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Protein Consumption and Bone Fractures in Women

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Dietary protein increases urinary calcium losses and has been associated with higher rates of hip fracture in cross-cultural studies. However, the relation between protein and risk of osteoporotic bone fractures among individuals has not been examined in detail. In this prospective study, usual dietary intake was measured in 1980 in a cohort of 85,900 women, aged 35–59 years, who were participants in the Nurses' Health Study. A mailed food frequency questionnaire was used and incident hip (n = 234) and distal forearm (n = 1,628) fractures were identified by self-report during the following 12 years. Information on other factors related to osteoporosis, including obesity, use of postmenopausal estrogen, smoking, and physical activity, was collected on biennial questionnaires. Dietary measures were updated in 1984 and 1986. Protein was associated with an increased risk of forearm fracture (relative risk (RR) = 1.22, 95% confidence interval (CI) 1.04–1.43, p for trend = 0.01) for women who consumed more than 95 g per day compared with those who consumed less than 68 g per day. A similar increase in risk was observed for animal protein, but no association was found for consumption of vegetable protein. Women who consumed five or more servings of red meat per week also had a significantly increased risk of forearm fracture (RR = 1.23, 95% CI 1.01–1.50) compared with women who ate red meat less than once per week. Recall of teenage diet did not reveal any increased risk of forearm fracture for women with higher consumption of animal protein or red meat during this earlier period of life. No association was observed between adult protein intake and the incidence of hip fractures, though power to assess this association was low. *Am J Epidemiol* 1996;143:472–9.

bone and bones; diet; femur; hip fractures; osteoporosis; proteins; questionnaires; radius fractures; women; wrist

The extent to which adult diet may retard or accelerate bone loss and influence fracture risk in later life is unclear. Most attention has focused on increased calcium intake, which has been shown to attenuate bone loss at several sites, particularly in older women and when added to low-calcium diets (1, 2). However, a similar relation with hip fractures has not generally been demonstrated, and evidence has suggested both a null (3–8) and a protective effect (9–11) from higher calcium intakes.

In two cross-cultural comparisons (12, 13), the incidence of hip fractures was found to be directly related to both per capita calcium and protein consumption, which suggests that calcium intake may be a marker for protein that may be causally related to bone fracture. This may be particularly true in western countries with high rates of osteoporosis, where diets generally appear adequate in calcium but are simultaneously high in protein content.

It is thought that dietary protein affects bone loss by increasing endogenous acid production which in turn elicits a mobilization of calcium from the skeletal reservoir to form salts and to neutralize the acidity (14, 15). Many studies have documented an increase in urinary calcium with higher protein intake (16, 17). Heaney (18) has estimated that a doubling of dietary protein can increase urinary calcium by about 50 percent, and ingestion of sodium and potassium bicarbonate has been shown to reduce these losses (19, 20). Dietary animal protein may increase endogenous acid production and urinary calcium loss to a greater extent than protein from vegetable sources (21, 22), perhaps due to the higher content of sulfur-containing amino acids in animal proteins or the greater alkaline ash found in the vegetarian diet. The naturally high phosphorus content of typical protein-rich foods lowers urinary calcium and has been thought to ameliorate the effects of the protein (23). However, phosphorus also decreases production of 1,25-dihydroxy-vitamin D

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Abbreviations: CI, confidence interval; RR, relative risk.

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(24) and increases fecal calcium loss through digestive secretions (25), which may offset its sparing effect on urinary calcium.

To our knowledge, no prior research has focused on the relation between dietary protein and the incidence of adult bone fractures. The present study examines this question by measuring dietary intake in a large cohort of middle-aged women and recording all incident hip and forearm fractures during 12 years of follow-up. Fracture risk by level of dietary protein is assessed in relation to calcium intake and other major factors known to affect the development of osteoporosis.

MATERIALS AND METHODS

This research is part of the Nurses' Health Study, which was begun in 1976 with 121,700 female nurses aged between 30 and 55 years from 11 US states (26). Based on a subsample, it is estimated that 98 percent of the cohort is white. The initial mailed questionnaire requested information on height, weight, medical history, and known and suspected risk factors for cancer and coronary heart disease (27, 28). Follow-up questionnaires have been mailed every 2 years to update health and life-style variables and to collect information on other diseases and risk factors of interest to women's health. A question on hip and forearm fractures was added in 1982 and was continued on subsequent biennial questionnaires. A semiquantitative food frequency questionnaire was included in the 1980, 1984, and 1986 mailings.

Hip and forearm fractures

In 1982, participants provided a date of occurrence, description of circumstances, and exact fracture site for all previous hip and forearm fractures, and incident fractures after 1982 were similarly reported on later questionnaires. Only fractures of the proximal femur were included in the definition of a hip fracture, and forearm fractures included only those of the distal radius. The ability of the nurses to accurately report their hip and forearm fractures was demonstrated in a small validation study in which 30 reported cases were all confirmed by medical records (29). Accurate self-report of fractures has also been observed by other researchers in a population of elderly white women (30).

To focus the analysis on fractures in which low bone mass was a likely contributor, the participant's description of the circumstances was used to code the fracture into one of 21 predefined categories, and fractures due to high trauma activities were excluded as endpoints in the analysis. Over 80 percent of the fractures coded into the low and moderate trauma categories were caused by slipping or tripping, falling on ice, snow, or a waxed or wet surface, or falling from a standing position. The majority of high trauma fractures involved falls down stairs or motor vehicle accidents. Of all reported hip and forearm fractures, 23 percent involved high trauma and were therefore not included as fracture cases.

Diet assessment

For each item on the semiquantitative food frequency questionnaire, participants checked one of nine frequency-of-consumption categories, ranging from "never or less than once per month" to "six or more per day." Participants were asked to estimate their frequency of consumption over the past year in terms of the portion size specified for each food on the questionnaire. Average daily nutrient intakes were calculated by multiplying the frequency of consumption of each food item by its nutrient content and summing over all foods. The 1980 baseline questionnaire contained 61 food items, including 6 dairy foods and 10 meat, fish, or egg items. Improvements to the original instrument resulted in a longer food list on the 1984 and 1986 versions, with four additional items in both the dairy and meat categories.

The validity of the food and nutrient measurements from the food frequency questionnaire has been evaluated in several studies (31–35). In a comparison of the original questionnaire with four 1-week diet records among 173 cohort members, correlations were 0.47 for protein intake (31) and 0.44 for meat consumption (32).

The 1986 mailing included a second, very brief list of foods for which participants were asked to estimate their frequency of consumption during their teenage years (ages 13–18 years). The following animal foods were included: skim or low-fat milk, whole milk, milk shake, ice cream, hard cheese, eggs, hot dogs, beef/pork/lamb, and fish (including tuna fish). In a reproducibility study among 249 of the women, we found a correlation of 0.37 between the 1986 measure of teenage protein intake and a second assessment 8 years later.

Assessment of non-dietary variables

Height and weight were ascertained on the initial questionnaire in 1976 and current weight was collected every 2 years to update the calculated body mass index (kg/m^2) used as a measure of obesity. Questions on current smoking habits, menopausal status, and use of postmenopausal hormones were also asked on each of the biennial questionnaires. Physical activity was assessed in 1980 when participants were asked to estimate the number of hours per week that they usually spend doing vigorous activities (e.g., jogging, digging in the garden, or heavy housework). Questions of the current use of thyroid hormone medication and thiazide diuretics were included on the 1980, 1982, and 1988 questionnaires.

Baseline population

For a prospective analysis of diet and fracture, the baseline population began with the 98,462 nurses who returned the initial food frequency questionnaire in 1980. Of these nurses, the 4 percent who failed to respond to 10 or more food items were excluded, as were another 2.7 percent with implausibly high or low food intakes. Women were also eliminated from the baseline population if they reported a diagnosis of cancer (other than non-melanoma skin cancer), coronary heart disease, stroke, or osteoporosis any time before 1980 or if they reported a fracture between 1976 and 1980, because these conditions were likely to cause changes in eating patterns and may invalidate the 1980 food frequency questionnaire as a measure of long-term diet. After all of the exclusions, 85,900 women remained for analysis.

Statistical analysis

Person-time for each participant began with the return date of her 1980 questionnaire and accumulated until the first report of fracture, until the diagnosis of cancer, heart disease, stroke, or osteoporosis, or until death. Study follow-up ended on June 1, 1992. For the non-dietary variables, person-time was allocated to their status at the beginning of each of the 2-year follow-up periods.

For protein and food sources of protein, the population was divided into quintiles or other suitable categories of increasing intake to examine their relation to fracture incidence. Protein and other nutrients were adjusted for total energy using regression analysis (36) to assess diet composition independent of energy intake, which is largely determined by physical activity and body size. In the primary analyses, all incident fractures were related to diet as reported on the 1980 food frequency questionnaire. In a second set of analyses, the 1980 protein intake was averaged with data from the subsequent food frequency questionnaires so that fracture incidence during the 1980–1984 time period was related to the protein intake from the 1980 questionnaire, fracture incidence during the 1984–1986 time period was related to the average protein intake from the 1980 and 1984 questionnaires, and fracture incidence after 1986 was related to the average protein intake from all three questionnaires.

Incidence rates of hip and forearm fractures were calculated by dividing the number of fractures by the person-time of follow-up per category of nutrient or food consumption. Relative risks were then computed as the incidence rate in a specific category divided by the incidence rate in the lowest category. Proportional hazards models were used to adjust simultaneously for age and for the other assessed variables which are potential confounders of the relation between protein and fracture.

RESULTS

During 931,512 person-years of follow-up, 234 hip fractures and 1,628 forearm fractures due to low or moderate trauma were identified.

There was a wide variation in the protein content of the diets of the women in this cohort. In 1980, total protein intakes at the 10th and 90th population percentiles were 50 and 119 g/day; intakes of animal protein at the same percentiles were 37 and 100 g/day. Between 1980 and 1986, the median intake of total protein for the study population changed very little (from 79.6 to 78.3 g/day), while the consumption of animal protein decreased from 64.0 to 56.6 g/day.

Total protein intake was positively associated with dietary calcium (r = 0.55), vitamin D, phosphorus, and potassium, and was negatively associated with alcohol intake (table 1). Women who consumed more protein were less likely to be cigarette smokers and were more likely to use thiazide diuretics. Age, caffeine intake, amount of vigorous activity, body mass index, and the use of postmenopausal hormones and thyroid hormones were unrelated to protein intake in this population.

Total protein, animal protein, and vegetable protein

In analyses adjusted only for age, the relative risk of a forearm fracture was significantly increased (relative risk (RR) = 1.29, 95 percent confidence interval (CI) 1.11–1.50) for women in the highest versus lowest quintile of total protein intake in 1980. A significant decrease in risk was observed in a similar analysis with hip fractures (RR = 0.64, 95 percent CI 0.42–0.97). Because protein is an important determinant of total energy and energy was positively associated with the risk of forearm fracture and negatively associated with the risk of hip fracture in this population, all subsequent analyses used energy-adjusted protein values (36).

TABLE 1. Distribution of covariates within quintiles of total protein consumption* among 85,900 women aged 34–59 years at baseline in 1980, Nurses' Health Study

Covariates	Total protein consumption, range (g/day)				
	<68	68–77	78–85	86–95	>95
Daily intake†, mean (SD‡)					
Total protein (g)	61 (18)	73 (20)	82 (21)	91 (23)	108 (33)
Calcium (mg)	586 (290)	677 (334)	718 (358)	756 (399)	794 (427)
Vitamin D§ (IU)	239 (241)	237 (265)	278 (261)	291 (277)	302 (291)
Phosphorus (mg)	905 (322)	1,041 (355)	1,122 (371)	1,204 (402)	1,345 (462)
Potassium (mg)	2,390 (782)	2,569 (800)	2,683 (815)	2,798 (845)	2,988 (953)
Alcohol (g)	9.0 (15)	7.2 (12)	6.5 (10)	5.8 (9.0)	4.4 (7.2)
Caffeine (mg)	390 (267)	391 (266)	392 (266)	394 (271)	392 (277)
Age (years), mean (SD)	45.7 (7.2)	46.1 (7.1)	46.4 (7.1)	46.8 (7.2)	47.5 (7.1)
Body mass index (kg/m²), mean (SD)	24.0 (4.4)	24.1 (4.3)	24.3 (4.4)	24.5 (4.4)	25.2 (4.6)
Vigorous activity (hours/week), mean (SD)	9.3 (10)	9.0 (10)	9.0 (10)	9.0 (10)	8.9 (10)
% Current users of					
Cigarettes	34.1	29.2	27.5	27.1	25.8
Postmenopausal hormones ‖	16.8	18.2	19.1	19.6	19.1
Thyroid hormones	1.6	1.4	1.5	1.7	1.9
Thiazide diuretics	7.0	7.8	8.6	9.1	11.5

* Adjusted for total energy intake using regression analysis.
† Raw values (not adjusted for total energy intake).
‡ SD, standard deviation.
§ Includes vitamin D from multivitamins.
‖ Percent users among the 37,277 women who were postmenopausal at baseline.

Table 2 shows the results of analyses that used only the baseline 1980 food frequency questionnaire as the dietary measure predicting risk over the 12 years of follow-up. No significant relation was observed between total protein intake and hip fracture, with an age-adjusted relative risk of 0.79 (95 percent CI 0.53–1.19, p for trend = 0.18) for women in the highest compared with the lowest quintile of intake. For forearm fractures, risk was significantly increased for women in the highest quintile of total protein intake and the test for trend over the quintiles of intake was also significant (RR = 1.18, 95 percent CI 1.01–1.38, p for trend = 0.04). Results for both hip and forearm fractures did not change appreciably when adjusted for body mass index, menopausal status, use of postmenopausal hormones, cigarette smoking, use of thyroid hormone medication, use of thiazide diuretics, vigorous activity, and alcohol and caffeine intakes. Multivariate models with calcium, vitamin D, potassium, and phosphorus yielded similar results but were less stable due to colinearity between nutrient intakes (data not presented).

The increased risk of forearm fracture seen with higher total protein consumption was replicated with animal protein (RR = 1.21, 95 percent CI 1.03–1.41, p for trend = 0.01), but no increase in risk was observed with higher intakes of vegetable protein. For hip fractures, the null association with total protein intake persisted in separate analyses with animal and vegetable protein.

We explored the interaction between total protein and dietary calcium in assessing risk of forearm fracture. Women were divided into tertiles of dietary calcium and total protein consumption according to their 1980 intakes, and those in the upper tertile of calcium (≥827 mg/day) and the lower tertile of protein (≤72 g/day) were designated as the reference group. In comparison, women with high protein (≥90 g/day) diets that were also high in calcium had a relative risk of 1.15 (95 percent CI 0.84–1.58) for forearm fracture while a more elevated risk of 1.31 (95 percent CI 0.94–1.82) was observed among women with high protein but low calcium (≤541 mg/day) diets, which suggests that risk of forearm fracture with higher intakes of protein may be exacerbated by a low calcium intake. To further test this hypothesis, we calculated a ratio of dietary calcium to total protein for each woman in the 1980 population. However, we did not observe any reduction in fracture risk when women with a high ratio (≥11) were compared with women with a low ratio (<5.5) (RR = 0.91, 95 percent CI 0.78–1.06).

The relation between total protein intake and fracture incidence was explored in analyses in which the 1980 protein measure was updated twice during the 12 years of follow-up: first in 1984 with an average of the

TABLE 2. Relative risks (RR) with 95% confidence intervals (CI) for hip and forearm fractures by quintiles of protein consumption* measured in a cohort of 85,900 women aged 34–59 years in 1980 and followed for 12 years, Nurses' Health Study

Protein consumption	Hip fractures					Forearm fractures				
	No. of cases	Age-adjusted model		Multivariate† model		No. of cases	Age-adjusted model		Multivariate† model	
		RR	95% CI	RR	95% CI		RR	95% CI	RR	95% CI
Total protein (g/day)										
<68	49	1.00‡		1.00‡		280	1.00‡		1.00‡	
68–77	51	1.00	0.67–1.48	1.05	0.71–1.56	317	1.10	0.94–1.29	1.11	0.94–1.30
78–85	43	0.82	0.55–1.24	0.89	0.59–1.34	329	1.13	0.96–1.32	1.14	0.97–1.33
86–95	46	0.84	0.56–1.26	0.94	0.63–1.42	340	1.14	0.97–1.34	1.16	0.99–1.36
>95	45	0.79	0.53–1.19	0.96	0.64–1.45	362	1.18	1.01–1.38	1.22	1.04–1.43
p trend§		0.18		0.70			0.04		0.01	
Animal protein (g/day)										
<51	50	1.00‡		1.00‡		280	1.00‡		1.00‡	
52–61	51	1.01	0.69–1.50	1.07	0.73–1.59	323	1.15	0.98–1.35	1.15	0.98–1.35
62–69	45	0.88	0.59–1.31	0.95	0.63–1.42	313	1.10	0.93–1.29	1.11	0.94–1.30
70–80	43	0.82	0.54–1.23	0.92	0.61–1.38	352	1.22	1.05–1.43	1.25	1.07–1.46
>80	45	0.81	0.54–1.22	0.98	0.65–1.47	360	1.21	1.03–1.41	1.25	1.07–1.46
p trend§		0.19		0.70			0.01		0.004	
Vegetable protein (g/day)										
<12	44	1.00‡		1.00‡		307	1.00‡		1.00‡	
12–14	44	0.96	0.63–1.45	0.98	0.64–1.49	323	1.02	0.87–1.19	1.01	0.87–1.18
15–16	43	0.91	0.60–1.39	0.92	0.60–1.41	351	1.09	0.94–1.28	1.08	0.93–1.26
17–19	45	0.92	0.61–1.40	0.94	0.62–1.43	336	1.03	0.88–1.20	1.01	0.86–1.18
>19	58	1.13	0.76–1.68	1.11	0.75–1.66	311	0.92	0.79–1.08	0.90	0.77–1.06
p trend§		0.50		0.58			0.28		0.17	

* Adjusted for total energy intake using regression analysis.

† Multivariate models were simultaneously adjusted for questionnaire time period; age (5-year intervals); body mass index and hours of vigorous activity per week (quintiles); menopausal status and use of postmenopausal hormones (premenopausal, postmenopausal-never user, postmenopausal-past user, postmenopausal-current user); cigarette smoking (never, past, current); use of thyroid hormone medication and thiazide diuretics (yes or no); and alcohol and caffeine intakes (quintiles).

‡ Referent group.

§ Trends across quintiles of total, animal, and vegetable protein using the median value in each quintile in logistic regression models.

1980 and 1984 dietary measures and again in 1986 with an average of all three (1980, 1984, and 1986) dietary measures. Results of the multivariate analyses were similar to those based solely on the dietary protein measured in 1980: women in the highest quintile had a relative risk of 0.76 (95 percent CI 0.47–1.23) for hip fracture and a relative risk of 1.17 (95 percent CI 0.99–1.39) for forearm fracture compared with women in the lowest quintile of total protein consumption based on the 1980, 1984, and 1986 dietary measures.

Animal protein foods

In this population of women, the five items from the 1980 food frequency questionnaire that contributed most to variation in animal protein intake were chicken, fish, skim milk, cottage cheese, and beef, pork, or lamb as a main dish. When fracture incidence was computed within categories of frequency of consumption for these foods items, most foods exhibited no discernible trend or significant increase or decrease in risk of fracture. For beef, pork, or lamb consumption, we did observe an increased risk of forearm fracture for women who consumed five or more servings per week compared with women who consumed less than one serving per week (RR = 1.23, 95 percent CI 1.01–1.50), although the same analysis for hip fractures showed no increase in fracture risk (RR = 0.84, 95 percent CI 0.49–1.44).

Teenage diet

We also explored the relation between teenage diet, as recalled by the women in 1986, and the incidence of adult fractures (table 3). Based on the limited number of fish, meat, and dairy foods listed on the questionnaire, there was no indication of increased risk of forearm fracture for women who consumed more than 70 g of protein per day compared with women who

TABLE 3. Relative risks* (RR) with 95% confidence intervals (CI) for hip and forearm fractures by daily intake of animal protein† and by servings of beef, pork, or lamb consumed per week during teenage years reported by women aged 40–65 years‡, Nurses' Health Study

Type of consumption	Person-years (thousands)	Hip fractures			Forearm fractures		
		No. of cases	RR	95% CI	No. of cases	RR	95% CI
Animal protein (g/day)							
≤30	133.9	47	1.00§		261	1.00§	
31–45	180.7	48	0.84	0.56–1.26	323	0.98	0.84–1.16
46–55	143.9	31	0.70	0.45–1.11	261	1.02	0.86–1.21
56–70	160.4	48	1.00	0.67–1.50	293	1.03	0.87–1.22
>70	104.4	19	0.64	0.38–1.10	186	1.03	0.86–1.25
p trend‖			0.28			0.58	
Beef, pork, or lamb (servings/week)							
≤1	126.0	37	1.00§		243	1.00§	
2–4	272.0	72	1.04	0.70–1.56	481	1.02	0.87–1.19
5–6	154.3	34	0.89	0.56–1.42	280	1.05	0.89–1.25
≥7	171.1	50	1.11	0.73–1.71	320	1.05	0.88–1.24
p trend‖			0.86			0.52	

* Models were adjusted for questionnaire time period; age (5-year intervals); body mass index (quintiles); menopausal status and use of postmenopausal hormones (premenopausal, postmenopausal-never user, postmenopausal-past user, postmenopausal-current user); and cigarette smoking (never, past, current).

† Daily intake of animal protein was calculated from reported frequency of consumption of a limited number of food items: skim milk, whole milk, milk shakes, ice cream, cheese, eggs, hot dogs, fish, and beef, pork, or lamb.

‡ Teenage food consumption was reported in 1986. Hip and forearm fractures occurred between 1980 and 1992.

§ Referent group.

‖ Trend across categories of animal protein and beef, pork, or lamb consumption using the median value in each category.

consumed 30 g or less (RR = 1.03, 95 percent CI 0.86–1.25, *p* for trend = 0.58). Teenage beef, pork, or lamb consumption also showed no association with forearm fractures when women who consumed one or more servings per day were compared with women who consumed one serving or less per week. For hip fractures, we observed a nonsignificant reduction in fracture risk for the women in the highest category of teenage animal protein intake (RR = 0.64, 95 percent CI 0.38–1.10, *p* for trend = 0.28), but higher teenage beef consumption did not yield any reduction in risk of hip fracture.

To determine whether lifetime protein consumption may be a stronger predictor of adult fracture than either adult diet or teenage diet alone, women with high intakes of protein (highest 35 percent of the population) during their teenage years and as adults in 1980 were compared with women who had lower intakes (lowest 35 percent) during both periods. As we observed for adult diet alone, an increased risk of forearm fracture was found for women who had a high lifetime protein intake (RR = 1.21, 95 percent CI 1.00–1.45), while no increased risk was observed for hip fracture (RR = 1.09, 95 percent CI 0.66–1.81).

DISCUSSION

There has been little epidemiologic evidence to support the hypothesis that high intake of protein may decrease bone density and increase the incidence of bone fracture. Early support came from a study of elderly North Alaskan Eskimo women (37), in which it was shown that these women had 10–15 percent lower levels of bone mineral content and a higher prevalence of osteoporotic vertebral fractures than non-Eskimo American women, although the Eskimo women consumed a high-calcium, high-protein diet. Also, two cross-cultural studies (12, 13) reported a direct association between per capita protein consumption and rate of hip fracture. However, a comparison of spinal x-rays from women in seven countries found the least evidence of vertebral osteoporosis in Finland and the United Kingdom, countries with high protein and high calcium consumption, while Japan, with a high per capita intake of protein but low calcium, had the highest percentage of x-rays that indicated osteoporosis (38). In addition, a milk-drinking region of Yugoslavia with high protein and high calcium intakes was found to have a lower rate of hip fracture than a non-dairy region with lower dietary protein and calcium, though differences in physical activity could also explain the difference in fracture rate (39). In most comparisons between vegetarian and omnivorous women, differences in bone densities have not been observed in either cortical or trabecular bone (40–42). A comparison of recent diet between adult women with and without a hip fracture found no significant differences in their protein, calcium, or phosphorus intakes (43).

The present study is a 12-year prospective investigation of diet and bone fractures in a large cohort of women. It thus provided more statistical precision and capacity to control for relevant covariates than previous epidemiologic research. The results yielded some evidence for the hypothesis that higher protein consumption contributes to increased incidence of adult bone fractures. Small but significant increases in risk of forearm fracture were observed, but no evidence was found for an increased risk of hip fracture. However, the number of hip fractures in this study was small and it is possible that we were unable to detect the magnitude of association seen for forearm fractures. In addition, the hip fracture cases in this study were younger (median age = 60 years) than typically seen for white women, and it is possible that the causes of their early hip fractures are different than those for women who experience fractures after age 70 years.

The increased risk of forearm fracture with higher total protein consumption was duplicated with animal protein, while no evidence was found to suggest that higher intakes of vegetable protein increase fracture risk, indicating that the animal protein component may be the true risk factor. However, it is possible that consumption levels of vegetable protein were too low, or that there was too little variation, to observe an effect. On the other hand, the level of dietary protein that is required to increase the risk of fracture may only be observed in a carnivorous diet.

It is likely that the recommendation for a reduction in animal protein extends to women who are more elderly than the population in this study, although very low protein diets must be viewed with caution because protein is beneficial for preserving muscle mass (44). Also, lower femoral bone density has been reported in elderly hospital patients with protein insufficiency (45).

If the mechanism of the effects of protein on bone is indeed through the need for buffering by calcium salts, it would seem likely that any detrimental effects on bone would depend on level of calcium intake. Gain in bone mass in young adult women has been positively correlated with a ratio of calcium to protein intakes (46), but no relation was observed with either hip or forearm fracture for the women in this study. We did see some reduction in risk of forearm fracture with high protein intake for women who consumed more calcium, but the reduction was small and a nonsignificant risk remained.

The multivariate analyses of protein and bone fracture in this study controlled for many of the factors that are thought to influence bone density, including age, menopausal status, use of postmenopausal hormones, obesity, physical activity, cigarette smoking, use of thiazide diuretics and thyroid hormone medication, caffeine and alcohol consumption, and dietary intakes of calcium, vitamin D, phosphorus, and potassium. However, other unmeasured factors related to protein intake that also influence fracture through their effects on bone architecture, bone mass, or the propensity to fall may have confounded the observed associations.

Previous evidence suggests that higher protein intakes in young adult women have a negative impact on radial bone measurements (47). However, the positive associations between forearm fracture and the consumption of meat and animal protein that we observed for adult diet were not found for these intakes during teenage years. Imperfect measurement of protein intake and the consumption of animal foods may have obscured the observation of a relation between dietary protein and hip fracture and may have attenuated the true positive association with forearm fracture. Recall of adult dietary intake should not have biased the results of this study, because analyses used dietary measures collected prior to fracture incidence. Data on teenage diet were collected after fracture follow-up was begun, but we have no reason to believe that fracture outcome would influence the recall of teenage diet.

The results of this study support the hypothesis that higher protein consumption increases the risk of osteoporotic forearm fractures. Although no increase in risk was observed for hip fractures, the power to detect a similar increase was limited by the smaller numbers of such fractures in the study.

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