bone mineral measurements. Am J Obstet Gynecol 153: 745–751, December 1985.
14. Krolner, B., and Nielsen, S. P.: Measurement of bone mineral content (BMC) of the lumbar spine. I. Theory and application of a new two-dimensional dual-photon attenuation method. Scand J Clin Lab Invest 40: 653–663 (1980).
15. Wahner, H. W., et al.: Dual-photon Gd-153 absorptiometry of bone. Radiology 156: 203–206, July 1985.
16. Laval-Jeantet, A. M., et al.: Influence of vertebral fat content on quantitative CT density. Radiology 159: 463–466 (1986).

Women's Health: Osteoporosis

Osteoporosis: Nutrition

RICHARD S. RIVLIN, MD

Dr. Rivlin is Chief, Nutrition Service, Memorial Sloan-Kettering Cancer Center, and Professor of Medicine and Chief, Nutirition Division, Cornell University Medical College and the New York Hospital, New York, NY.

This research was supported by grants 5P01CA29502, 5T32CA09427, and CA08748 from the National Institutes of Health and by grants from the American Cancer Society, Stella and Charles Guttman Foundation, William H. Donner Foundation, the Alcohol Beverage Medical Research Foundation, and the General Foods Fund. This paper was the basis of Dr. Rivlin's presentation at the National Conference on Women's Health, held in Bethesda, MD, June 17–18, 1986.

Synopsis

Nutrition has important potential for the prevention and treatment of osteoporosis. Ensuring the adequacy of calcium intake is central to any program of osteoporosis control, but it must be considered in the context of the many factors, including other nutrients, diseases, and drugs, which influence calcium absorption, utilization, and excretion. The dietary consumption of calcium by large segments of the U.S. population remains inadequate. More attention must be paid not only to increasing calcium intake, but also to maximizing its availability from food sources and its retention by the body. As individuals age, it becomes increasingly difficult to maintain adequate calcium balance; dietary selection must be made with special care for older persons to ensure that all of the nutrients are consumed in sufficient quantities and that neither excessive weight loss nor weight gain occurs.

IN DISCUSSING THE POTENTIAL role of nutrition in the prevention and treatment of osteoporosis, it is essential first to understand what comprises the science of nutrition. Nutrition is much more than just the study of what constitutes a good diet. Rather nutrition includes the science of how nutrients are used by the body. Utilization of dietary nutrients, in turn, involves intestinal absorption, transport, metabolic transformations and interconversions, storage, and excretion *(1)*. These considerations are particularly relevant to the issue of calcium and osteoporosis, inasmuch as many factors, such as disease, other nutrients, and certain drugs, may interfere in a clinically significant fashion with the utilization of dietary calcium even when its content in the diet may be adequate. When the diet is marginal or deficient in calcium, then the adverse effects of these interfering factors become even more evident.

Many changes occur in our bodies as we age. Nutrition is of universal concern because we all eat and we all grow old. Our challenge is to understand how to design an optimal diet and then to maximize the utilization of dietary nutrients in such a way as to derive the greatest benefits in delaying the degenerative diseases of aging. Osteoporosis is an excellent example of a disease for which nutrition has potential for prevention or reduction of disability and death.

Calcium and Osteoporosis

Calcium is critical to any discussion of osteoporosis, since bone constitutes the major reservoir of calcium, containing 99 percent of the total body supply *(2)*. A number of studies document the fact that the consumption of dietary calcium is inadequate in large segments of the U.S. population. Figure 1 shows the intake of calcium in men and women throughout their lifetimes, according to the results of the recent HANES II study *(3)*. At every age, men have higher intakes than women. The

Figure 1. Median intakes of calcium for U.S. men and women aged 18-70 years, as derived from the NHANES II study (*3*)

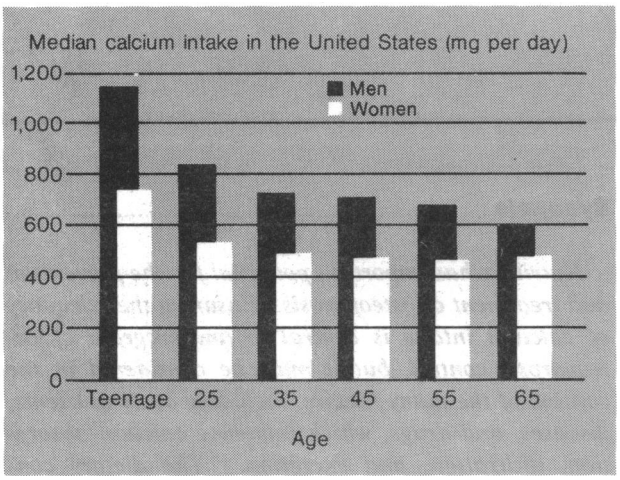
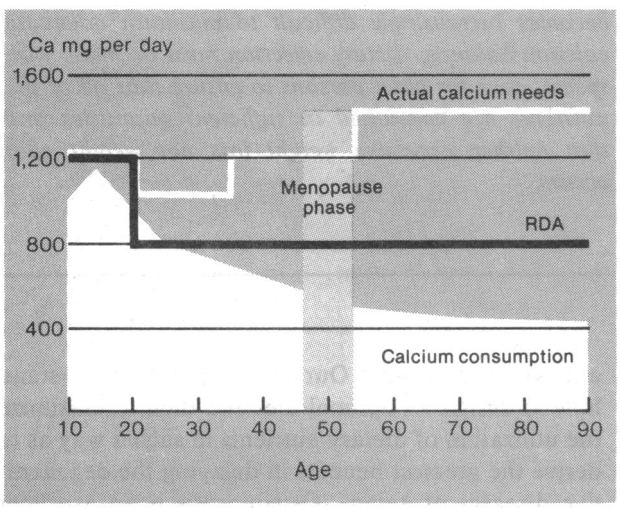


Figure 2. Estimated Recommended Dietary Allowance for calcium in U.S. men and women of different ages, superimposed upon their median intake



RDA (Recommended Dietary Allowance) for calcium is 800 mg for adults. The median adult female consumes only 500-600 mg per day. With increasing age, dietary calcium intake progressively declines. Heaney and co-workers (*4*) have pointed out that, after the age of 15, half the women in the United States consume dietary calcium at a level below the RDA. When bone is being formed at ages from 18 to 30, more than two-thirds of all women consume less than the RDA. In one-fourth of all adult women, calcium intake is so low that less than 300 mg per day is consumed. These figures give one an appreciation for how little calcium is consumed by the typical woman in the United States. The data were obtained prior to the current era in which calcium supplementation is becoming much more fashionable. Obviously, new data are needed, but it is highly likely that substantial portions of the population still do not consume enough calcium either from dietary sources or from supplements.

The low intake of dietary calcium is all the more relevant when one considers the evidence that dietary requirements for calcium may actually become greater with advancing age (fig. 2). The intestinal absorption of calcium declines with age (*5, 6*). The serum level of the physiologically active form of vitamin D, 1.25-dihydroxycholecalciferol (1.25-$(OH_2)D_3$), which stimulates calcium absorption, also declines with age (*7*), most likely as a result of its diminished synthesis. In addition, the serum level of parathyroid hormone tends to rise with aging (*8*), which may accelerate the resorption of bone. Furthermore, there is some evidence that as we get older, we adapt less well to a low calcium diet: the rate of intestinal absorption of calcium increases less than in younger subjects. The urinary loss of calcium, or "renal leak" as it has been designated, may also increase with aging. Thus, the physiological changes which are associated with the aging process in their aggregate make it increasingly difficult for older people to absorb and retain adequate amounts of calcium.

Dietary Sources of Calcium

One may wonder why the dietary intake of calcium decreases in older persons at a time when the physiological needs for calcium may be greater. In the United States, milk and dairy products constitute the largest and most important food group that supplies calcium, and older people do not eat enough of these items. In a study at a chronic care facility for the elderly, the reasons for lack of milk intake among the residents were determined (*9*). A number of the elderly women reported that "milk is fattening", "milk gives me gas", "milk is constipating," and "milk is a drink for children." These responses should be very useful in understanding the behavior of older persons and in designing education programs for them.

For those people who cannot or will not consume milk and dairy products in adequate quantities, it is essential to be familiar with the large number of other excellent dietary sources of calcium (*10*), including vegetables, custards, sardines, and soybean products, including tofu, as shown in figure 3. No one has to rely on a single food to obtain calcium from the diet. Elderly persons need to make espe-

cially wise dietary choices, as their caloric requirements are lower than formerly, they are often unable to afford what they need, and it becomes increasingly difficult for them to taste, smell, chew, swallow, digest, absorb, and excrete many dietary nutrients (*11*). Thus, it becomes a particular challenge for an older person on a limited budget to select a diet which will provide all of the other nutrients as well as calcium in adequate amounts without yielding excessive calories or producing significant weight loss.

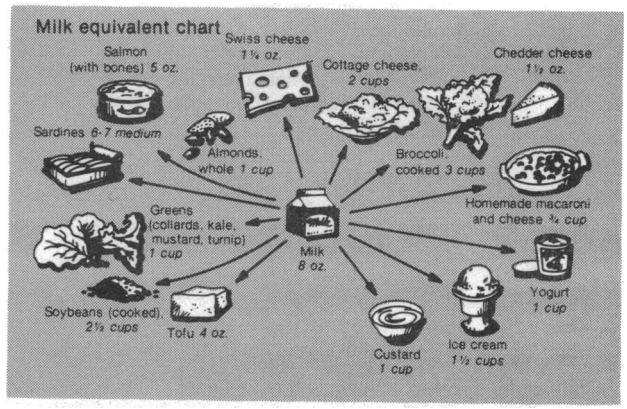
Regulation of Calcium Bioavailability

In addition to being concerned about dietary calcium intake, one should also be aware of the many factors that regulate its absorption, excretion, and utilization. In the author's opinion, too much attention has been centered on the exact number of mg of calcium that should be consumed, rather than upon making sufficient efforts to maximize the utilization of that calcium. Figure 4 illustrates the metabolism of calcium, showing that the major excretory route is through the stool and that substantial quantities of calcium are reabsorbed into the intestinal tract each day. There are many points in this sequence at which other nutrients, drugs, and diseases may have important influences on utilization of dietary calcium.

Some of these factors are shown in figure 5 (*12*). Vitamin D is crucial to the regulation of calcium absorption. With aging comes a decrease in the serum level of 1,25-$(OH)_2D_3$, the active form of vitamin D, probably due to its diminished synthesis. Any factor tending to increase the endogenous production of 1,25-$(OH)_2D_3$, as well as administration of this vitamin, will favor net calcium absorption. Vitamin D is synthesized in the skin under the influence of sunlight. Many investigators believe that the endogenous synthesis of vitamin D in the skin is a more important source of the vitamin than has been previously appreciated (*13*). Vitamin D levels in blood may be considerably lower at the end of a long winter than after the summer. Encouraging older people to go outdoors even for brief periods may be extremely beneficial by enabling them to increase their body stores of this important vitamin as well to obtain healthful exercise.

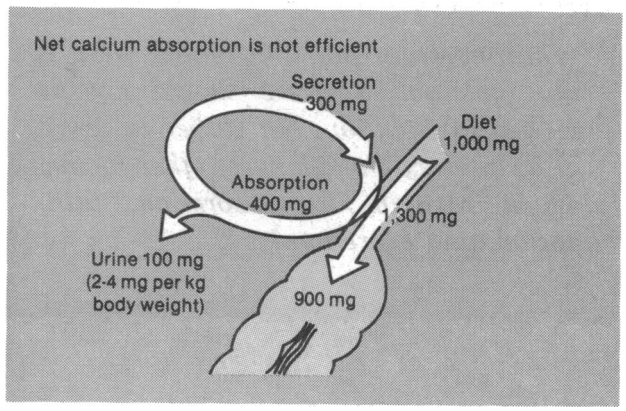
A second major dietary factor which seems to promote the absorption of calcium from the gastrointestinal tract is lactose, the sugar found in milk. Caucasians who are lactose-intolerant have a higher prevalence of osteoporosis than those who have a normal complement of this enzyme (*14*). Much needs to be learned about the relationship of lactase deficiency to osteoporosis. Among blacks the prevalence of lactase deficiency is extremely high, but osteoporosis is nevertheless uncommon.

Figure 3. Dietary sources of calcium and their milk equivalent (*9*)



SOURCE: "Become Calcium Conscious!" by the Clinical Nutrition Research Unit of the New York Hospital-Cornell Medical Center and Memorial Sloan-Kettering Cancer Center, 1983.

Figure 4. Diagrammatic representation of calcium metabolism



SOURCE: American Gastroenterological Association

Although only a few factors enhance calcium absorption, many factors have the potential for diminishing it (*15*). Substances from plants, called phytates, bind calcium and render it less available for intestinal absorption. Oxalates, present in high amounts in spinach and other vegetables, also bind calcium within the intestinal tract. While certain vegetables have a significant calcium content, the oxalate present significantly diminishes the bioavailability of the calcium that is present in these food items. Oxalate is also an important component of many kidney stones, and it is essential when considering the possible hazards of large doses of calcium to remember that it may be even more important to restrict the intake of foods containing high amounts of oxalate. Vitamin C, or ascorbic acid, is degraded directly to oxalate, and when

Figure 5. Some factors which regulate the intestinal absorption and excretion of dietary calcium

Food components that affect calcium balance

	Increases absorption	Decreases absorption	Increases excretion	Probably not a significant effect
Lactose	X			
Vitamin D	X			
Phosphorus				X
Protein			X	
Phytates		X		X
Fiber		X		
Oxalates		X		X
Sodium			X	
Caffeine			X	

'The important point to realize here is that calcium nutriture should not be viewed in isolation, but rather in terms of its interaction with many other factors which regulate its absorption, utilization, and excretion.'

consumed in large amounts may elevate urinary oxalate excretion.

A diet which is high in fat will decrease the bioavailability of dietary calcium. At a time when we are concerned that a high fat diet may be a significant factor in the development of heart disease, stroke, and certain forms of cancer, attention should also be directed to its possible role in producing calcium deficiency and osteoporosis.

Dietary fiber in large amounts interferes with calcium bioavailability (*16*). Zinc will also interfere with calcium absorption. Zinc supplements are extremely popular items in contemporary America, and are often abused. When consumed at many times the level of the RDA, zinc may have a clinically significant impact upon the metabolism of calcium and other metals. Megadoses of vitamin A may produce disturbances in calcium metabolism, the exact mechanisms of which require further elucidation (*17*). Caffeine increases the urinary excretion of calcium; alcohol affects calcium and vitamin D metabolism, probably at several sites (*18*). Furthermore, there is also some evidence that under certain circumstances iron may interfere with calcium absorption. Thus, consuming a diet which is highly unbalanced, and particularly using irrational, megadose supplements of vitamins and minerals, may have important adverse effects upon bone status in particular and body health in general.

Furthermore, a diet high in protein tends to increase the urinary excretion of calcium. This effect may be less prominent with animal protein than with vegetable protein, possibly because the former tends to have a high phosphate content. Phosphate tends to decrease urinary calcium excretion and increase fecal calcium excretion. The net effect of a diet high in phosphate is probably not to influence calcium balance significantly (*19*).

Dietary sodium will exchange with calcium in the renal tubule; hence a diet high in salt will result in greater delivery of sodium to the renal tubule, greater exchange with calcium, and thereby greater facilitation of urinary calcium loss (*15*). Conversely, a diet low in salt will tend to favor urinary calcium retention, which constitutes another good reason why restriction of sodium intake may provide health benefits.

The important point to realize here is that calcium nutriture should not be viewed in isolation but rather in terms of its interactions with many other factors which regulate its absorption, utilization, and excretion. Much remains to be learned about the quantitative effects on calcium metabolism of these and other nutrient interactions.

Drugs and Diseases in Relation to Calcium Nutrition

Certain diseases, operations, and drugs may be associated with the development of osteoporosis in as many as 20-40 percent of patients with hip fractures (*20*). Health professionals must be aware of these relationships and institute appropriate preventive and therapeutic measures.

The adrenal corticosteroids, widely utilized in patients with arthritis, inflammatory bowel disease, asthma, cancer, and many other conditions, have devastating effects on bone when administered at high doses for a prolonged period. These agents accelerate bone destruction, suppress new bone formation, and may produce significant hypercalciuria. Drugs affecting calcium and/or vitamin D metabolism include isoniazid, heparin, aluminum-containing antacids and anticonvulsants, and others (*21*). Certain diuretics, such as furosemide, increase calcium

excretion, while others, such as the thiazide diuretics, tend to favor calcium retention (*22*). Thiazide diuretics may not be as beneficial in this respect as believed formerly, inasmuch as the intestinal absorption of calcium may decrease with their use (*23*).

A number of diseases cause disturbances in calcium balance. Hyperthyroidism, for example, will decrease calcium absorption and increase urinary calcium excretion. Disorders of the intestinal mucosa may lead to malabsorption of vitamin D and/or calcium. Hyperparathyroidism, whether primary or secondary to renal disease, will result in accelerated bone resorption. Many other examples could be cited. Thus, nutrition plays a critical role in osteoporosis, and knowledge of nutrition should be an important means of designing appropriate prevention and treatment strategies.

References

1. Rivlin, R. S.: Summary and concluding statement: evidence relating selected vitamins and minerals to health and disease in the elderly population in the United States. Am J Clin Nutr 36: 1083–1086 (1982).
2. Albanese, A. A.: Bone loss; causes, detection, and therapy. Alan R. Liss, New York, 1977, p. 23.
3. Abraham, S., Carroll, M. D., Dresser, C. M., and Johnson, C. L.: Dietary intake findings, United States 1976–1980. National Center for Health Statistics, U.S. Department of Health and Human Services, 1983.
4. Heaney, R. P., et al.: Calcium nutrition and bone health in the elderly. Am J Clin Nutr 36: 986–1013 (1982).
5. Bullamore, J. R., et al.: Effect of age on calcium absorption. Lancet 2: 535–537 (1970).
6. Gallagher, J. C., et al.: Intestinal calcium absorption and serum vitamin D metabolites in normal subjects and osteoporotic patients: effect of age and dietary calcium. J Clin Invest 64: 729–736 (1979).
7. Tsai, K. S., Heath, H., III, Kumar, R., and Riggs, B. L.: Impaired vitamin D metabolism with aging in women: possible role in pathogenesis of senile osteoporosis. J Clin Invest 73: 1668–1672 (1984).
8. Wiske, P. S., et al.: Increases in immunoreactive parathyroid hormone with age. N Engl J Med 300: 1419–1421 (1979).
9. Alexander, M., et al.: Relation of riboflavin nutriture in healthy elderly to intake of calcium and vitamin supplements: Evidence against riboflavin supplementation. Am J Clin Nutr 39: 540–546 (1984).
10. Rivlin, R. S., and Levine, B. L.: Calcium—dietary and supplemental. Medical Health Annual. Encyclopedia Britanica, 1985, pp. 337-340.
11. Young, E. A., editor: Nutrition, aging and health. Alan R. Liss, New York, 1986.
12. Stark, C.: Calcium—How much do adults need? Professional Perspectives, Cornell University. October-November, 1984.
13. DeLuca, H. F.: Vitamin D: the vitamin or the hormone. Fed Proc 33: 2211–2219 (1974).
14. Newcomer, A. D., Hodgson, F. S., McGill, D. B., and Thomas, P. J.: Lactase deficiency: prevalence in osteoporosis. Ann Intern Med 89: 218–220 (1978).
15. Heaney, R. P.: Calcium intake, bone health and aging. *In* Nutrition, aging and health, edited by E. A. Young. Alan R. Liss, New York, 1986, pp. 165–186.
16. Heaton, K. W., and Pomare, E. W.: Effect of bran on blood lipids and calcium. Lancet 1: 49–50 (1974).
17. Navia, J. M., and Harris, S. S.: Vitamin A influences on calcium metabolism and calcification. *In* Micronutrient interactions: vitamins, minerals and hazardous elements, edited by O. A. Levander and L. Ching. Ann N Y Acad Sci 355: 45–57 (1980).
18. Farley, J. R., et al.: Direct effects of ethanol on bone resorption and formation *in vitro*. Arch Biochem Biophys 238: 305–314 (1985).
19. Heaney, R. P., and Recker, R. R.: Effects of nitrogen, phosphorus and caffeine on calcium balance. J Lab Clin Med 99: 46–55 (1982).
20. Riggs, B. L., and Melton, L. J., III: Involutional osteoporosis. N Engl J. Med 314: 1676–1686 (1986).
21. Haussler, M. R.: Vitamin D. Metabolism, drug interactions and therapeutic applications in humans. *In* Nutrition and drug interrelations, edited by J. N. Hathcock and J. Coon. Academic Press, New York, 1978, pp. 717–750.
22. Wasnich, R. S., et al.: Thiazide effect on the mineral content of bone. N Engl J Med 309: 344–347 (1983).
23. Sakhae, E. K., et al.: Reduction in intestinal calcium absorption by hydrochlorothiazide in postmenopausal osteoporosis. J Clin Endocrinol Metab 59: 1037–1043 (1984).