# Bone mineral density and dietary patterns in older adults: the Framingham Osteoporosis Study[1–3]

*Katherine L Tucker, Honglei Chen, Marian T Hannan, L Adrienne Cupples, Peter WF Wilson, David Felson, and Douglas P Kiel*

**ABSTRACT**

**Background:** Several nutrients are known to affect bone mineral density (BMD). However, these nutrients occur together in foods and dietary patterns, and the overall effects of dietary choices are not well understood.

**Objective:** We evaluated associations between dietary patterns and BMD in older adults.

**Design:** Of the original Framingham Heart Study subjects, 907 aged 69–93 y completed food-frequency questionnaires as part of an osteoporosis study. We defined dietary patterns by cluster analysis. BMD was measured at the proximal right femur (femoral neck, trochanter, Ward's area) with a dual-photon absorptiometer and at the 33% radial shaft with a single-photon absorptiometer. We regressed BMD measures onto the cluster variable, adjusting for potential confounders.

**Results:** Six dietary patterns were identified, with relatively greater proportions of intake from meat, dairy, and bread; meat and sweet baked products; sweet baked products; alcohol; candy; and fruit, vegetables, and cereal. After adjustment for multiple comparisons, men in the last group had significantly ($P = 0.05$) greater BMD than did 2–4 other groups at the hip sites and the candy group at the radius. Men in the candy group had significantly ($P < 0.05$) lower BMD than did those in the fruit, vegetables, and cereal group for 3 of the 4 sites. Women in the candy group had significantly ($P < 0.01$) lower BMD than did all but one other group at the radius.

**Conclusions:** Dietary pattern is associated with BMD. High fruit and vegetable intake appears to be protective in men. High candy consumption was associated with low BMD in both men and women. *Am J Clin Nutr* 2002;76:245–52.

**KEY WORDS** Bone mineral density, dietary patterns, fruit and vegetables, older adults, Framingham Osteoporosis Study

## INTRODUCTION

With estimated lifetime risks of fracture >40% for women and 13% for men, osteoporosis is well recognized as a major public health problem (1). Although a great deal of attention has been given to the importance of calcium and vitamin D intake, much less is known about the effects of other nutrients on bone, although recent reports have supported the importance of potassium, magnesium, vitamin K, and fruit and vegetables (2, 3). Effects have also been hypothesized for protein, saturated fat, phosphorus, vitamin C, sodium, and several trace minerals, including manganese, zinc, copper, and silicon (4–7). Bone is a complex living tissue, and it is probable that a wide spectrum of micronutrients contributes to its maintenance. Because of that complexity, examining nutrients individually may sometimes be misleading. Nutrients tend to be packaged together in foods, and therefore associations seen with a single nutrient may, in fact, be caused by a more complex constellation of other nutrients consumed contemporaneously. Conversely, adjusting for other nutrient contributors to bone mineral density (BMD) may make it difficult to see a true association because of their close association with one another in a healthy diet. If a variety of individual nutrients are in fact important, then overall dietary patterns that maximize those nutrients should also be associated with BMD. This approach allows us to consider overall dietary recommendations for improving BMD. The aim of this study was, therefore, to relate existing overall dietary patterns within the elderly cohort of the Framingham Osteoporosis Study population to BMD.

## SUBJECTS AND METHODS

The Framingham Heart Study is a longitudinal cohort study that began in 1948 to examine risk factors for heart disease. The original subjects ($n = 5209$, aged 28–62 y) were selected as a population-based random sample of households in Framingham, MA (8). The Framingham Osteoporosis Study began at the 20th

---

[1] From the Jean Mayer US Department of Agriculture Human Nutrition Research Center on Aging, Tufts University, Boston (KLT and HC); the Hebrew Rehabilitation Center for Aged and the Harvard Medical School Division on Aging, Boston (MTH and DPK); the Boston University School of Public Health (AC and PWFW) and Arthritis Center (DF); and the Framingham (MA) Heart Study, National Heart, Lung, and Blood Institute, Framingham, MA (PWFW).

[2] Supported in part by USDA Agricultural Research Service contract 53-3K06-01, NIH grants R01 AR/AG 41398 and AR20613, and NIH/NHLBI contract N01-38038.

[3] Address reprint requests to KL Tucker, Jean Mayer USDA Human Nutrition Research Center on Aging, Tufts University, 711 Washington Street, Boston, MA 02111. E-mail: tucker@hnrc.tufts.edu.

Received February 9, 2001.

Accepted for publication July 18, 2001.

biennial examination, in 1988–1989, when BMD measurements were made on 1164 surviving subjects. Usable dietary questionnaires were completed by 907 of these subjects, 345 men and 562 women. The surviving, now elderly, cohort subjects follow the same age- and sex-specific population proportions found in the general Framingham population (9). The Boston University Institutional Review Board approved our study, and written, informed consent was obtained for all study subjects.

BMDs of the proximal right femur (femoral neck, trochanter, and Ward's area) were measured in g/cm$^2$ with a Lunar dual-photon absorptiometer (DP3; Lunar Radiation Corp, Madison WI). Bone density at the 33% radial shaft was measured in g/cm$^2$ with a Lunar SP2 single-photon absorptiometer. The right side was scanned at each exam unless there was a history of previous fracture or hip joint replacement. For these individuals, the left side was scanned. CVs in younger subjects without osteoporosis measured twice with repositioning for the DP3 were 2.6% (femoral neck), 2.8% (trochanter), 4.1% (Wards area), and 2% (radial shaft).

### Dietary intake

Usual dietary intake was assessed at the 20th examination with the use of a semiquantitative, 126-item food-frequency questionnaire (10, 11). Questionnaires were mailed to the subjects before the examination, and they were asked to complete them, on the basis of their intake over the previous year, and to bring them to the exam. This food-frequency questionnaire has been validated for many nutrients and in several populations against multiple dietary records and blood measures (10–13). Questionnaire totals showing energy intakes $<2.51$ or $>16.74$ MJ (600 or 4000 kcal)/d or with $>12$ food items left blank were considered invalid (8%) and excluded from further analysis.

### Measurement of confounders

In addition to diet, factors reported to affect BMD include body weight or height and body mass index [BMI; in wt (kg)/ht$^2$ (m)], physical activity (14), smoking (15), estrogen use by women (16), and use of calcium or vitamin D supplements or both (17, 18). BMI was calculated from measurements of height at exam 1 (1948–1949), taken without shoes, in inches, and measurements of weight taken at the 20th examination in pounds (converted to kilograms) with a standardized balance-beam scale. Because BMI is a measure of relative weight, designed to be independent of height, we included both BMI and height in our equations to capture the total effect of total body mass on BMD (19). We repeated these equations with weight replacing BMI and found that the resulting BMD and dietary associations were almost identical. Therefore, only the calculations that used BMI and height are presented here.

Smoking status was assessed via questionnaire at the 20th examination as current cigarette smoker (smoked regularly in the past year), former smoker, or never smoked. Physical activity was measured with the Framingham physical activity index, which asked about number of hours spent in heavy, moderate, light, or sedentary activity and number of hours spent sleeping during a typical day. Each component of these 24-h summaries was then multiplied by an appropriate weighting factor, on the basis of estimated level of associated energy expenditure, and summed to arrive at a physical activity score (20).

For estrogen use, women were divided into 2 groups: those currently using who had been using continuously for ≥1 y and those who had never used, had used previously, or had used short term, because there is evidence that past use does not sustain bone benefits (21). Alcohol and dietary calcium, vitamin D, magnesium, potassium, and vitamin C intakes were assessed from the food list section of the food-frequency questionnaire. Intake of calcium or vitamin D supplements, as recorded on the supplement section of the food-frequency questionnaire, were coded as yes-no variables.

Previous research showed that there are seasonal changes in BMD in New England (18, 22). We therefore created a categorical variable for time of BMD measurement: July, August, and September were coded as summer; October, November, and December as fall; January, February, and March as winter; and April, May, and June as spring.

### Statistical analysis

All statistical analyses were performed using SAS PC+ release 7 (SAS Institute, Inc, Cary, NC). First, we created food group variables. Data from the food-frequency questionnaire were collapsed into 34 food groups, based on food and nutrient composition similarity. The percentage total daily energy intake contribution from each food group was calculated and used in subsequent analyses. This standardization by energy contribution helps to remove dietary variation due to differences in sex, age, body size, and physical activity and to retain the proportionally based food-intake patterns.

We generated dietary patterns with the FASTCLUS procedure. This procedure applies the K-means method to classify subjects into a predetermined number of mutually exclusive groups by comparing Euclidean distances between each subject and each cluster center in an interactive process. Cluster analysis is sensitive to outliers. We therefore removed individuals with energy contributions from food groups that were ≥5 SDs away from the mean energy contribution for that group ($n = 127$). We also ran the FASTCLUS procedure with a predefined number of 20 clusters and removed individuals who fell into clusters with $<5$ subjects ($n = 14$). With the remaining subjects, we ran several analyses, specifying the number of clusters from 3 to 10. The final cluster set was selected by comparing between-cluster variance and within-cluster variance ratios and by examining Scree plots to assess the separation of groups within the study population. Finally, we examined the content of the clusters for nutritionally meaningful separation. The 6-cluster set was selected on the basis of these determinations. All outlier subjects previously identified were then assigned to a cluster by calculating Euclidean distances between individual subjects and the presaved center of each cluster (23).

Descriptive comparisons across dietary pattern were assessed by regressing continuous descriptive and nutrient variables onto the cluster variable in the general linear models procedure. Comparisons across categorical variables were evaluated by using the chi-square test. We regressed each of our 4 measures of BMD onto the categorical dietary pattern variable separately for men and women, adjusting for potential confounders, in the general linear models procedure. Potential confounders included age, BMI, height, physical activity index, smoking status, total energy intake, use of a calcium supplement, use of a vitamin D supplement, season of bone measurement, and for women, current estrogen use. Resulting least-squares means for each BMD measure were compared across all pairwise combinations of dietary pattern groups with the use of the Tukey-Kramer option to adjust for multiple comparisons, in the general linear models procedure.

**TABLE 1**
Characteristics of the Framingham cohort at the time of the bone mineral density measurement[1]

| | Men | Women |
|---|---|---|
| Age (y) | 75.1 ± 4.9[2] | 75.3 ± 4.8 |
| BMI (kg/m$^2$) | 27.1 ± 4.0[3] | 26.3 ± 5.0 |
| Physical activity score | 33.9 ± 6.4 | 33.2 ± 5.0 |
| Smoking status (%) | | |
| Past smoker | 56.8[4] | 40.6 |
| Current smoker | 9.3[4] | 11.7 |
| Calcium supplement user (%) | 8.7[5] | 23.0 |
| Vitamin D supplement user (%) | 22.6[4] | 29.7 |
| Current estrogen user (%) | — | 5.0 |
| Season of measurement (%) | | |
| Winter | 28.8 | 30.0 |
| Spring | 28.2 | 28.5 |
| Summer | 23.3 | 19.0 |
| Fall | 19.7 | 22.4 |
| Energy intake (MJ) | 7.79 ± 2.6[5] | 6.91 ± 2.3 |
| Potassium intake (mg) | 2988 ± 1011 | 2930 ± 995 |
| Magnesium intake (mg) | 299.7 ± 110.2 | 287.7 ± 105.8 |
| Calcium intake (mg) | 739.8 ± 378.2 | 709.2 ± 333.0 |
| Vitamin D intake (IU) | 232.9 ± 164.8 | 212.5 ± 139.9 |
| Bone mineral density (g/cm$^2$) | | |
| Femoral neck | 0.878 ± 0.146[5] | 0.720 ± 0.115 |
| Trochanter | 0.847 ± 0.151[5] | 0.625 ± 0.127 |
| Ward's area | 0.686 ± 0.173[5] | 0.559 ± 0.126 |
| Radius | 0.719 ± 0.085[5] | 0.512 ± 0.092 |

[1] Sample sizes varied from 322 to 345 for men and from 532 to 562 for women.

[2] $\bar{x}$ ± SD.

[3–5] Significantly different from women, [3] $P < 0.01$, [4] $P < 0.05$, [5] $P < 0.0001$.

## RESULTS

Means (±SDs) for BMD measures and for continuous potential confounders used in these analyses are presented in **Table 1**. Proportional distributions are presented for categorical variables. The average age for both men and women in this group was 75 y. Average BMIs were 27.1 for men and 26.3 for women ($P < 0.01$). Proportionally more women than men were current smokers (11.7% compared with 9.3%), although more men were past smokers ($P < 0.05$). Only 9% of men used calcium supplements, compared with 23% of women ($P < 0.0001$). More (23% and 30%, respectively) used vitamin D supplements ($P < 0.05$ between men and women). Only 5% of this sample of women was using estrogen. For both men and women, mean dietary intakes of calcium, magnesium, and vitamin D were lower those currently recommended for this age group (24).

In **Table 2**, the dietary pattern groups are described by showing the percentage energy contribution from each of the food groups that made meaningful contributions to both total intake and dietary pattern differences. Food groups making significantly different energy intake contributions across patterns are identified by superscripts. Food groups that were included in forming the clusters but are not shown because they did not differ measurably across groups include added fats, potatoes, nuts, pizza, pasta, rice, snacks, legumes, eggs, soups, coffee and tea, sweet potatoes, other grains, condiments, and diet drinks. Because these groups were designed to differ maximally, we compared these means descriptively but did not test them for significance of the differences.

Relative to most other groups, members of group 1 (meat, dairy, and bread, $n = 313$) derived more of their total energy

**TABLE 2**
Average percentage of total energy intake from individual food groups across dietary pattern groups[1]

| | Meat, dairy, and bread group ($n = 313$) | Meat and sweet baked products group ($n = 260$) | Sweet baked products group ($n = 69$) | Alcohol group ($n = 81$) | Candy group ($n = 75$) | Fruit, vegetables, and cereal group ($n = 109$) |
|---|---|---|---|---|---|---|
| | | | | % | | |
| Citrus fruit and juice | 4.8 ± 3.4[2] | 4.1 ± 3.3 | 3.2 ± 2.4 | 3.1 ± 2.8[2] | 3.1 ± 2.3[2] | 4.8 ± 3.7[2] |
| Other fruit and juice | 6.5 ± 3.6 | 6.9 ± 3.5 | 4.8 ± 3.4[2] | 5.0 ± 3.5 | 5.4 ± 4.1 | 19.9 ± 6.8[2] |
| Dark-green vegetables | 1.2 ± 1.0 | 1.0 ± 0.7 | 0.9 ± 0.7[2] | 0.9 ± 0.8[2] | 0.9 ± 0.7[2] | 1.5 ± 1.2[2] |
| Other vegetables | 3.1 ± 1.7 | 2.6 ± 1.5 | 2.4 ± 1.5[2] | 2.5 ± 1.1 | 2.4 ± 1.5[2] | 3.5 ± 2.2[2] |
| Low-fat milk | 5.4 ± 6.2[2] | 2.3 ± 3.3 | 2.2 ± 3.7 | 2.6 ± 3.4 | 1.9 ± 2.8[2] | 4.4 ± 5.0 |
| Whole milk | 1.2 ± 3.4[2] | 1.8 ± 3.7 | 1.4 ± 3.6 | 1.9 ± 5.8 | 1.6 ± 3.5 | 2.1 ± 4.7[2] |
| Other dairy | 6.2 ± 5.3[2] | 6.3 ± 4.8 | 4.3 ± 2.8[2] | 5.1 ± 3.9 | 5.9 ± 4.6 | 4.8 ± 4.6 |
| Bread | 11.0 ± 7.7[2] | 8.0 ± 4.4 | 7.2 ± 5.5 | 8.7 ± 5.9 | 8.0 ± 4.8 | 7.4 ± 5.7 |
| Breakfast cereal | 5.4 ± 4.8 | 3.7 ± 3.5 | 2.5 ± 2.8[2] | 4.0 ± 5.3 | 3.6 ± 3.7 | 6.6 ± 5.3[2] |
| Sweet baked products | 4.8 ± 3.2[2] | 14.0 ± 3.8[2] | 28.7 ± 7.3[2] | 5.6 ± 4.3 | 8.7 ± 4.9 | 5.9 ± 4.8 |
| Red meat | 8.8 ± 6.2[2] | 8.6 ± 5.2[2] | 6.9 ± 4.5 | 7.6 ± 5.2 | 5.9 ± 3.9 | 4.4 ± 3.4[2] |
| Processed meat | 1.7 ± 2.3 | 2.2 ± 2.6[2] | 1.8 ± 1.8 | 1.9 ± 2.1 | 1.4 ± 1.5 | 1.1 ± 1.5[2] |
| Chicken | 4.4 ± 3.4[2] | 3.3 ± 2.7 | 2.6 ± 2.2[2] | 2.9 ± 2.1 | 3.4 ± 3.2 | 4.0 ± 3.3 |
| Fish | 3.2 ± 3.3[2] | 2.6 ± 2.1 | 2.0 ± 2.0[2] | 2.6 ± 1.9 | 2.0 ± 1.8[2] | 2.7 ± 2.4 |
| Liquor | 1.1 ± 2.0 | 0.9 ± 1.9[2] | 1.6 ± 4.0 | 15.1 ± 5.2[2] | 1.0 ± 2.5 | 0.9 ± 2.7[2] |
| Beer | 0.9 ± 3.2 | 1.2 ± 4.2 | 0.5 ± 2.1[2] | 1.8 ± 4.9[2] | 0.9 ± 3.6 | 0.5 ± 2.0[2] |
| Wine | 1.0 ± 2.6 | 1.0 ± 2.7 | 0.2 ± 0.7[2] | 1.6 ± 3.9[2] | 0.6 ± 2.1 | 0.7 ± 1.9 |
| Candy | 2.7 ± 2.4 | 3.6 ± 2.7 | 5.1 ± 4.1 | 2.5 ± 2.3[2] | 20.0 ± 9.3[2] | 2.5 ± 3.1[2] |
| Soft drinks | 2.0 ± 4.3 | 3.7 ± 5.9[2] | 2.2 ± 3.7 | 3.4 ± 6.4 | 2.2 ± 3.8 | 1.0 ± 2.8[2] |

[1] $\bar{x}$ ± SD. Total energy contributions sum to < 100% because some food groups are not presented in the table. Remaining food groups that were included in forming the clusters but are not shown because they did not differ measurably across groups include added fats, potatoes, nuts, pizza, pasta, rice, snacks, legumes, eggs, soups, coffee and tea, sweet potatoes, other grains, condiments, and diet drinks.

[2] Significantly different than most other groups, on the basis of comparisons in general linear models, $P < 0.05$.

**TABLE 3**
Characteristics of participants across dietary pattern groups[1]

| | Meat, dairy, and bread group ($n = 313$) | Meat and sweet baked products group ($n = 260$) | Sweet baked products group ($n = 69$) | Alcohol group ($n = 81$) | Candy group ($n = 75$) | Fruit, vegetables, and cereal group ($n = 109$) | $P$ |
|---|---|---|---|---|---|---|---|
| Age (y) | 74.8 ± 4.7 | 75.7 ± 4.9 | 75.5 ± 5.2 | 73.6 ± 4.1 | 75.1 ± 4.8 | 76.2 ± 5.2 | 0.003 |
| Men (%) | 33.23 | 41.15 | 43.48 | 53.09 | 37.3 | 30.28 | 0.008 |
| BMI (kg/m$^2$) | 26.7 ± 4.7 | 26.8 ± 4.8 | 26.7 ± 5.4 | 25.7 ± 3.4 | 26.3 ± 4.5 | 26.7 ± 4.4 | 0.50 |
| Physical activity score | 33.3 ± 5.0 | 33.9 ± 6.3 | 33.8 ± 6.1 | 34.0 ± 5.6 | 33.4 ± 5.3 | 32.4 ± 5.3 | 0.27 |
| Smoking status (%) | | | | | | | |
| Past smoker | 50.5 | 45.0 | 39.1 | 55.6 | 45.3 | 39.4 | 0.0001 |
| Current smoker | 7.4 | 10.0 | 14.5 | 28.4 | 14.7 | 4.6 | |
| Vitamin D supplement user (%) | 31.3 | 23.1 | 21.7 | 27.2 | 24.0 | 29.4 | 0.25 |
| Calcium supplement user (%) | 21.1 | 16.2 | 14.5 | 12.4 | 13.33 | 19.3 | 0.29 |

[1] $\bar{x}$ ± SD.

intake from meat, poultry, and fish (18.1% compared with 12.2–16.7% in other groups), milk and dairy products (12.8% compared with 7.9–11.3%), and bread (11% compared with 7.2–8.7%), and less from sweet baked products. Group 2 (meat and baked products, $n = 260$) also had high meat intake (16.7% of total energy intake), including the highest intake of processed meats, and had a moderately high intake of sweet baked products (14%). Group 3 (sweet baked products, $n = 69$) had a high intake of sweet baked products, including cakes, pies, doughnuts, and cookies (28.7% compared with 4.8–14%), and a low intake of fruit, vegetables, bread, and cereal. Group 4 (alcohol, $n = 81$) had a high intake of alcohol (18.5% compared with 2.1–3.1%). Group 5 (candy, $n = 75$) had a high candy intake (20% compared with 2.5–5.1%). Group 6 (fruit, vegetables, and cereal, $n = 109$) had the highest intake of fruit and vegetables (29.7% compared with 11.3–15.6%) and of breakfast cereal (6.6% compared with 2.5–5.4%) and the lowest intake of red and processed meats and of candy and soft drinks.

Some of the descriptive variables by food group are shown in **Table 3**. BMI, physical activity score, and use of either calcium or vitamin D supplements did not significantly differ across dietary pattern groups. Age did differ significantly ($P < 0.01$) across groups and ranged from an average of 73.6 y in the alcohol group to 76.2 y in the fruit, vegetables, and cereal group. Although men composed 38% of the total group, they made up a larger proportion of the alcohol group (53%) and a smaller proportion of the fruit, vegetables, and cereal group (30%). The alcohol group also contained the most current and former smokers (28.4% and 55.6%, respectively). The fewest smokers were in the fruit, vegetables, and cereal group (4.69% and 39.4% current and former smokers, respectively).

These dietary patterns, defined by food intake, also differed significantly in nutrient intake (**Table 4**). The candy group had the highest energy intake; the fruit, vegetables, and cereal and the meat, dairy, and bread groups had the lowest. The highest protein intakes were in the meat, dairy, and bread group. The lowest protein intakes were in the candy and the sweet baked products groups. After adjustment for total energy intake, the fruit, vegetables, and cereal and the meat, dairy, and bread groups had the highest micronutrient intakes, and the candy and the sweet baked products groups tended to have the lowest.

Results of the comparisons of BMD across dietary pattern groups are presented in **Figures 1–4**. Overall interpattern differences were significant for men at the femoral neck ($P = 0.001$) and Ward's area ($P = 0.002$) and approached significance at the trochanter and radius ($P < 0.06$). For women, the overall comparison across groups was significant only at the radius ($P = 0.004$).

For men, at all sites, the dietary pattern group with the greatest average BMD was the fruit, vegetables, and cereal group. For all 3 of the hip sites, and after adjustment for potential confounders and for multiple comparisons, this group's BMD was significantly greater than 2 or more of the other groups ($P = 0.05$). BMD at the

**TABLE 4**
Energy-adjusted nutrient intakes across dietary pattern groups[1]

| | Meat, dairy, and bread group ($n = 313$) | Meat and sweet baked products group ($n = 260$) | Sweet baked products group ($n = 69$) | Alcohol group ($n = 81$) | Candy group ($n = 75$) | Fruit, vegetables, and cereal group ($n = 109$) | $P$ |
|---|---|---|---|---|---|---|---|
| Energy (MJ) | 6.8 ± 2.3 | 7.3 ± 2.3 | 8.1 ± 2.7 | 7.4 ± 2.6 | 8.4 ± 3.0[2] | 6.8 ± 2.4[2] | 0.0001 |
| Protein (g) | 76.6 ± 0.7[2] | 67.1 ± 0.8 | 57.6 ± 1.6[2] | 61.0 ± 1.4 | 58.0 ± 1.5[2] | 64.2 ± 1.2 | 0.0001 |
| Calcium (mg) | 933 ± 20[2] | 731 ± 21 | 633 ± 42[2] | 696 ± 38 | 705 ± 40 | 873 ± 33 | 0.0001 |
| Vitamin D (IU) | 384 ± 14[2] | 296 ± 16 | 246 ± 31[2] | 297 ± 28 | 261 ± 30[2] | 375 ± 24[2] | 0.0001 |
| Phosphorous (mg) | 1237 ± 13[2] | 1041 ± 14 | 898 ± 27[2] | 966 ± 25 | 942 ± 26 | 1139 ± 21 | 0.0001 |
| Magnesium (mg) | 319 ± 3.7 | 276 ± 4.1 | 229 ± 8.0[2] | 268 ± 7.3 | 250 ± 7.7[2] | 341 ± 6.3[2] | 0.0001 |
| Potassium (mg) | 3210 ± 31 | 2807 ± 34 | 2381 ± 67[2] | 2598 ± 61 | 2494 ± 64 | 3493 ± 53[2] | 0.0001 |
| Vitamin C (mg) | 275 ± 15 | 226 ± 16 | 182 ± 32 | 247 ± 29 | 168 ± 31[2] | 305 ± 25[2] | 0.0011 |
| Vitamin K (μg) | 165 ± 6.0 | 156 ± 6.5 | 115 ± 13[2] | 138 ± 12 | 122 ± 12 | 198 ± 10[2] | 0.0001 |

[1] For total energy intake, $\bar{x}$ ± SD; for nutrient intakes, $\bar{x}$ ± SE, adjusted for total energy intake.

[2] Significantly different than most other groups, on the basis of comparisons in general linear models, $P < 0.05$.

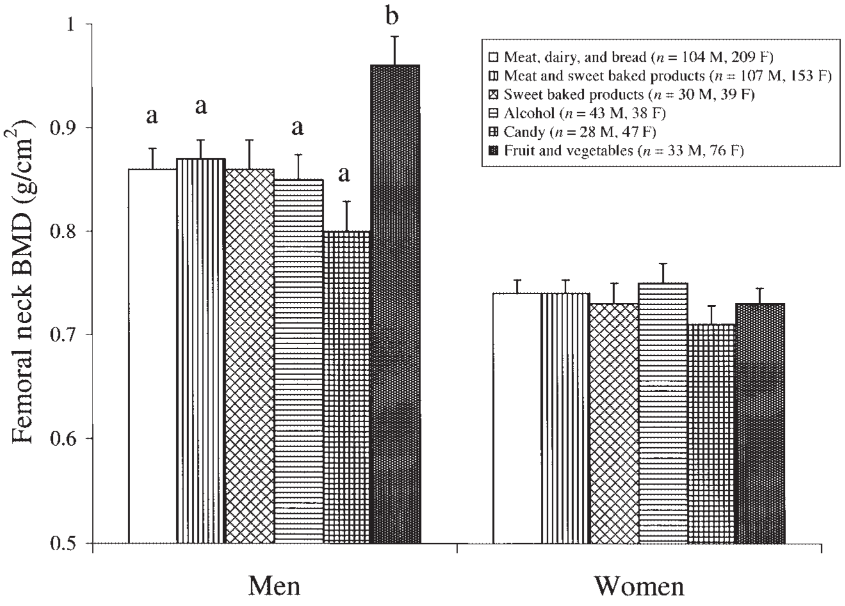

**FIGURE 1.** Adjusted mean (±SE) bone mineral density (BMD) at the femoral neck by dietary pattern. Overall significance of pattern, after adjustment for BMI, height, age, energy intake, physical activity score, smoking, vitamin D supplement use, calcium supplement use, and season: $P = 0.001$ in men and $P = 0.3$ in women (with additional adjustment for estrogen use). Bars with different letters are significantly different, $P < 0.05$; the Tukey-Kramer option was used to correct for multiple comparisons in general linear models.

radius was significantly greater in the fruit, vegetables, and cereal group than in the candy group. The mean BMD in the candy group was significantly lower than in the fruit, vegetables, and cereal group for the Ward's area and femoral neck sites ($P < 0.001$), with differences of 16.5% and 23.8%, respectively.

For women, the candy group also had the lowest average BMD at most sites and was significantly lower than all but one other group (the sweet baked products group) at the radius. The advantage of the fruit, vegetables, and cereal group was not as clear in the women as in the men, but their BMD tended to be higher than in several other groups. BMD in the candy group was significantly lower, by 11.5%, than in the fruit, vegetables, and cereal group at the radius. In contrast with the men, women in the alcohol group tended to have higher BMD than did other dietary groups among the women; it was significantly greater than the candy group, by 14.7%.

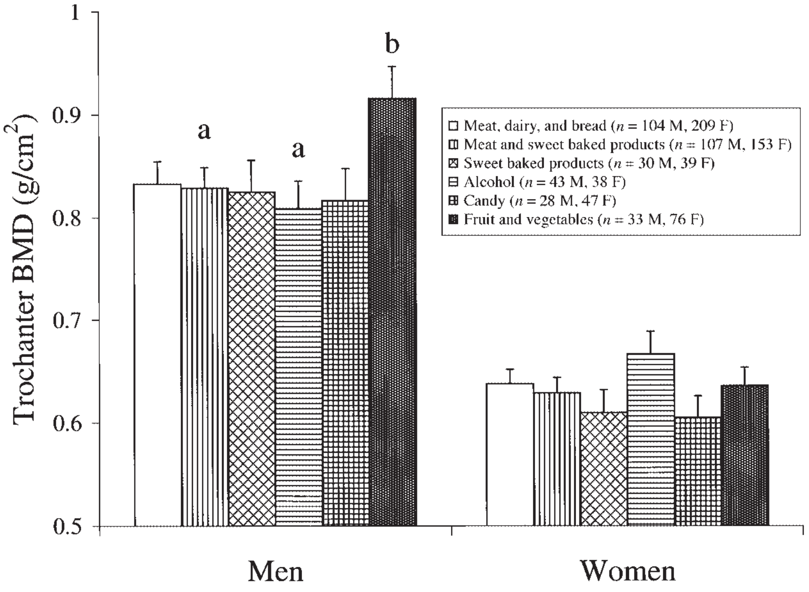

**FIGURE 2.** Adjusted mean (±SE) bone mineral density (BMD) at the trochanter by dietary pattern. Overall significance of pattern, after adjustment for BMI, height, age, energy intake, physical activity score, smoking, vitamin D supplement use, calcium supplement use, and season: $P = 0.06$ in men and $P = 0.4$ in women (with additional adjustment for estrogen use). Bars with different letters are significantly different, $P = 0.05$; the Tukey-Kramer option was used to correct for multiple comparisons in general linear models.

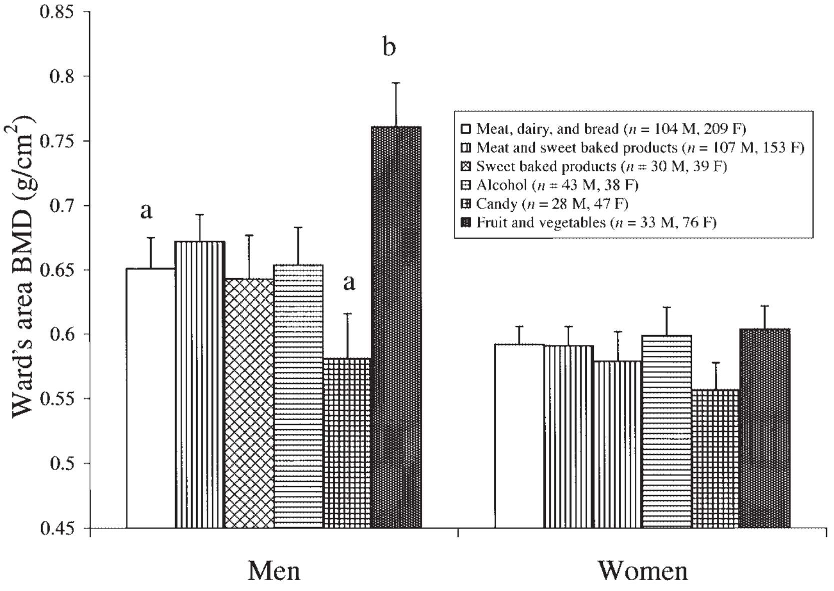

**FIGURE 3.** Adjusted mean (±SE) bone mineral density (BMD) at Ward's area by dietary pattern. Overall significance of pattern, after adjustment for BMI, height, age, energy intake, physical activity score, smoking, vitamin D supplement use, calcium supplement use, and season: $P = 0.002$ in men and $P = 0.2$ in women (with additional adjustment for estrogen use). Bars with different letters are significantly different, $P < 0.05$; the Tukey-Kramer option was used to correct for multiple comparisons in general linear models.

## DISCUSSION

We identified 6 distinct dietary patterns in this population of Framingham elderly adults and found that these dietary patterns were associated with BMD. Men with a diet high in fruit, vegetables, and cereal had significantly greater BMD than did men with other dietary patterns. In contrast, those consuming the most candy had significantly lower BMD than did most other groups. Results were not as clear among women, but the candy group consistently had the lowest BMD. Although women in the fruit, vegetables, and cereal group tended to have higher BMD than did other groups, the alcohol group also had high BMD, comparable to the fruit, vegetables, and cereal group at most sites. This apparent protective effect of alcohol was not seen in men. The meat, dairy, and bread and the meat and sweet baked products groups tended to have intermediate BMD.

We previously found that greater fruit and vegetable intake, along with magnesium and potassium intake, was associated with greater BMD in this population (2), and the results of the present study are consistent with that finding. New et al (25, 26) found similar associations with fruit and vegetables in a population of premenopausal women. Not surprisingly, compared with other dietary pattern groups, our fruit, vegetables, and cereal group had the highest intakes of magnesium, potassium, vitamin C, and vitamin K—nutrients recently receiving more attention in relation to bone status. Intakes of the nutrients most associated with bone—calcium and vitamin D—were greatest in the meat, dairy, and bread group but were also high in the fruit, vegetables, and cereal group.

Protein has been associated with calcium loss (27), and high protein intake has been hypothesized to contribute to BMD loss. However, results of epidemiologic studies have been conflicting. We previously showed that total protein and animal protein intakes were protective against bone loss in this population (28), and others also showed better bone status with higher protein intake (29, 30). In contrast, a recent study reported greater bone loss at the femoral neck and more hip fracture with higher animal-vegetable protein ratios (31). Heaney (4) argues that the actual effect of protein intake on bone is complicated and dependent on other components in the diet. He suggests, for example, that the calciuric effect of protein may be offset by increased intestinal calcium absorption, unless calcium intakes are quite low. Other nutrients in the diet are also likely to affect the association between protein intake and calcium loss. This is one reason that the use of dietary pattern analysis is particularly useful. In the present analysis, those with the highest protein intake were in the meat, dairy, and bread and the meat and sweet baked products groups, both with average BMDs that were higher than those of the candy group (significantly in women) but lower than those of the fruit, vegetables, and cereal group. These groups also had higher intakes of calcium, vitamin D, phosphorous, magnesium, potassium, and vitamin C than did the alcohol, candy, or sweet baked products groups. Consistent with these overall nutrient profiles, the candy group, followed by the sweet baked products group, had the lowest BMD, suggesting that the displacement of nutrient-dense foods in the diet may explain why high intake of these foods is detrimental to bone status.

Although alcoholism is known to have negative effects on bone (32), a positive association between alcohol intake and BMD in women was previously reported in this population (33) and others (34–36). This positive association has been hypothesized to be caused by the effects of alcohol on adrenal androgens or estrogen concentrations (37). The alcohol group in the present study consumed, on average, ≈18.5% (17% for women and 20% for men) of their energy intake from alcohol [≈1.17 MJ (≈2 drinks)/d for women and 1.56 MJ (3 drinks)/d for men, based on reported energy intakes], and they had moderate intakes of several micronutrients. At this level, alcohol intake appeared to be protective in women at the radius, where the BMD of the alcohol group was significantly greater than that of the candy group. We may have seen this association among women and not

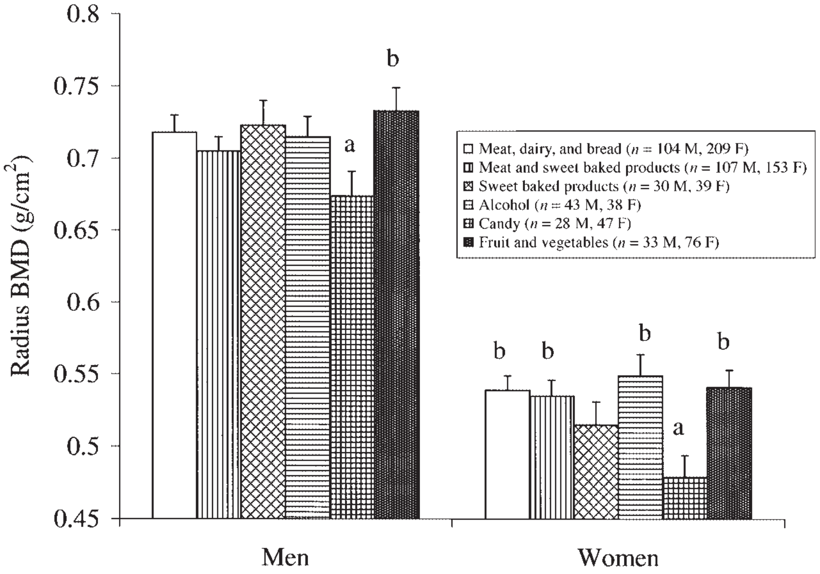

**FIGURE 4.** Adjusted mean (±SE) bone mineral density (BMD) at the radius by dietary pattern. Overall significance of pattern, after adjustment for BMI, height, age, energy intake, physical activity score, smoking, vitamin D supplement use, calcium supplement use, and season: $P = 0.06$ in men and $P = 0.004$ in women (with additional adjustment for estrogen use). Bars with different letters are significantly different, $P < 0.05$; the Tukey-Kramer option was used to correct for multiple comparisons in general linear models.

men because of the importance of the estrogen boost from alcohol in these postmenopausal women or because of the lower levels of absolute alcohol consumption among women in the alcohol cluster than among men in that cluster. Although alcohol is apparently protective of BMD in these women, further investigation of its effect on bone status and fracture risk is needed. A recent study showed that women who consumed alcohol (yes or no) had significantly fewer fractures than nondrinkers (38). However, another study showed that >14 drinks/wk was associated with greater fracture risk (39).

In addition to cluster analysis, common methods of defining dietary patterns include principal component analysis and the creation of scores relative to dietary recommendations. In these various forms, dietary patterns were associated with different nutrient profiles, socioeconomic factors, and health outcomes (40–45). As with all of these methods, cluster analysis is data dependent, and different dietary patterns will be found in population groups with differing dietary intakes. Despite this, investigations in US and European populations have generated similar dietary pattern groups that usually include, among others, groups with high intakes of bread or sweets, of alcohol, of fruit and vegetables, and of meat (41, 42, 46, 47). The examination of total dietary patterns facilitates a different, more holistic assessment of the evidence and thereby complements the more common analysis of individual foods and nutrients. The results of such analyses can both confirm the findings about individual nutrients and foods and tell us if our overall constellation of food choices is associated with health outcomes.

These results suggest that a good-quality diet with high intakes of fruit, vegetables, and breakfast cereal—and limited in less nutrient-dense foods—may contribute to better accumulated BMD in old age, particularly in men. In women, alcohol may also be protective. Both men and women consuming nutrient-poor diets, particularly those with a high intake of candy, had significantly poorer BMD. The use of dietary patterns is helpful in clarifying associations of actual dietary choices on bone and in placing observed individual food and nutrient associations into context.

## REFERENCES

1. Kanis J and the WHO Study Group. Assessment of fracture risk and its applications to screening for postmenopausal osteoporosis of a WHO report. Osteoporos Int 1994;4:368–81.
2. Tucker KL, Hannan MT, Chen H, Cupples LA, Wilson PWF, Kiel DP. Potassium, magnesium, and fruit and vegetable intakes are associated with greater bone mineral density in elderly men and women. Am J Clin Nutr 1999;69:727–36.
3. Booth SL, Tucker KL, Chen H, et al. Dietary vitamin K intakes are associated with hip fracture but not with bone mineral density in elderly men and women. Am J Clin Nutr 2000;71:1201–8.
4. Heaney RP. Nutritional factors in osteoporosis. Annu Rev Nutr 1993;13:287–316.
5. Wohl GR, Loehrke L, Watkins BA, Zernicke RF. Effects of high-fat diet on mature bone mineral content, structure, and mechanical properties. Calcif Tissue Int 1998;63:74–9.
6. Robins SP, New SA. Markers of bone turnover in relation to bone health. Proc Nutr Soc 1997;56:903–14.
7. Eisinger J, Clairet D. Effects of silicon, fluoride, etidronate and magnesium on bone mineral density: a retrospective study. Magnes Res 1993;6:247–49.
8. Dawber T, Meadors G, Moore FJ. Epidemiological approaches to heart disease: the Framingham Study. Am J Public Health 1951;41: 279–286.
9. Hannan M, Felson D, Anderson J. Bone mineral density in elderly men and women: results from the Framingham osteoporosis study. J Bone Miner Res 1992;7:542–53.
10. Rimm EB, Giovanncci EL, Stampfer MJ, Colditz GA, Litin LB, Willett WC. Reproducibility and validity of an expanded self-administered semiquantitative food frequency questionnaire among male health professionals. Am J Epidemiol 1992;135:1114–26.
11. Willett W, Stampfer MJ. Total energy intake: implications for epidemiologic analyses. Am J Epidemiol 1986;124:17–27.

12. Ascherio A, Stampfer M, Coldtiz G, Rim E, Litin L, Willett W. Correlation of vitamin A and E intake with plasma concentrations of carotenoids and tocopherols among American men and women. J Nutr 1992;122:1792–801.
13. Jacques PF, Sulsky SI, Sadowski JA, Philips JC, Rush D, Willett WC. Comparison of micronutrient intake measured by a dietary questionnaire and biochemical indicators of micronutrient status. Am J Clin Nutr 1993;57:182–9.
14. Greendale GA, Barrett-Connor E, Edelstein S, Ingles S, Haile R. Lifetime leisure exercise and osteoporosis: the Rancho Bernardo Study. Am J Epidemiol 1995;141:951–9.
15. Kiel DP, Zhang Y, Hannan MT, Anderson JJ, Baron JA, Felson DT. The effect of smoking at different life stages on bone mineral density in elderly men and women. Osteoporos Int 1996;6:240–8.
16. Felson DT, Zhang Y, Hannan MT, Anderson JJ. Effects of weight and body mass index on bone mineral density in men and women: the Framingham Study. J Bone Miner Res 1993;8:567–73.
17. Dawson-Hughes B. Calcium supplementation and bone loss: a review of clinical trials. Am J Clin Nutr 1991;54(suppl):274S–80S.
18. Dawson-Hughes B, Dallal GE, Krall E, Harris S, Sokoll LJ, Falconer G. Effect of vitamin D supplementation on wintertime and overall bone loss in healthy postmenopausal women. Ann Intern Med 1991;115:505–12.
19. Michels KB, Greenland S, Rosner BA. Does body mass index adequately capture the relation of body composition and body size to health outcomes? Am J Epidemiol 1998;147:167–72.
20. Kannel W, Sorlie P. Some health benefit of physical activity: the Framingham Study. Arch Intern Med 1979;139:857–61.
21. Cauley JA, Seeley DG, Ensrud K, Ettinger B, Black D, Cummings SR. Estrogen replacement therapy and fractures in older women. Study of Osteoporotic Fractures Research Group. Ann Intern Med 1995;122:9–16.
22. Krall EA, Sahyoun N, Tannenbaum S, Dallal GE, Dawson-Hughes B. Effect of vitamin D intake on seasonal variations in parathyroid hormone secretion in postmenopausal women. N Engl J Med 1989;321:1777–83.
23. Hartigan J. Clustering algorithms. New York: John Wiley and Sons, 1975.
24. Food and Nutrition Board. Dietary reference intakes for calcium, phosphorus, magnesium, vitamin D, and fluoride. Washington, DC: National Academy Press, 1999.
25. New SA, Bolton-Smith C, Grubb DA, Reid DM. Nutritional influences on bone mineral density: a cross-sectional study in premenopausal women. Am J Clin Nutr 1997;65:1831–9.
26. New SA, Robins SP, Campbell MK, et al. Dietary influences on bone mass and bone metabolism: further evidence of a positive link between fruit and vegetable consumption and bone health? Am J Clin Nutr 2000;71:142–51.
27. Heaney RP, Recker RR. Effects of nitrogen, phosphorus, and caffeine on calcium balance in women. J Lab Clin Med 1982;99:46–55.
28. Hannan MT, Tucker KL, Dawson-Hughes B, Cupples LA, Felson DT, Kiel DP. Effect of dietary protein on bone loss in elderly men and women: the Framingham Osteoporosis Study. J Bone Miner Res 2000;15:2504–12.
29. Freudenheim JL, Johnson NE, Smith EL. Relationships between usual nutrient intake and bone-mineral content of women 35–65 years of age: longitudinal and cross-sectional analysis. Am J Clin Nutr 1986;44:863–76.
30. Munger RG, Cerhan JR, Chiu BC-H. Prospective study of dietary protein intake and risk of hip fracture in postmenopausal women. Am J Clin Nutr 1999;69:147–52.
31. Sellmeyer DE, Stone KL, Sebastian A, Cummings SR. A high ratio of dietary animal to vegetable protein increases the rate of bone loss and the risk of fracture in postmenopausal women. Am J Clin Nutr 2001;73:118–22.
32. Scharpira D. Alcohol abuse and osteoporosis. Semin Arthritis Rheum 1990;19:371–6.
33. Felson DT, Zhang Y, Hannan MT, Kiel DP. Alcohol intake and bone mineral density in elderly men and women. Am J Epidemiol 1995;142:485–92.
34. Hansen MA, Overgaard K, Riis BJ, Christiansen C. Potential risk factors for development of postmenopausal osteoporosis—examined over a 12-year period. Osteoporos Int 1991;1:95–102.
35. Holbrook TL, Barrett-Connor E. A prospective study of alcohol consumption and bone mineral density. BMJ 1993;306:1506–9.
36. Laitinen K, Valimaki M, Keto P. Bone mineral density measured by dual-energy X-ray absorptiometry in healthy Finnish women. Calcif Tissue Int 1991;48:224–31.
37. Wild RA, Buchanan JR, Myers C, Demers LM. Declining adrenal androgens: an association with bone loss in aging women. Proc Soc Exp Biol Med 1987;186:355–60.
38. Baron JA, Farahmand BY, Weiderpass E, et al. Cigarette smoking, alcohol consumption, and risk of hip fracture in women. Arch Intern Med 2001;161:983–8.
39. Hoidrup S, Gronbaek M, Gottschau A, Lauritzen JB, Schroll M. Alcohol intake, beverage preference, and risk of hip fracture in men and women. Copenhagen Centre for Prospective Population Studies. Am J Epidemiol 1999;149:993–1001.
40. Randall E, Marchall J, Graham S, Brasure J. High-risk health behaviors associated with various dietary patterns. Nutr Cancer 1991;16:135–51.
41. Tucker KL, Dallal GE, Rush D. Dietary patterns of elderly Boston-area residents defined by cluster analysis. J Am Diet Assoc 1992;92:1487–91.
42. Wirfalt AK, Jeffery RW. Using cluster analysis to examine dietary patterns: nutrient intakes, gender, and weight status differ across food pattern clusters. J Am Diet Assoc 1997;97:272–9.
43. Slattery ML, Boucher KM, Caan BJ, Potter JD, Ma KN. Eating patterns and risk of colon cancer. Am J Epidemiol 1998;148:4–16.
44. Hu FB, Rimm E, A.Smith-Warner S, et al. Reproducibility and validity of dietary patterns assessed with a food frequency questionnaire. Am J Clin Nutr 1999;69:243–9.
45. Kant AK, Schatzkin A, Graubard BI, Schairer C. A prospective study of diet quality and mortality in women. JAMA 2000;283:2109–15.
46. Huijbregts PP, Feskens EJ, Kromhout D. Dietary patterns and cardiovascular risk factors in elderly men: the Zutphen Elderly Study. Int J Epidemiol 1995;24:313–20.
47. SENECA Investigators. Food patterns of elderly Europeans. Eur J Clin Nutr 1996;50:S86–100.