every effort was made to ensure that fruit and vegetables from composite dishes were accounted for separately, the contribution made to fruit and vegetable intake by some composite dishes, such as lasagna and fruit scones, was not accounted for. For the purposes of this study, fruit juice (fresh, concentrated, and canned) was included in fruit intake, and potatoes were excluded from the vegetable group.

Energy and nutrient intakes were calculated by using a computer program (WISP; Tinuviel Software, Warrington, United Kingdom) based on *McCance and Widdowson's Composition of Foods* (10). A food file was also created by using the WISP software. For each subject, the food file recorded every type of food eaten, the quantity of every food eaten, and the energy and nutrient values corresponding to the specific weight of each food recorded. Questions on habitual use of nutritional supplements were asked during the diet history interview and in a questionnaire completed by each adolescent's parent or guardian. In the present article, the latter method was used to ascertain supplement use.

Other measurements

Standing height was measured to the nearest millimeter by using a Holtain stadiometer (Holtain Ltd, Crymych, United Kingdom), and body weight was measured to the nearest 0.1 kg by using a Seca 770 electronic weighing scale (Seca Ltd, Hamburg, Germany). For both measurements, the subjects wore light indoor clothes and no shoes. The pubertal status of each subject was assessed by a pediatrician using visual signs such as non-genital secondary hair growth, vocal timbre, body habitus, general muscular development, and overall breast development in girls. The length of time postmenarche was used as proxy for estrogen exposure. Lifestyle data were obtained from a self-report questionnaire, which included questions designed to assess smoking habits; smokers were defined as those reporting smoking one or more cigarettes per week. Physical activity data were obtained by using a modification of the Baecke questionnaire of habitual physical activity (11), which was designed to quantify work (school) activity, sports activity, and nonsports leisure activity. Fathers' social class, obtained from a parental questionnaire, was coded according to the UK Office of Population Censuses and Surveys standard occupational classification (1990) (12) and was used as a proxy for adolescent social class.

Statistical analyses

The statistical analyses were performed by using SPSS (SPSS for WINDOWS 10.0; SPSS Inc, Chicago). Independent-sample t tests were used to ascertain whether there were any significant differences between subjects with BMD data and those without and also to examine dietary and other differences between the sexes and age groups. Independent t tests were also used to identify any physical or environmental differences between dietary supplement users and nonusers. Fruit intakes and vegetable intakes were grouped separately into tertiles, and a one-way ANOVA was used to determine whether mean BMD measured in the low, moderate, and high tertiles of fruit and vegetable intakes differed significantly. Tukey's post hoc test enabled the identification of where the difference in consumption lay. Regression analyses, for each age-sex group, were then undertaken to assess the extent of the association between fruit and vegetable intake and BMD. The intake tertiles were coded by using a dummy variable coding scheme, which allowed comparisons to be made between the high intake group and the moderate intake group and between the high intake group and the low intake group. Univariate models were constructed with nondominant forearm BMD or dominant heel BMD as the dependent variable and 3 fruit intake categories and 3 vegetable intake categories (low, moderate, and high) as the explanatory variables. Multivariate models were then constructed to include adjustment for



TABLE 1Descriptive characteristics of the study population¹

	12-y-old Boys (n = 324)	12-y-old Girls (n = 378)	15-y-old Boys (n = 274)	15-y-old Girls (n = 369)
Height (cm)	152.3 ± 7.6 ²	154.0 ± 6.9	172.1 ± 7.6 ²	162.6 ± 5.7
Weight (kg)	45.8 ± 10.4 ²	48.0 ± 10.5	62.4 ± 12.7 ²	58.0 ± 10.3
Forearm BMD (g/cm ²)	0.336 ± 0.05 ²	0.326 ± 0.05	0.387 ± 0.06 ²	0.408 ± 0.06
Heel BMD (g/cm ²)	0.469 ± 0.08 ²	0.450 ± 0.08	0.557 ± 0.09 ²	0.489 ± 0.08
Physical activity score ³	32 ± 16.0 ²	22.6 ± 13.7	28.3 ± 14.8 ²	18.2 ± 12.8
Alcohol intake (g/d)	0.12 ± 1.0	0.02 ± 2.1	6.8 ± 10.5 ²	4.7 ± 8.4
Calcium intake (mg/d)	1045 ± 373.8 ²	884 ± 316	1152 ± 454 ²	865 ± 344
Fruit intake (g/d)	143.2 ± 147.0 ²	178.0 ± 163.7	143.7 ± 151.7	162.9 ± 154.7
Vegetable intake (g/d)	61.2 ± 42.9 ²	54.6 ± 34.8	69.6 ± 53.0 ²	59.2 ± 45.7

¹ All values are $\bar{x} \pm$ SD. BMD, bone mineral density.² Significantly different from girls of the same age, $P < 0.05$ (independent t test).³ Highest possible activity score = 100.

potential physical and lifestyle confounders, including height, weight, pubertal status, social class, alcohol drinking, smoking habits, physical activity, and supplement use. The models were further adjusted for nutrients found in fruit and vegetables or thought to play a role in bone health. These were vitamin C, fiber, potassium, magnesium, carotene, calcium, and vitamin D. Finally, interactions between age and sex and fruit and vegetable intake were investigated.

RESULTS

Of the 2017 participants, BMD was recorded in 1345 subjects. There were no significant differences in physical, dietary, or lifestyle characteristics between the subjects with BMD data and those without.

Subject characteristics, BMD measurements, and selected nutritional information for the sample by age and sex group are presented in **Table 1**. Boys aged 12 y had greater forearm BMD, had greater heel BMD, were more physically active, and reported consuming more vegetables and calcium than did their female counterparts. Girls aged 12 y were taller, were heavier, and reported consuming more fruit than did boys aged 12 y. Boys aged 15 y were taller, were heavier, were more physically active, reported consuming more vegetables and calcium, and had greater heel BMD than did their female counterparts. Girls aged 15 y had greater forearm BMD than did boys aged 15 y. Of the 12-y-olds, 6% of the boys and 3% of the girls reported that they smoked, and of the 15-y-olds, 22% of the boys and 27% of the girls reported smoking.

Of the sample with BMD measurements, 14.9% of the boys and 17.0% of the girls used dietary supplements. Boys and girls reporting using supplements had significantly lower heel BMD, and girls using supplements had significantly lower forearm BMD, than did subjects not using supplements. Boys and girls who used supplements were more physically active, weighed less, were not as pubertally advanced, came from a higher social class, were less likely to smoke, and reported consuming more fruit than did their non-supplement-using counterparts. Owing to these differences, an adjustment for supplement use was included in the multiple regression analyses.

Presented in **Table 2** are the adjusted and unadjusted associations observed between the low, medium, and high categories of

fruit intake and heel BMD in 12-y-old boys, 12-y-old girls, 15-y-old boys, and 15-y-old girls. In unadjusted analyses, 12-y-old girls with a high fruit intake had significantly higher heel BMD than did subjects with a moderate fruit intake, and 15-y-old girls with a high fruit intake had significantly higher heel BMD than did subjects with a low fruit intake.

Also presented in **Table 2** are the associations between the low, moderate, and high categories of fruit intake and BMD, adjusted for the influence of physical and environmental factors, including weight, height, pubertal status, social class, physical activity, alcohol intake, smoking, and supplement use. The significant positive association between high fruit intake and heel BMD in the 12-y-old girls strengthened, and the significant positive association between high fruit intake and heel BMD in the 15-y-old girls was removed.

Also shown in **Table 2** is the effect of further adjustment for selected nutrients, including potassium, magnesium, calcium, fiber, vitamin C, vitamin D, and carotene. After this adjustment, the association between high fruit intake and heel BMD in the 12-y-old girls strengthened further.

With the use of regression analysis, no associations were observed between fruit intake and forearm BMD or between vegetable intake and either forearm or heel BMD (data not shown). The significance of the age-sex interaction ($P = 0.094$) was sufficiently small to justify analyzing the age-sex groups separately.

DISCUSSION

The present study differs from previous reports (5, 6, 13) that investigated the relation between fruit and vegetable intake and bone health in that it examined BMD in a large, representative sample of healthy adolescents. Another strength of the present study lies in its use of a relatively robust, validated method (7) for the collection of data concerning habitual food and beverage intakes in an adolescent population. In addition, the current study collected extensive information on other factors known to affect bone health, such as body weight, physical activity, smoking, and drinking habits, thus enabling the association between BMD and fruit and vegetable consumption to be adjusted for the potential confounding effects of these variables. The assessment of pubertal status may have limited the study, because it was not



TABLE 2

Regression analysis for the relation between fruit intake tertiles (low, moderate, and high) and heel bone mineral density (BMD)¹

	Heel BMD							
	12-y-old Boys (n = 324)		12-y-old Girls (n = 378)		15-y-old Boys (n = 274)		15-y-old Girls (n = 369)	
	β	SE	β	SE	β	SE	β	SE
Unadjusted								
D1	-0.004	0.010	0.024 ²	0.009	-0.005	0.013	0.012	0.010
D2	-0.004	0.011	0.012	0.010	-0.005	0.013	0.023 ²	0.010
Adjusted for physical and lifestyle characteristics ³								
D1	-0.005	0.009	0.028 ²	0.009	-0.002	0.013	0.000	0.010
D2	-0.019	0.010	0.007	0.010	-0.004	0.013	0.006	0.010
Further adjusted for specific nutrients ⁴								
D1	-0.007	0.010	0.037 ²	0.010	-0.002	0.014	-0.002	0.011
D2	-0.021	0.012	0.017	0.012	-0.006	0.014	-0.002	0.012

¹ β is the estimated unstandardized regression coefficient. For boys, low fruit intake was defined as <65.57 g/d and high fruit intake as >151.43 g/d. For girls, low fruit intake was defined as <83.38 g/d and high fruit intake as >196.71 g/d. D1 compares the high fruit intake group with the moderate fruit intake group. D2 compares the high fruit intake group with the low fruit intake group. $P = 0.094$ for the interaction between age and sex; $P = 0.819$ for the interaction between age, sex, and D1; and $P = 0.190$ for the interaction between age, sex, and D2.

² $P < 0.05$.

³ Adjustment for physical and lifestyle characteristics: height, weight, pubertal stage, physical activity, social class, alcohol intake, smoking, and supplement use.

⁴ Further adjustment for potassium, magnesium, calcium, vitamin D, vitamin C, fiber, and carotene.

possible to fully implement Tanner staging, owing to the personal nature of the method and the unwillingness of the subjects to be examined fully in the required manner. Instead, pubertal status was assessed by a qualified pediatrician using visual signs of secondary sexual characteristics, which may have weakened our ability to discriminate between the various pubertal stages. A further limitation may have been the underestimation of fruit and vegetable intake, because fruit and vegetables included in some composite dishes were not accounted for, possibly attenuating the strength of any observed associations.

Evidence for an effect of fruit and vegetables on BMD from previous studies remains inconclusive. Reports in adults that examined the relation showed significant associations between fruit and vegetable intake and BMD (4, 5, 14), and a recent study in 8- and 13-y-old girls ($n = 56$) showed a significant association between bone size and high intakes of fruit and vegetables (6). To the best of our knowledge, however, the current study is the first to show a positive association between fruit intake and BMD in girls after adjustment for potential physical and environmental confounding variables in a large, randomly selected sample. This lends support to the findings of other investigators which suggested that childhood consumption of fruit may be important to bone health (6, 14). It is likely that we observed a positive association between high fruit intake and heel BMD only in the 12-y-old girls because they reported consuming the highest quantities of fruit.


The association between higher consumption of fruit and greater BMD is thought to be caused by the base excesses of these foods buffering the acid produced by dietary protein of animal origin, which is rich in the sulfur-containing amino acids methionine and cystine, which metabolically generate sulfuric acid. It has been postulated that this acid load is, in part, buffered by bone mineral, leading to bone dissolution and reduced bone density (15). Conversely, fruit and vegetables rich in potassium citrate metabolically generate base, thus buffering the acid produced by animal foodstuffs and conserving bone mineral (16).

After adjustment for the potential influence of nutrients found in abundance in fruit and vegetables or associated with bone status—such as potassium, magnesium, calcium, vitamin C, vitamin D, fiber, and carotene—the positive association between fruit intake and heel BMD in the 12-y-old girls remained. It is possible that the observed association between fruit and BMD may be related to mechanisms other than the alkaline-forming properties of nutrients found in fruit. Although we were unable to account for all nutritional compounds associated with bone, such as vitamin K and sodium, we did include potassium, which has received much attention relating to its role as a buffer for endogenous acid production (15). A recent study on ovariectomized rodents suggests that it may be unidentified pharmacologic compounds in plant-based foods that inhibit bone resorption rather than the base excess of these compounds (17). Moreover, other compounds occurring in plant-derived foods, such as phytoestrogens (coumestrol, zearalenol, isoflavones, and humulone), have been identified as being potentially important for bone health (18). It is possible that our observation of the association between fruit intake and heel BMD in the 12-y-old girls is an indication of an overall healthier lifestyle, although we attempted to adjust for this by including social class in the regression analysis.

We observed the positive influence of fruit intake on BMD at the heel and not the wrist. This may be because the heel is composed mainly of trabecular bone, whereas the forearm is composed mainly of cortical bone. Trabecular bone is more metabolically active than cortical bone (19) and may be more susceptible to nutritional influences.

We were unable to show a relation between vegetable intake and BMD, although a positive relation between vegetable consumption and BMD was reported elsewhere (20). The lack of association in the present study may be due to the relatively small quantities of vegetables consumed. Our finding is not surprising, because on average, UK children eat less than one-half of the suggested target intakes for fruit and vegetables, particularly vegetables (21), and only 21% of Irish adults manage to meet the

400-g/d recommendation for fruit and vegetable intake (22). Furthermore, vegetables are more likely to be consumed through composite dishes and may have been underestimated, although every effort was made to account for them independently and code them separately.

In conclusion, we found a positive association between high fruit consumption and heel BMD in 12-y-old girls after adjustment for potential confounders. Girls and older women are already at increased risk of osteoporosis; recommending that they increase their consumption of fruit may be a cost-effective means of improving bone health. However, to clarify the relation and make evidence-based public health recommendations, further observational and intervention studies are needed. Such studies must include biochemical measurements of nutritional status, BMD measurements at different anatomical sites, and some attempt at quantifying the acid-base load of the diet. Only then will it be possible to confirm the apparent beneficial effect of fruit on bone observed in this study. 

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CMcG, PJR, and LJM were primarily responsible for study conceptualization, data collection and handling, interpretation of the resultant data, and preparation of the manuscript. GWC advised on statistical analysis, assisted with interpretation of the data, and assisted with manuscript preparation. DCW participated in the design and conduct of the work and assisted with manuscript preparation. MMR and MJS participated in the study conceptualization and design and assisted with interpretation of the bone mineral measurements. CAB was the principal investigator, and as such, played a role in all areas associated with the preparation of this manuscript. None of the authors had any conflicts of interest.

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