Vegetarian lifestyle and bone mineral density[1-3]

Alice G Marsh, ScD, RD; Tom V Sanchez, BS; Olaf Michelsen, PhD; Fonda L Chaffee, PhD, RD; and Sylvia M Fagal, MS, RD

ABSTRACT The amount and type of dietary protein affect bone mineral loss after the menopause. This observation was substantiated in 10 y of studies by direct photon absorptiometry, four results of which follow. *1*) Studies of 1600 women in southwestern Michigan revealed that those who had followed the lactoovovegetarian diet for at least 20 y had only 18% less bone mineral by age 80 whereas closely paired omnivores had 35% less bone mineral. *2*) A study of self-selected weighed food intake showed no statistical difference in nutrient intakes but a difference in Ca:P ratio and acid-base formation of diet, each significant to $p < 0.001$. *3*) When sulfur intake of a fixed diet was increased, the titratable acidity of the urine increased proportionately. *4*) Bone mineral densities of 304 older women from the continental United States closely paralleled those from earlier Michigan studies. *Am J Clin Nutr* 1988;48: 837–41.

KEY WORDS Osteoporosis, bone mineral density, vegetarians, omnivores, protein, dietary sulfur

Introduction

Today's popular interest in bone mineral density and aging follows substantial scientific study of this subject that suggested that omnivores have less bone mineral than long-term vegetarians. Mazess and Mather (1) paired Eskimos on a high-meat intake with Caucasian omnivores who used much less meat. Younger Eskimo and Caucasian women had a similar bone mass but elderly Eskimos had a significantly lower bone mineral mass than did age-matched Caucasians, but the study did not control for the possible influence of racial and geographical variables.

Marsh et al (2, 3) studied a large number of vegetarians (~1600) in Southwestern Michigan who volunteered for direct photon absorptiometry testing. Reports to date (2, 3) concentrated on Caucasian, nonhospitalized, ambulatory, right-handed women who did not use vitamin or mineral supplements, who had no physical or medical restrictions, and who had followed the lactoovovegetarian (LOV) diet for at least 20 y. These vegetarians were closely paired with omnivorous volunteer subjects in Southern Michigan. All subjects resided in a university community (Andrews University, Berrien Springs; Michigan State University, East Lansing; University of Michigan, Ann Arbor). This study, in harmony with the Mazess and Mather study (1), showed the younger paired LOVs and omnivores had no statistical differences in bone mineral density. However, between the ages of 50 and 87, increasing differences in bone mass appeared so that by the end of four decades, omnivores had 35% less bone mass whereas vegetarians had 18% less bone mass. These differences were statistically significant for the last three decades (**Fig 1**).

A similar study (4) of lactoovovegetarian men 20–79 y of age paired with omnivores showed no statistical difference in bone mineral density at any age. This study supports the concept that the menopause marks a time in life when most women begin dramatically to lose bone mass.

Following is a report of further studies by Marsh et al, some of which were published.

Dietary intake study

The lower bone mineral mass of omnivorous women compared with LOV women posed the question: What are the nutrient differences, if any, in the diets of these two groups? To answer this question a precise, weighed, 7-d, self-selected dietary intake study was performed (AG Marsh, DK Christensen, FL Chaffee, and TV Sanchez, unpublished observations, 1983).

[1] From the Department of Home Economics, Andrews University, Berrien Springs, MI; the Norland Corporation, Fort Atkinson, WI; and the Department of Food Science and Human Nutrition, Michigan State University, East Lansing, MI.

[2] Supported in part by Andrews University research and private grants.

[3] Address reprint requests to AG Marsh, Professor of Home Economics, Emeritus, Andrews University, Berrien Springs, MI 49104.

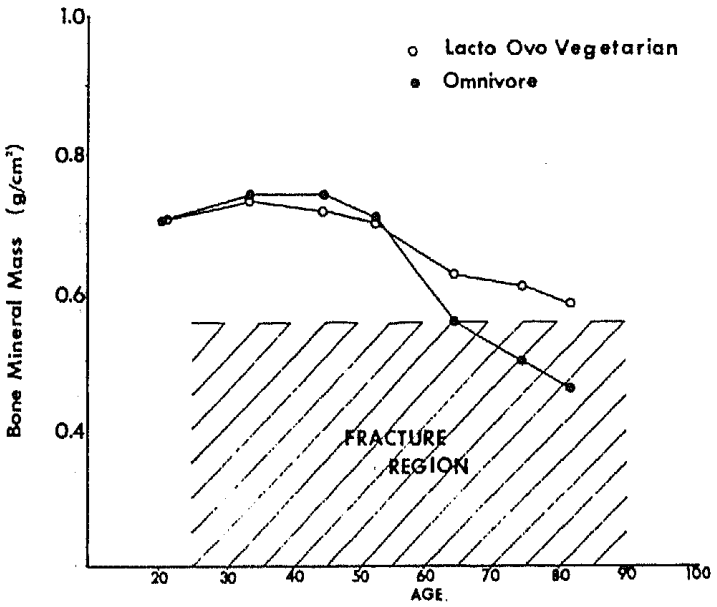

FIG 1. Mean bone mineral density, calculated by decades of carefully matched pairs of lactoovovegetarians (filled symbols) and omnivores (open symbols). Differences in the 60s at $p < 0.01$, in the 70s at $p < 0.05$, and in the 80s at $p < 0.05$. From reference 3.

The subjects consisted of 20 postmenopausal, Caucasian women who were free of medical or activity restrictions and lived within a 24.1 km radius of Andrews University. This was the same geographical area from which the bone mineral data were taken in the study referred to above (2, 3) (Fig 1).

Ten women, all Seventh-day Adventists, were LOV all or most of their lives. The 10 omnivorous women had been lifetime omnivores. The LOV mean age was 66.8 y, ranging from 52 to 87 y; the mean age of the omnivores was 64.4 y, ranging from 53 to 87 y.

Each subject was provided a Hanson dietary gram scale and standard measuring cups. Oral and written instructions in their use were given each subject in her home. Each participated in monitored practice with the equipment until she was comfortable using and reading the scales and recording information in a notebook. Instruction included weighing back food or drink not eaten as well as weighing even an additional bite should that be necessary. Each subject had the office and home phone numbers of two research personnel and was urged to call at any time, day or night, should she need any information or direction. To enable research personnel to provide full attention to the subjects, no more than two were enrolled in the study at any one time.

The dietary intake study was conducted for a full 7 d. St Jeor et al (5) indicated such 7-d dietary records are most effective in reflecting group dietary intakes.

A nutrient analysis was made from the food intake diary of each subject based on the data in the USDA handbook #456, *Nutritive Value of American Foods* (6), and data of certain proprietary vegetarian foods. Acid or base excesses of the diets were calculated from available sources (7, 8) or, where no data were available, were determined by analysis of ashed samples. Statistical analysis of differences between LOV and omnivorous diets was by the *t* test for two means.

Both the LOV and omnivorous subjects met and exceeded the Recommended Dietary Allowances except that the omnivores were slightly low in calcium intake (712 mg). None of the nutrients showed a significant difference between the two groups (Table 1). Two nutrient relationships that could affect bone mineral density upon aging showed significant differences: *1*) calcium to phosphorus ratio ($p < 0.001$) in which the LOV had the higher ratio and *2*) the acid or base excesses of the diets ($p < 0.001$).

Although the mean differences of Ca and P in the two diets are not significant in respect to the two elements, when they shifted in opposite directions the two means reached significance by the *t* test. By treating the two sets of figures individually the ratio becomes important. Furthermore, the ash of the LOV diets had a mean value of 26.1 mmol excess NaOH whereas the omnivorous had a mean value of 9.8 mmol excess HCL. The method used in determining the dietary acid and base excesses, though imprecise, gives acceptable indications of these values for the LOV and omnivorous diets (9).

Other findings of this study, of interest to cardiologists, were the lower intake of cholesterol by the vegetarians ($p < 0.025$) and the higher P:S ratio of their diets ($p < 0.025$).

Sulfur study

Comparing the nutrient intakes of the two diets, LOV and omnivorous, it is evident that the meat-containing

TABLE 1
Customary self-selected diets of 10 lactoovovegetarians and 10 omnivores

	Daily average intake of 7 d	
Diet analysis	Lactoovovegetarian	Omnivore
Energy (kcal)	1612	1641
Protein (g)	56	68
Fat (g)	65	77
Fat kcal (%)	36	42
P:S ratio*	0.75	0.48
Calcium (mg)	898	712
Phosphorus (mg)	1094	1103
Ca:P ratio†	0.81	0.66
Iron (mg)	12.27	13.34
Potassium (mg)	2238	2177
Acid-base excess‡	26 (basic)	10 (acid)
Vitamin A (μg RE)	1914	1776
Thiamin (mg)	1.33	1.22
Riboflavin (mg)	1.68	1.70
Vitamin C (mg)	92	105
Cholesterol (g)*	194	294
Fiber, crude (g)	5.2	4.7

* P:S, ratio of polyunsaturated to saturated fatty acids. Difference between groups significant at $p < 0.025$.

† Difference between groups significant at $p < 0.001$.

‡ Reaction of food expressed as the number of milliliters of 1 mol NaOH/L (basic) or 1 mol HCl/L (acid) to which it is equivalent.

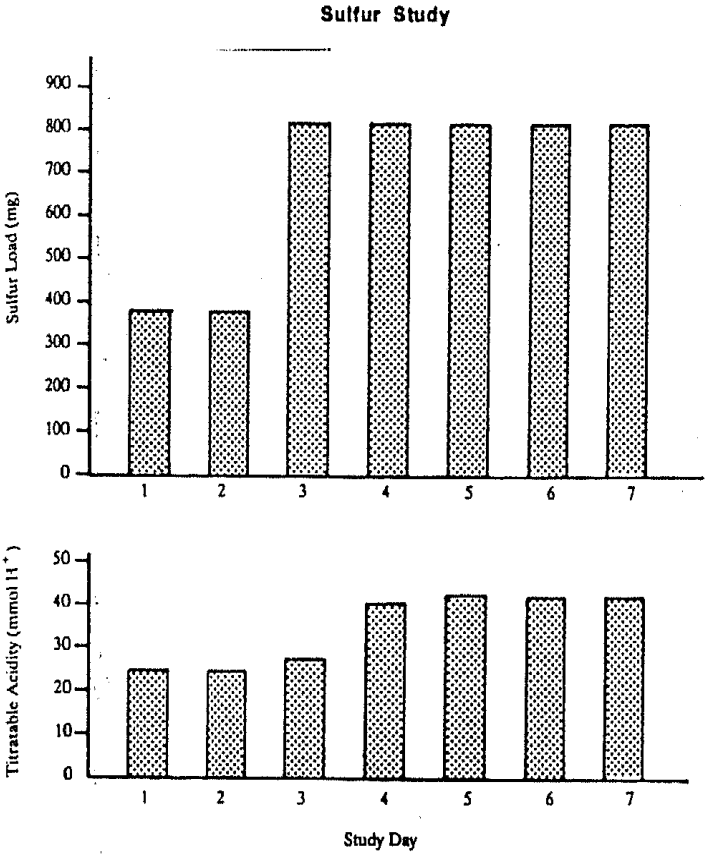

FIG 2. Titratable acidity of urine increased from average base-line levels of 25.0 to 40.4 mmol H^+ the second day of loading (day 4) and remained elevated through the sulfur loading period (through day 7).

diet has a much higher S content. This suggests that dietary S may be a participating factor in bone loss through its effect on the acidity of the urine.

The following study (AG Marsh, TV Sanchez, DK Christensen, and FL Chaffee, unpublished observations, 1984) evaluated the effect of increasing the S load on the titratable acidity of the urine in women who had a 20-y-or-more history of adherence to the LOV diet. Six postmenopausal women followed a fixed LOV diet for 7 d. The energy remained constant while the S intake was increased by food selection from 379 mg for days 1 and 2 to 822 mg for days 3–7. During the study distilled water was used for drinking and food preparation. All women provided a 24-h urine collection each study day. Titratable acidity of the urine was analyzed by the Folin method (10). The titratable acidity increased from base-line levels of 25.0 to 40.4 mmol H^+ the second day of the sulfur loading (day 4) and remained elevated through day 7 (**Fig 2**).

This study supports indirect evidence that meat in the diet results in a shift toward an acidic urine, which produces a negative Ca balance as a result of an increased urinary Ca loss (11–13). Other evidence indicates that meat-containing diets have a significant effect on acid-base balance of the body (14). Hunt (15) suggested that the metabolic oxidation of the S in meat to a sulfate is responsible for an increase in titratable acidity in urine. Relman et al (16) and Lennon et al (17) reported that the high S content of meat diets generates a high endogenous fixed acid load that the body must buffer. Paralleling these results, the present study shows that a S-loaded LOV diet results in an increase in titratable urinary acidity similar to that in an omnivorous diet. In 1968 Wachman and Bernstein (18) proposed that such a shift in acid load would, in time, result in a substantially greater degree of bone loss.

Lincoln, Nebraska study

Marsh et al collected more bone mineral density data on older vegetarians at the fifth annual meeting of Seventh-day Adventist retirees at Lincoln, NE. Four hundred volunteers from various parts of the United States and Canada were tested for bone mineral density by direct photon absorptiometry using the Norland Digital Densitometer Model 2780. Tests were made on the radius as described by Sanchez et al (2) and Marsh et al (3). Demographic data were taken for each subject as well as other information of possible relation to bone strength.

Of the 400 volunteers tested, 304 were women 52–90 y of age. **Table 2** shows the distribution of these women according to race, type of diet, and mean bone mineral density. The types of vegetarian diets that the women followed varied widely. These women were categorized as lifetime lactoovovegetarians, lactoovovegetarians for ≥ 20 y (but not lifetime), lactoovovegetarians for ≤ 19 y, lactovegetarians, ovovegetarians, lactoovovegetarians with fish and chicken, vegetarians who used meat on a regular basis (at least once a week), and total vegetarians.

Although the data from the Seventh-day Adventist retirees involves too few subjects in each group for statistical analysis, the results concur with our previous studies. These findings primarily accomplish two other purposes: *1*) they emphasize the importance of carefully identifying the various types of vegetarian diets and *2*) they provide data on bone mineralization of women from a wide geographic area.

The data from Lincoln, NE can be used only in comparison with the results of the original southwestern Michigan study. **Table 3** compares five groups of Caucasian vegetarian women with the 16 women from southwestern Michigan who were in our original study and who were at the Lincoln meeting. The bone density of the latter group secured in Lincoln was higher than the mean for the other LOV subjects at that meeting. What may be responsible for this difference can only be conjectured at this time: *1*) The Berrien Springs community is a hard-water area and many who soften their household water have a hard-water tap in the kitchen; *2*) since 1976 the community has been exposed to unusual awareness of bone mineralization through the on-going studies.

Because milk is a primary dietary source of Ca, the mean intake of this food reported by the Lincoln subjects is of interest and is shown in Table 2. Only two categories of subjects, lifetime LOVs and the LOVs from the Berrien Springs area, maintained bone mineral from 70 to

TABLE 2
Lincoln, Nebraska subjects

Dietary type	Number	Mean BMD*	Mean milk intake	Calcium supplementation	
				None	≥1 yr
		g/cm²	*mL*	*n (%)*	*n (%)*
Women, Caucasian					
LOV lifetime	78	0.571	450	35 [45]	28 [36]
LOV ≥ 20 y	135	0.583	430	56 [41]	58 [43]
LOV ≤ 19 y	6	0.546	280	3 [50]	3 [50]
LOV with fish and chicken	26	0.600	430	6 [23]	14 [54]
LOV with meat at least once/wk (semi-LOV)	18	0.602	470	4 [22]	8 [44]
Lactovegetarians	8	0.512	380	4 [50]	2 [25]
Ovovegetarians	6	0.595	0	2 [33]	2 [33]
Total vegetarians	11	0.465	0	4 [36]	6 [55]
Women, non-Caucasian					
Black (three types of diet)	11	0.633	310	7 [64]	4 [36]
Oriental (two types of diet)	5	0.541	380	3 [60]	1 [20]

* BMD, bone mineral density.

89 y of age. Those who had the least bone mineral density as they entered their 80s were the total vegetarians who used no milk and the LOVs who used meat regularly.

The number of subjects using Ca supplements reflected the present emphasis on the threat of postmenopausal osteoporosis (Table 2). Of all women subjects at Lincoln, 41% had taken Ca supplements for ≥ 1 y, 18% had taken supplements for < 1 y, and 41% had taken none. Two dietary groups varied from this trend: 45% of the lifetime LOV had taken no calcium supplements nor had 75% of the black women.

Summary

Southwestern Michigan has served as a rich resource for the study of lifetime and near-lifetime lactoovovegetarians and bone density. These subjects by their 80s had 18% less bone mineral whereas the omnivores they were paired with from the same area had 35% less bone mineral compared with subjects in their 50s.

A weighed food intake study of 10 lactoovovegetarians > 55 y of age compared with 10 omnivorous women showed no statistical differences in nutrient intakes. However, significant differences (each $p < 0.001$) were found both in the Ca:P ratio and the acid-forming or base-forming potential of the diet.

A fixed dietary study of lactoovovegetarian women > 50 years of age in which the dietary S load was increased from 379 to 822 mg resulted in an incr titratable urinary acidity from 25.0 to 40.4 mm. Such an increase of urine acidity suggests an inci Ca loss.

TABLE 3
Lincoln, Nebraska subjects

Dietary tpe	Number	50–59			
Women, Caucasian					
LOV lifetime	78	0.623 (*n* = 6)	0.589 (*n* = 28)	0.553 (*n* = 34)	0.553 (*n* = 10)
LOV ≥ 20 y	135	0.692 (*n* = 6)	0.612 (*n* = 49)	0.568 (*n* = 67)	0.502 (*n* = 13)
LOV with fish and chicken	26	—	0.591 (*n* = 16)	0.632 (*n* = 7)	0.569 (*n* = 3)
LOV with meat at least once/week (semi-LOV)	18	0.712 (*n* = 1)	0.602 (*n* = 5)	0.618 (*n* = 10)	0.470 (*n* = 2)
Total vegetarians	11	—	0.494 (*n* = 3)	0.519 (*n* = 5)	0.433 (*n* = 2)
Women, black					
All vegetarian types	11	—	0.657 (*n* = 5)	0.585 (*n* = 5)	0.706 (*n* = 1)
Women, Caucasian, from Berrien Springs					
All vegetarian types	16	—	0.669 (*n* = 4)	0.583 (*n* = 10)	0.585 (*n* = 2)

0.229 (*n* = 1)

Bone mineral density data was obtained on 304 women > 50 y of age from a wide geographical area. Those who were lactoovovegetarians for at least the preceding 20 y resemble the Michigan data on paired LOV and omnivore subjects. Trends in milk consumption and Ca supplementation are reported.

These studies provide support for the postulate that the lactoovovegetarian lifestyle may be a protective factor in preventing osteoporosis.

References

1. Mazess RB, Mather W. Bone mineral content of North Alaskan Eskimos. Am J Clin Nutr 1974;27:916–25.
2. Sanchez TV, Mickelsen O, Marsh AG, Garn SM, Mayor GH. Bone mineral in elderly vegetarian and omnivorous females. In: Mazess RB, ed. Proceedings of the fourth international conference on bone measurement. Bethesda, MD: NIAMMD 1980:94–8. (NIH publication #80-1983.)
3. Marsh AG, Sanchez TV, Mickelsen O, Keiser J, Mayor G. Cortical bone density of adult lacto-ovo-vegetarian and omnivorous women. J Am Diet Assoc 1980;76:148–51.
4. Marsh AG, Sanchez TV, Chaffee FL, Mayor GH, Mickelsen O. Bone mineral mass in adult lacto-ovo-vegetarian and omnivorous males. Am J Clin Nutr 1983;37:453–6.
5. St Jeor ST, Guthrie HA, Jones MB. Variability in nutrient intake in a 28-day period. J Am Diet Assoc 1983;83:155–62.
6. Adams CF. Nutritive values of American foods in common units. Washington, DC: US Government Printing Office, 1975. (US Department of Agriculture handbook #456.)
7. Wayler TJ, Klein RS. Applied nutrition. New York: Macmillan, 1965.
8. Sherman HC. Handbook of food and nutrition. 4th ed. New York: Macmillan, 1935.
9. Dwyer J, Foulkes E, Evans M, Ausman L. Acid/alkaline ash diets: time for reassessment and change. J Am Diet Assoc 1985;85: 841–5.
10. Oser BL, ed. Hawk's physiological chemistry. 14th ed. New York: McGraw-Hill, 1965.
11. Chu JY, Margen S, Costa FM. Studies in calcium metabolism. II Effects of low calcium and variable protein intake on human calcium metabolism. Am J Clin Nutr 1975;26:1028–35.
12. Licata AA, Bou E, Bartter FC, West F. Acute effects of dietary protein on calcium metabolism in patients with osteoporosis. J Gerontol 1981;36:14–9.
13. Lutz J. Calcium balance and acid-base status of women as affected by increased protein intake and by sodium bicarbonate ingestion. Am J Clin Nutr 1984;39:281–8.
14. Lemann J, Relman AS, Conners HP. The relation of sulfur metabolism to acid-base balance and electrolyte excretion: the effects of DL-methionine in normal man. J Clin Invest 1959;38:2215–23.
15. Hunt NJ. The influence of dietary sulfur on the urinary output of acid in man. Clin Sci 1956;15:119–34.
16. Relman AS, Lennon EJ, Lemann J. Endogenous production of fixed acid and the measurement of the net balance of acid in normal subjects. J Clin Invest 1961;40:1621–30.
17. Lennon EJ, Lemann J, Relman AS, Conners HP. The effects of phosphoproteins on acid balance in normal subjects. J Clin Invest 1962;41:637–45.
18. Wachman A, Bernstein DS. Diet and osteoporosis. Lancet 1968;1: 958–9.