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NUTRITIONAL REQUIREMENTS OF THE ELDERLY[1]

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INTRODUCTION

Nutrition can be considered to interact with aging in several ways. First, most bodily functions decline progressively throughout adult life (141). We can ask how nutrition and other features of adult life-style contribute to or ameliorate this age-related loss of tissue structure and function. An important example with nutritional implications is osteoporosis. Second, the frequency of many chronic degenerative conditions such as cardiovascular disease and cancer increases with advancing age. There is evidence implying a role for nutrition in the etiology of these conditions. Finally, most adults eat less as they grow old, and in consequence the intakes of some nutrients can sometimes fall below the Recommended Dietary Allowances (126).

In this review, it is our purpose to evaluate this last aspect of nutrition in relation to aging; namely, what do we know about the nutrient needs and intakes of old people, and is the nutritional status of the elderly often endangered? In reviewing the nutritional requirements of the elderly, it should be emphasized that intakes of nutrients recommended as adequate for the elderly are often based on tenuous evidence and frequently rely on extrapolations from the better-defined requirements of young adults. This lack of solid data has made it justifiable to categorize elderly into broad groups when prescribing nutrient requirements. Thus, the Ninth Edition of the Recommended Dietary Allowances (126) follows its predecessors in combining all adults over 50 years of age into one group covering a period of extensive degenerative changes and of diminishing food intakes. The reader's attention is drawn to a number of multiauthored volumes dealing in detail with various aspects of the role of nutrition in aging and the nutrient needs of the elderly (8, 43, 83).

ENERGY INTAKES AND REQUIREMENTS

Studies in several countries agree that the energy intakes of adults diminish progressively with age. This is well documented by the Baltimore Longitudinal Study of Aging of male executives and civil servants recruited from the Washington area. This study initially included a cross-sectional comparison of nutrient intakes of men of different ages (110). Total energy intake declined progressively from 2700 kcal for those around 30 years old to 2100 kcal for those around 80 years, a reduction of 600 kcal. Part of this reduction (200 kcal) results from the fall in basal metabolism brought on by the steadily diminishing mass of active tissue (lean body mass) with advancing age (142). However, a larger component (400 kcal) was due to a decline in physical activity. Following this initial cross-sectional study, 180 of the men were retested twice during the subsequent 15 years (40). This longitudinal study confirmed the effect of age on energy intake and also identified effects due to changes in food preferences common to the general population. Thus, over the 15-year period, the decline in energy intake was accompanied by a reduction in total fat intake, but an increase in polyunsaturated fat intake so that the ratio of polyunsaturated to saturated fat rose among the elderly, just as it did among younger people over the same period. This implies that the elderly can share in nutritional trends.

These findings agree generally with other studies of the energy intakes of aging populations. The second HANES survey (71), based on a representative sample of the US population, showed that men reduced their energy intake from 2700 kcal at age 23–34 years to 1800 kcal at 65–74 years, while the daily energy consumption of women fell from 1600 kcal to 1300 kcal over the same time period (103). The Nationwide Food Consumption Survey conducted by the Department of Agriculture (117) confirmed the low energy intakes of elderly men and women; a report based on data from nursing homes in Colorado (147) showed that elderly men averaged 1700 kcal daily while old women consumed 1330 kcal. In the later years of life, there is some evidence that the reduction in energy intake accelerates. In a study of London women living alone, Exton-Smith & Stanton (44) report a reduction of 19% in caloric intake during the decade between 70 and 80 years of age, a reduction they attribute to increasing disabilities restricting physical activity. Similar data emerge from other studies made outside the US. In a survey carried out in Scotland 30 years ago (114), young male clerks were found to consume 3000 kcal daily, middle-aged clerks had intakes averaging 2400 kcal, while retired men consumed only 2050 kcal. These intakes for Scottish males are compatible with the findings of the Baltimore (110) and HANES (71) surveys; however, while Scottish women examined in the same survey (114) showed an age-related decline in energy intake, their absolute caloric intakes were about 500 kcal higher than those found in the HANES survey. This probably represents greater physical activity, an interpretation strengthened by a French study (32) in which elderly townswomen were found to average 1710 kcal daily, while those from the surrounding countryside consumed 2170 kcal daily on the average.

The progressive fall in energy intake as age advances suggests that amounts of nutrients contained in the sources of the calories will also diminish. Individual nutrient intakes of men measured in the course of the Baltimore cross-sectional study (110) indeed showed that as age advanced there was a tendency to consume less iron, thiamin, riboflavin, and nicotinic acid, but not calcium, vitamin A, or ascorbic acid. In the study by Exton-Smith & Stanton (44) of elderly London women living alone, intakes of many nutrients were considerably less at 80 years than at 70 years. Over the decade, protein intake fell by 29%, calcium by 18%, iron by 19%, and vitamin C by 31% when total energy intake was reduced by 19%. An analysis based on the HANES II survey and the Nationwide Food Consumption Survey showed that intake of zinc decreased in parallel with declining caloric consumption after age 55 years (136). Although we do not know whether these reductions in nutrient intakes with age are liable to place elderly subjects in jeopardy of nutrient deficiencies, it would seem desirable to increase food consumption by maintaining physical activity into old age, a policy that has other advantages related to the health of the elderly.

How do these values equate with official recommendations for energy intakes? Energy intakes recommended in the Ninth Edition of the RDA (126) for men of 70 kg are 2400 kcal at 51–75 years and 2050 from 76 years onward. For women weighing 55 kg the corresponding data are 1800 and 1600 kcal respectively. A recent WHO/FAO/UNU Report (168) on energy and protein requirements used regression equations to compute the daily caloric needs to be 2300 kcal for 70-kg men over 60 years of age who were expending 1.6 times basal metabolic rate and 1900 kcal for 55-kg women of similar age and energy expenditure. Finally, it should be noted that the energy expenditures of men and women will probably be more accurately measured in the future with a new technique involving dissociation of $D_2{}^{18}O$ (124) as well as by a number of ongoing studies involving direct and indirect calorimetry.

PROTEIN NUTRITURE AND REQUIREMENTS

At different adult ages, consumption of protein usually represents a constant 12–14% of energy intake (114), and in consequence total protein intake falls in parallel with energy intake as people grow older. Aging is also associated with a progressive loss of active tissue (lean body mass) (50), which might be attributed to the reduction in protein intake. Consequently, one objective in recommending levels of protein intake would be to prescribe an intake associated with the least age-related loss of tissue protein, if indeed such losses can be influenced by diet.

The protein requirements of adults have traditionally been based on nitrogen balance, as measured by comparing intake with output. The amount of protein needed to prevent a negative balance has been estimated by two approaches. The factorial approach measures the total loss of body protein as nitrogen through various channels (urine, feces, skin) when the adult is receiving a protein-free diet and then equates the sum of these losses with the need for replacement as protein in the diet. A procedure more commonly used in recent years has been to feed adults diets containing levels of dietary protein below and above the amount required to sustain nitrogen equilibrium and then estimating the least amount of protein needed to preserve nitrogen balance by interpolation. Early estimates of the protein requirements of aging adults by nitrogen balance are summarized elsewhere (115) and have been superseded by more refined approaches that recognize minor routes of nitrogen loss, the need for avoiding stress (which promotes loss of body protein), and the fact that the energy balance of the subject affects the estimated needs for protein (113). This last point is important because of the reduced energy intakes of the elderly. As Kishi et al (91) have shown, increasing the energy intake of young men from 40 to 48 kcal/kg reduces the average protein requirements needed to maintain nitrogen equilibrium from 0.8 to 0.5 g/kg.

The current allowance of protein for adults of all ages is 0.8 g/kg according to the US Dietary Allowance Committee (126) and 0.75 g/kg body weight in the WHO/FAO/UNU Report (168). However, some of the problems of interpreting data on the elderly are illustrated by four studies carried out recently in order to determine the minimum level of dietary protein needed to sustain nitrogen balance in elderly men and women. Using young and old Chilean prisoners, Cheng et al (24) fed three levels of protein (0.4, 0.8, and 1.6 g/kg per day) for 11 days and found, in agreement with the Recommended Dietary Allowance (126) and the WHO/FAO/UNU (168), that 0.8 g/kg allowed equilibrium to be maintained in both age groups. However, the use of the same calorie intake (40 kcal/kg) at both ages is likely to cause the older subjects to retain nitrogen better and thus obscure the greater need of the elderly for protein that might become evident at 30 kcal/kg. Another study by Zanni et al (170) showed that only 0.57 g protein/kg was needed by elderly men to maintain nitrogen equilibrium, but this experiment was carried out after a period on a protein-deficient diet that could have adapted the subjects to a lower intake than normal. Other experiments have suggested intakes higher than 0.8 g protein/kg. In a study of elderly men and women receiving 0.8 g protein and 30 kcal/kg body weight, Uauy et al (159) found that some of the subjects were unable to achieve nitrogen equilibrium. This was confirmed by Gersovitz et al (57) in a similar experiment lasting one month, during which half the elderly men and women remained in negative balance.

Nitrogen balance has also been used to test the needs of the elderly for essential amino acids. It has been claimed that the requirements for methionine and for lysine are greater among old people (158), but other investigations (166) assert that the elderly need less sulfur-containing amino acids. An alternative measure of essential amino acid requirements has been to use the response of plasma amino acids to different intakes of individual amino acids. In the case of tryptophan (152) and threonine (153), this criterion does not suggest increased requirements by the elderly. Since the combined essential amino acid requirements of adults probably represent only one fifth of their total protein needs (168), it is improbable that essential amino acid deficiency is ever likely to affect elderly adults.

These findings show that nitrogen balance experiments have not yet provided definitive conclusions about the protein requirement of the elderly nor of how it might affect age-related loss of lean body mass. This is not surprising. A Swedish study (146) of the healthy elderly between the ages of 70 and 75 years showed a loss of 1 kg of lean body mass during this 5-year period. This is equivalent to a daily negative balance of 20 mg nitrogen, whereas significant changes in nitrogen balance are not less than 500 mg per day. Consequently, nitrogen balance is not a reliable means of determining the best level of protein to minimize the age-related loss of lean body mass. Since people in industrialized countries continue to lose lean body mass even though they consume much more than 0.8 g protein/kg body weight, it can be concluded that high protein intakes are unlikely to suppress completely the age-related erosion of active tissue.

Finally, we may ask whether protein-calorie deficiency is a significant syndrome among the elderly. A study was made in the Boston area on 239 men and 452 women, aged 60 to 98 years, assessing their food intake, biochemical parameters of protein sufficiency, and body composition (116). Their protein intakes averaged 1.05 g/kg body weight, well above the recommended 0.8 g/kg. The concentrations of several plasma proteins (albumin, prealbumin, transferrin) were slightly reduced as age advanced, but this was not correlated with a low intake of protein, and the muscle mass of the upper arm was not less among those with the lowest protein intakes. Thus there was no evidence of protein deficiency within this group. On the other hand, the British Department of Health and Social Security surveyed the nutrient intakes and nutritional status of an unselected group of British citizens (34) and found that 6% of men and 5% of women aged 70–79 years were malnourished, while among those over 80 years the incidences were 12% and 8% respectively. All of the cases of malnutrition suffered from some condition (chronic bronchitis, emphysema, depression, etc) likely to depress appetite and even to increase dietary requirements. On the other hand, the Boston subjects were selected to exclude such chronic diseases. It can be concluded (*a*) that protein deficiency is unlikely in the US elderly population who do not have a debilitating disease, and (*b*) that the needs of the healthy elderly will be met by 1 g protein/kg in the daily diet, and probably by less.

CALCIUM AND OTHER NUTRIENTS IN OSTEOPOROSIS

Bone loss in osteoporosis begins somewhere between the ages of 20 (127) and 40 years (55). In women, this slow erosion accelerates during the two decades after the menopause and accounts for the high incidence of fractures of wrist, hip, and spine. From English statistics, Nordin (118) estimates that, by the age of 80 years, women show a cumulative incidence of 14% wrist fractures, 8% vertebral compression fractures, and 5% fractures of the neck or femur. Factors claimed to be involved in the severity of osteoporosis include insufficiency of calcium, phosphorus, and vitamin D; excess of protein, phytate, and fiber; and lack of exercise. Much of the evidence on the role of these factors comes from studies on postmenopausal loss of bone density, but there is also evidence that nutritional factors still operate in old age.

The role of calcium in osteoporosis has been extensively investigated and was evaluated in depth by a panel of experts (74). Using the data of the Health and Nutrition Examination Survey (HANES I AND II), they show persuasively that adults consume on average much less than the Recommended Dietary Allowances (126); this is especially true for women, who receive about 500 mg calcium daily from the diet instead of the 800 mg recommended. Such low calcium intakes have been associated with impaired bone density at all ages of adulthood. Studies in Yugoslavia (107) showed that at age 30 years those living in an area in which the diet is typically high in calcium (average 1100 mg daily) had greater metacarpal cortical thickness than did those living in an area with a typically low-calcium (500 mg daily) diet. Although metacarpal cortical area decreased in people in both districts as age advanced, the population in the high-calcium area had fewer hip fractures in later life because it took longer for them to lose a critical amount of bone strength. In middle life, there is evidence to show that calcium intake is still relevant to the accelerated postmenopausal loss of bone mineral. Studies by groups in the US (73, 125) and in England (81, 82) show that raising calcium intake to 1.5 g daily over a period of 2–3 years can reduce loss of bone from the appendicular skeleton. The amount of dietary calcium needed to achieve equilibrium can be reduced to 1000 mg if an appropriate level of estrogen is also given.

Other nutrients are relevant to calcium balance. Raising intake of protein orally (5) or of an amino acid mixture parenterally (15) increased urinary output of calcium and impaired calcium balance. However, when Spencer and colleagues (144) added meat instead of pure protein to the diet, the effect on calcium balance was transitory, which they attributed to the beneficial effect of phosphorus in the meat. According to Heaney & Recker (72), however, the magnitude of the response of calcium balance to increased phosphorus is not adequate to eliminate the protein effect. A consensus report by an expert committee (122) and a review by DeLuca (35) illustrate the complexity of the role of vitamin D in metabolic bone disease. In part, vitamin D acts to ensure adequate calcium absorption following conversion of the vitamin by sequential reactions in liver and kidney to yield the active metabolite 1,25-dihydroxy vitamin D, the second hydroxylation in the kidney being under control of the parathyroid gland (35). Vitamin D deficiency in adults leads to a failure of bone calcification with accumulation of osteoid tissue, a pathological condition known as osteomalacia. The incidence of osteomalacia is less in the US than in Europe, probably because of the vitamin D fortification of US milk and margarine and because of the great exposure of Americans to sunshine, which allows for synthesis of the vitamin in the skin (76).

Several other factors appear to be relevant to calcium balance. Cereals in the unrefined state contain significant amounts of phytic acid and of fiber, both of which can reduce available minerals, including calcium (74). Exercise has repeatedly been shown to improve bone density. Thus, a group of middle-aged male marathon runners had 11% more bone calcium than did sedentary men of similar age (2). Three groups of investigators (3, 95, 143) have shown middle-aged and older women can retain or increase bone density by regular exercise.

TRACE ELEMENTS

Essential trace elements continue to be identified, the most recently described members still lacking recommendations on requirements. The Ninth Edition of Recommended Dietary Allowances (126) includes essential elements for which allowances were established some time ago (iron, zinc, and iodine) and also introduces a series of trace elements (copper, manganese, fluoride, chromium, selenium, and molybdenum) for which ranges of intakes are recommended as a preliminary step in better defining allowances. For each element the range provides a lower level adequate to prevent deficiency and an upper limit beyond which toxicity is likely to occur if intakes in excess of this are habitually consumed. The Ninth Edition provides only one recommended range for all adults irrespective of age.

In reviewing the trace element needs of the elderly, Mertz (108) has developed an imaginative classification of trace elements that puts the importance of current research in perspective. First, he identifies problem elements, namely calcium for its role in osteoporosis, selenium as a factor in cancer, chromium in relation to carbohydrate metabolism, and silicon as possibly an important factor in bone structure. Second, he lists elements that may be involved in aging and that are not well distributed in diets. This list includes magnesium and copper in relation to cardiovascular disease, zinc in relation to immune functions, and fluorine to bone health. Finally, he recognizes elements usually adequately provided in the diet, namely manganese, molybdenum, iron, and iodine. In reviewing trace elements requirements, it should be emphasized that bioavailability is significantly affected by other dietary constituents including other trace elements.

Iron

The iron status of elderly North Americans has been reviewed by a panel (103). The criteria of iron status of a population includes not only hemoglobin levels but also saturation of serum transferrin, amount of ferritin in the serum as an index of iron in storage, and the free protoporphyrin content of the red cells. Using these criteria, a survey of an inner city US population (27) showed only 6% of women and 4% of men over 45 years with an insufficient level of stored iron, while 2% had frank iron-deficiency anemia. Indeed, serum ferritin estimations show progressive accumulation of body iron content throughout adult life for men and after 50 years for women (27, 103). The infrequency of iron deficiency among older adults is confirmed by the analysis of Dallman et al (29) of the HANES survey data for Americans aged 65–74 years using the criteria cited above. The observed incidence of 4% anemia in old men was mostly attributable to infection; primary iron-deficiency anemia was also rare in old women. Among a group of elderly Boston women, Gershoff et al (56) found only a few with mildly depressed hemoglobin levels who mostly reverted to normal on repeat testing, whether they were given supplemental iron or not. These demonstrations that iron-deficiency anemia is rare among the elderly are consistent with the finding in a population of elderly in New Mexico (53) that almost all old men and two thirds of old women were receiving the daily Recommended Dietary Allowance of 10 mg iron (126). They are also compatible with evidence (103) extracted from the HANES survey of the US population showing that daily iron intakes at age 65–74 years average 14 mg for elderly men and 10 mg for elderly women. Lipschitz (100) suggests that some cases of anemia in the elderly are due to age-related reductions in the reserves of hemopoietic cells.

Zinc

In recent years, the status of zinc nutriture in the elderly has been reviewed several times (60, 86, 169) and has also been the subject of a consensus report (136). The latter report shows that the zinc intake of older people declines with advancing age in parallel with the decrease in energy intake and, in contrast to iron, is much less than the Recommended Dietary Allowance (126) of 15 mg zinc daily for men and women. Actual intakes average only 10 mg for old men and 7 mg for old women (136); 95% of a healthy elderly population in New Mexico were receiving less than the Recommended Dietary Allowance (53), although most of them corrected this situation by supplementation. Other surveys of zinc intakes by older people confirm this picture (86).

Important considerations in evaluating these findings of low zinc intakes are whether they are associated with blood zinc levels lower than normal, whether there is any evidence of compensation for the low intakes through better absorption of the dietary zinc, and finally, whether there are any specific signs of zinc deficiency. In 1971, Lindeman et al (99) reported that plasma zinc levels declined progressively throughout adult life, whereas red cell zinc concentrations were unaffected. A series of five subsequent studies reviewed by Jacob et al (86) failed to confirm age-related changes in plasma zinc levels, a view shared by the consensus report (136), which also draws attention to a few low hair zinc concentrations in several surveys of the elderly (e.g. Deeming & Weber, 33). A working party (98) has concluded that plasma zinc levels are unreliable indices of adequate intakes and suggests other potential tests. Signs and symptoms associated specifically with zinc deficiency have been disappointing. Although experimental zinc deficiency leads to hypogeusia (loss of taste acuity), a review (136) of five studies of the taste thresholds of old people failed to show a relationship to zinc status or to undergo correctional improvement when hypogeusic subjects were given supplementary zinc.

There is insufficient evidence to know if those on low zinc intakes adapt by more efficient absorption, which is regarded as normally some 30% of intake but which can be adversely affected by other dietary constituents, notably phytate, fiber, phosphate, and protein (136). Sandstead et al (136) used multiple regression analysis to show that the lower intake of protein and phosphorus in the elderly should allow old men and women to achieve zinc equilibrium with intakes respectively of 10 and 7 mg at age 65–74 and 9 and 6 mg after age 75 years. Using a stable isotope of zinc, Turnlund et al (157) found only 17% zinc absorption in elderly men.

The lack of specific signs of zinc deficiency does not imply that the response of old people to injury is unimpaired. Delayed wound healing has been observed in several studies (66, 68, 75) in which administration of zinc to people with low plasma zinc levels appeared to accelerate healing. Zinc deficiency has also been found to impair immune function (136). Thus, the capacity to respond appropriately to injury and infection may require adequate zinc nutriture. In this connection, it should be noted that urinary excretion of zinc is increased during the catabolic response to injury (28), thus further depleting the body.

Copper

Data on the copper nutriture of the elderly is scanty and insecure. The recommended intake for adults (126) lies in the range 2–3 mg daily. Studies of copper consumption by elderly Canadian women (58) suggested 1.1–1.2 mg daily as their intake, although no signs of copper deficiency were evident. Using a stable copper isotope, Turnlund et al (156) showed absorption by elderly men to be 25% when 3.3 mg copper were fed, a level of copper intake at which balance is attained in old men (155). In another study on elderly men and women (20), copper balance was obtained with a diet containing less copper (2.3 gm daily) whether combined with low or high zinc intakes.

Exploration of the copper content and availability in national diets is needed, especially since Klevay (92) has suggested that US diets often provide less than a daily average of 2 mg copper. Like other trace minerals, copper is subject to interactions with other dietary constituents such as zinc (121) and these may determine its availability. Sandstead (135) used multiple regression to adjust copper requirements for the impact of dietary zinc (which depresses copper utilization) and protein (which improves it). He concluded that copper balance on a diet providing 10 mg zinc and 80 g protein requires only 1.14 mg of copper (range 0.9 to 1.5 mg, sweat losses not included). Recent studies on rats by Fields et al (46) show that fructose in the diet can precipitate copper deficiency. The plasma level of copper, used as an indicator of nutriture, has been reported to increase in the elderly, possibly in relation to the effects of hormones on levels of ceruloplasmin, the major form of copper in the blood (86, 169).

The fragmentary information about other trace elements (selenium, manganese, molybdenum, and chromium) in relation to aging is summarized by Yunice & Hsu (169).

VITAMINS

In contrast to trace element nutrition in aging, there is an increasing abundance of literature on the vitamin needs of the elderly, and recommended allowances exist for almost all of them (126). Recently, Garry & Hunt (54) have made a careful analysis of factors in the vitamin assessment of the elderly, including their supplemental intakes. They conclude that biochemical measures of the water-soluble vitamins correlate reasonably well with assessed intakes, including supplements, of these vitamins. Correlation coefficients are 0.59 for plasma ascorbic acid, 0.45 for plasma cobalamin, and 0.50 and 0.49 for plasma and erythrocyte folate respectively. Current information about the metabolism and active forms of the water-soluble vitamins is summarized by Danford & Munro (30).

Vitamin A

The liver is the dominant storage site for vitamin A. This deposit is maintained in most people throughout life (80) and even increases with age (159a). It accounts for the maintenance of plasma vitamin A above the critical level of 20 μg/dl even when intake appears to be inadequate according to measurement of food consumed. Surveys of the nutrient intakes of the elderly usually show a considerable percentage of people receiving less than the RDA for vitamin A (14, 19, 53, 101), an exception being the adequate intakes of those in a retirement community in Southern California (61). This general inadequacy of dietary vitamin A is not reflected in plasma retinol levels, which are sustained throughout life (36). For example, 42–65% of the elderly surveyed in HANES I had vitamin A intakes less than two thirds of the RDA, but less than 1% had plasma retinol A levels below the critical 20 μg/dl (19). A factor in evaluating the vitamin A needs and nutriture of the elderly is evidence from human (94) and animal (77) studies that vitamin A is better absorbed by the aging mammal, possibly because of age-related thinning of the unstirred water layer of the small intestine. However, other studies on rats (47) did not show this improvement in absorption with advancing age.

From this analysis of the literature we conclude that there is no evidence of insufficiency in the vitamin A nutriture of senior citizens on the present RDA of 1000 μg retinol daily for men and 800 μg for women.

Vitamin D

Daily vitamin D requirements are met by foods containing vitamin D_3 or enriched with vitamin D_2, and by vitamin D_3 synthesis in the epidermis on exposure to sunlight. Unfortified food (except deep sea fish) is a poor vitamin D source, and 62–74% of healthy free-living elderly have dietary intakes below two thirds of the RDA (53, 122). Data on whether age influences vitamin D absorption from the gastrointestinal tract is conflicting (13, 46, 78).

The concentration of 25-hydroxy vitamin D, the major form of vitamin D in plasma, declines with age in the rat (7) as well as in man (12, 102, 122). It has been claimed (131) that there is an age-related reduction in 25-hydroxylation of administered vitamin D by the liver (75), but this has been challenged in a consensus report (122). There is good evidence that the reduced blood level of 25(OH)-vitamin D in the elderly is related to less exposure to sunlight. Thus, most institutionalized and housebound elderly have lower 25(OH)-vitamin D levels than the free-living elderly (12, 102, 164), presumably caused by differences in exposure to the sun. The reduced levels may also result from less efficient synthesis of vitamin D in the skin of the elderly (104). With regard to the active form, 1-25$(OH)_2$-vitamin D, normal, healthy elderly, osteoporotic patients and aged animals all show lower serum levels than younger controls, even when 25(OH)-vitamin D levels are within the normal range. This is apparently due to a decreased capacity for conversion of 25(OH)-vitamin D to 1-25$(OH)_2$-vitamin D by the kidney (7, 35).

Although vitamin D metabolism thus undergoes age-related changes due to low dietary intake, lack of sun exposure, reduced vitamin D synthesis in the skin, and impaired 1-hydroxylation by the kidney, there is as yet not enough evidence to propose changing the RDA of vitamin D in the elderly. The best approach to improving the vitamin D status of the elderly is to increase sunlight exposure, supplemented with low levels of vitamin D (10 μg/day), during the winter months and throughout the year for housebound elderly.

Vitamin E

Because of vitamin E's wide distribution in foods, vitamin E deficiency in man is rare (45). The vitamin E intake of free-living elderly Canadians was found to be adequate by RDA standards (97); however, Garry et al (53) report dietary intakes below three quarters of the RDA in 45% of healthy, noninstitutionalized elderly. From a survey of seven published studies of plasma vitamin E levels at different ages, Kelleher & Losowsky (89) conclude that serum tocopherol levels usually increase in the elderly, probably because its carrier β-lipoprotein also increases. The age-related increase in plasma tocopherol also appears to be related to more vitamin E in the liver, where it correlates with liver lipid content (160). However, Vatassery et al (161) report a more complex situation in which total and α-tocopherol levels in plasma do not change with age, while plasma γ-tocopherol and platelet total, α-, and γ-tocopherol all decrease in older people.

In the healthy elderly, responses of plasma tocopherol levels in vitamin E tolerance tests do not change with age (89), nor does the prevalence of erythrocyte hemolysis, an indicator of vitamin E deficiency, change significantly (154). In contrast, old rats required much more vitamin E than did young rats in order to prevent erythrocyte hemolysis upon exposure to dialuric acid and to maintain fertility (4). Old rats had a higher rate of lipid peroxidation in liver tissue as compared to younger rats fed the same vitamin E–containing diet (23). However, in contrast, Grinna (62) reports that with increasing age it became more difficult to deplete body vitamin E stores in rats and erythrocyte hemolysis decreased. It is uncertain how relevant the contradictory rat data are to human needs. The evidence showing maintained levels of tocopherol in the plasma and liver of elderly humans suggests that there is no reason to recommend increased requirements of vitamin E for the elderly. However, evidence of the role of vitamin E in maintenance of tissue functions related to peroxidation (17) may alter this conclusion.

Vitamin K

Vitamin K is essential for maintaining blood coagulation and synthesis of several vitamin K–dependent gamma-carboxylated proteins (162). Absorbed vitamin K comes partly from dietary sources and partly from intestinal bacterial synthesis. Frick et al (51) studied blood coagulation in patients with sterile intestinal tracts and concluded that the minimum dose needed to restore coagulation was 0.03 μg/kg body weight. There is no RDA for vitamin K, but the range of requirement for adults has been set at 70–140 μg daily (126). Purely diet-induced vitamin K deficiency in humans is rare (26).

Information on vitamin K status and metabolism in the elderly is scanty. At present, vitamin K deficiency is usually diagnosed by a prolonged prothrombin time and can be corrected by vitamin K supplementation. The recently introduced determination of the circulating levels of abnormal prothrombin (with reduced content of gamma-carboxy glutamic acid residues) provides a more sensitive test for vitamin K deficiency (119). Hazell & Baloch (70) evaluated the vitamin K status in elderly patients using the "thrombotest," an assay of coagulation factors. In 74% of subjects, the thrombotest value was abnormal but returned to normal in most subjects after oral administration of a vitamin K analogue. The increased sensitivity of humans and rats to the anticoagulant warfarin with age may represent age-related changes in vitamin K metabolism (140). It has also been shown that experimental vitamin K deficiency is induced more easily in old rats than in young ones (37).

No statement about the vitamin K requirements of the elderly can be made at present, but further research employing new assay methods such as the determination of abnormal prothrombin should yield better information.

Vitamin C

Cheng et al (25) provide an extensively documented review of the literature on ascorbic acid requirements and nutriture of the elderly. Despite the abundance of this vitamin in fruits and vegetables, there is nevertheless wide variation in ascorbic acid intake by the US elderly. Thus, among old people surveyed in HANES I, between 23 and 42% (depending on race and income) had intakes below 30 mg per day (19). In the Ten-State Survey (150), intakes and plasma ascorbic acid levels were low in 10% of the low-income elderly. Nevertheless, frank scurvy with capillary hemorrhages is a rare clinical consequence (24), being seen mainly in alcoholics and impoverished old men who exclude fruit and vegetables from their menus. Clinical experience of scurvy suggests that in some old people inherent capillary weakness may make them more susceptible to scorbutic hemorrhages under adverse nutritional conditions (96).

A plasma ascorbic acid level below 0.4 mg% is regarded as indicating deficiency, while less than 0.2 mg% is found in cases of scurvy. Most investigators have observed a decline with increasing age in ascorbate levels in whole blood, in plasma, and in leukocytes (19). The age-related decline in blood ascorbic acid has been attributed to reduced consumption as age advances (19), in agreement with the conclusion of Garry & Hunt (54). Ascorbic acid levels also decline in the tissues of aging rats, even though the rat does not depend on an external source of ascorbic acid (123). Of interest is the finding in hospitalized elderly British women of especially low levels of ascorbic acid in white blood cells, levels that were only restored to normal by administering 80 mg ascorbic acid daily as a dietary supplement (6). This implies that total intake was probably over 100 mg ascorbic acid daily. However, generous doses of ascorbic acid given daily for lengthy periods failed to improve the clinical condition of nursing-home patients (6, 21) or resulted at best in small increases in body weight and in plasma protein levels (139). Garry & Hunt (54) recently made the interesting observation that elderly subjects with low plasma ascorbic acid values show impaired cognitive functioning.

In conclusion, there is no published evidence to suggest that ascorbic acid absorption diminishes in aging, and we must accept the view of Garry & Hunt (54) that low intakes of vitamin C account for most of the low plasma levels of ascorbic acid among the elderly. Encouraging the consumption of vitamin C–rich food may be the most effective way of improving vitamin C nutriture of the elderly. At present, there is no compelling evidence for altering requirements of vitamin C for the elderly.

Vitamin B_1

Although thiamin (vitamin B_1) occurs in food in only small concentrations, the classical deficiency syndrome of beriberi is hardly seen in Western societies, except in alcoholics (84). Because of the involvement of thiamin in carbohydrate metabolism, thiamin requirements are considered to correlate with overall energy intake (84, 126), so that the requirement would be expected to be reduced in the elderly because of their lower energy intakes. While advising intake of at least 0.5 mg thiamin per 1000 kcal, the RDA handbook (126) nevertheless recommends maintaining a daily intake of not less than 1 mg thiamin for older men and older women even when caloric intake falls below 2000 kcal. A consensus report on the thiamin needs and nutriture of the elderly (84) challenges these as being too generous, pointing out that no biochemical evidence of deficiency emerged when young adults received 0.3 mg/1000 kcal (137).

Surveys of nutrient consumption by the US population show that from 0 to 47% of the elderly have thiamin intakes lower than two thirds of the RDA (19, 84). Of the elderly (aged 65–74 yr) surveyed in HANES I, 18 to 46% had daily thiamine intakes (depending on race and income) below two thirds of the RDA (19). In HANES I and II the calorie-adjusted thiamin intakes of the elderly surveyed was in the range 0.73–0.77 mg/1000 kcal, well above the recommended allowance of 0.5 mg/1000 kcal (84). A recent survey of Boston healthy elderly (111) concluded that no more than 5% were receiving less than two thirds of the RDA for thiamine. However, more than one third of the low-income elderly examined in the Ten-State Nutrition Survey had intakes below 0.4 mg/1000 kcal (120).

Due to methodological difficulties, blood thiamin is generally not used as a measure in surveys. In one such study of free-living elderly, 11% showed thiamine hypovitaminemia (11). On the other hand, red blood cell transketolase, a thiamine pyrophosphate-dependent enzyme, is often measured for the assessment of thiamine nutriture and has been found to undergo a slight but significant decrease in activity from birth through old age (105). A variant of this assay is the transketolase-activated coefficient, in which the response of the enzyme to thiamine pyrophosphate is measured. This test showed inadequate responses in 3 to 15% of healthy free-living elderly in different surveys (84). Using urinary thiamin excretion as an index of thiamine nutriture, 0–9% of the elderly had low values (14, 97, 101). There is no agreement on whether thiamine absorption in man changes with age (84, 151). No age-related changes in thiamine metabolism appear to have been reported.

In conclusion, impairment of thiamine nutriture in the elderly appears to be due to low intakes secondary to social factors or chronic illness. The present RDA for thiamine seems to be appropriate or even generous (84) for the older population in good health.

Vitamin B_2

Depending on income, 12 to 36% of elderly surveyed in HANES I had intakes below two thirds of the 1974 RDA for vitamin B_2 (19), while in the Ten-State Survey (14) 19 to 27% were below this intake. On the other hand, less than 6% of the 60–93-year-old healthy middle-class elderly surveyed by Garry et al (53) had riboflavin intakes from their diets below three fourths of the RDA. This once more emphasizes the impact of social status on nutrient intake.

Using the erythrocyte glutathione reductase (EGR) activity coefficient for assessing riboflavin status, different surveys show 0–28% of elderly to be vitamin B_2 deficient (52, 149). A similar prevalence of impaired riboflavin status in healthy elderly has been found by measuring urinary riboflavin excretion (1, 101). However, mean EGR activity coefficients tend to decrease with age independently of riboflavin intake (54). There is no definitive evidence for changes in riboflavin absorption by human subjects due to aging (134) and no significant age-related changes occur in riboflavin tissue levels (138). It can be concluded that riboflavin requirements are not affected by aging.

Niacin

There are extensive variations in niacin intakes of the elderly, 0 to 53% of whom, depending on race and income, have intakes below two thirds of the RDA (19, 53, 61). Because of the limitations of current biochemical methods, reliable information on niacin nutriture among the elderly is scanty. Using urinary excretion of *N*-methyl-nicotinamide as an index of niacin nutriture, 1–50% of different heterogeneous elderly population samples (including free-living, institutionalized, and ill individuals) have been assessed as niacin-deficient (112, 149). In rats, niacin absorption is reported to be unchanged by aging (48). Lack of data makes it inappropriate to comment on the present niacin RDA (126) for the elderly.

Vitamin B_6

Vitamin B_6 occurs as three vitamers, namely pyridoxine, pyridoxal, and pyridoxamine, each of which can be phosphorylated. The active form, pyridoxal phosphate (PLP), is made mostly in the liver and exported in the plasma to other tissues (30). Despite the wide distribution of vitamin B_6 in foods, 50–90% of surveyed elderly have low vitamin B_6 intakes as assessed by the 1980 RDA (39, 53, 63, 163).

Fasting plasma levels of PLP decrease with age (69, 129). Rose et al (129) report a fall of 0.9 ng/ml per decade in plasma PLP. Consequently, in subjects not receiving supplements, the prevalence of low plasma PLP levels increases with age: only 3% under 40 years of age had PLP plasma levels below 5 ng/ml, as compared to 12% over 80 years (129). None of the subjects receiving vitamin B_6 supplements had any values as low as this. These population studies on elderly subjects should be repeated using recent techniques for measuring the various B_6 vitamers in blood (30). In mice, ^{3}H-pyridoxine injected into elderly animals converted less to PLP and more to pyridoxal and pyridoxine than it did in young mice (49). However, vitamin B_6 content of arterial and venous tissue from adults ranging in age from 20 to 86 years showed no age-related changes (90).

Measurements of transaminase activities (erythrocyte glutamate–oxaloacetate transaminase and erythrocyte glutamate–pyruvate transaminase) are widely used indices of vitamin B_6 nutriture. Several studies have shown that some 30–40% of free-living elderly have subnormal erythrocyte transaminase activity coefficients (39, 163). Usually such low enzyme activity coefficients return to normal upon oral vitamin B_6 supplementation (69, 87). However, Vir & Love (163) could not demonstrate normalization of abnormal transaminase activity coefficients with oral vitamin B_6 supplementation in approximately 20% of an elderly heterogeneous population. Others have reported similar findings, which thus suggest increased vitamin B_6 requirements with age (63, 64, 79). The capacity to catabolize tryptophan, which also correlates directly with vitamin B_6 nutriture, also diminishes with age (69). At present, the data are insufficient for making a final statement on the appropriateness of the current RDA for elderly humans.

Folate

Reported folate intakes by the elderly show wide variations (53, 88, 130). These are confounded by the incomplete analyses available for the folate content of many foods (52). The most recent RDA (126) for elderly adults is 400 μg/day, but most surveys put the average intakes well below this. Thus 70% of men and 84% of women among healthy elderly surveyed by Garry et al (53) had folate intakes below three fourths of the RDA, while the Nutrition Canada Survey (130) found mean folate intakes of 151 μg (elderly men) and 130 μg (elderly women). A Swedish survey (88) reported very similar intakes.

In a review of published plasma folate levels in elderly populations, low levels (i.e. < 3 μg/ml) were reported in only 3–7% of free-living elderly

(130). Similarly, Girdwood et al (59) could not find a difference in serum folate levels between a free-living elderly Scottish population and younger controls, whereas patients in a geriatric hospital had significantly lower plasma folate levels. In a 6-year study of 35 healthy elderly people, Jagerstad & Westesson (88) showed that folate nutriture can be maintained despite folate intakes of 100–200 μg/day, which is well below the RDA. The absence of clinical evidence of folate deficiency in the surveys described above suggests that the RDA for folate may be excessive.

Old age by itself does not affect folic acid absorption by rats (16). However, folate absorption is strongly pH-dependent. Gastric atrophy and atrophic gastritis with achlorhydria and hypochlorhydria occur in 10–30% of people over 60 years of age and cause malabsorption of folate by raising intraluminal pH in the proximal small intestine (22, 132). It might be anticipated that elderly persons with achlorhydria would display low blood folate levels, but Russell et al (132) found that serum folate levels were normal in such subjects, probably because increased bacterial synthesis of folate in the upper intestine compensates for the diminished absorption. Prior to absorption, dietary polyglutamates need to be hydrolyzed to folate monoglutamate by gamma glutamyl peptidase (folate conjugase) in the upper jejunum, but no consistent age-related changes in the activity of the folyl conjugase have been reported (10). Finally, attention should be drawn to the adverse effects on folate absorption and metabolism of a number of drugs commonly taken by the elderly (129). Alcohol alters the kinetics of folate metabolism and increases its excretion (133) while chronic alcoholism can cause megaloblastic anemia (130).

In summary, healthy elderly people appear to be able to maintain normal folate nutriture despite folate intakes well below the RDA. The RDA for folate (126) may thus be too high.

Vitamin B_{12}

Diet-induced deficiency of vitamin B_{12} is uncommon even among vegetarians (171). The usual cause of vitamin B_{12} deficiency is loss of gastric intrinsic factor in pernicious anemia. There is wide variation of vitamin B_{12} intakes in the healthy elderly population: Garry et al (53) found that 24% of men and 39% of women among healthy elderly had vitamin B_{12} intakes below three fourths of the RDA.

With increasing age there is a decline in the mean serum vitamin B_{12} levels. Vitamin B_{12} serum or plasma levels below 150 pg/ml have been reported to increase with aging (38, 41, 149). There are no consistent data on age-related changes in liver vitamin B_{12} content (67), and age alone does not influence vitamin B_{12} absorption by rats (48) or humans (109). However, elderly subjects with hypo- or achlorhydria due to atrophic gastritis may malabsorb cobalamin (38). Atrophic gastritis in the elderly can affect vitamin B_{12} absorption in three ways. First, vitamin B_{12} bound to food proteins cannot be freed because of protein maldigestion (31). Second, in achlorhydria bacteria overgrow in the upper gastrointestinal tract and are capable of binding vitamin B_{12} and/or transforming it to nonfunctioning analogues (167). Third, there may be lack of intrinsic factor needed for vitamin B_{12} absorption (9).

Despite the reported age-related changes in vitamin B_{12} utilization described above, there is at present no reason to alter vitamin B_{12} requirements with age. However, certain substrata of the older population (e.g. those with atrophic gastritis) could require higher dietary vitamin B_{12} than is presently recommended.

Biotin

Biotin is widely distributed in foods and is also available from intestinal bacterial synthesis, so that deficiency is rare (18). There are limited studies on biotin nutriture in the aged. In a survey of 473 free-living or institutionalized elderly, essentially all were found to have normal blood biotin levels (11). In contrast, Bonjour (18) reported significantly lower blood levels in elderly as compared to younger controls. Urinary biotin excretion is lower in subjects with achlorhydria, possibly because release of food-bound biotin is impaired (106).

Pantothenic Acid

There is no clearly defined pantothenic acid deficiency syndrome in man, and data on pantothenic acid nutriture in the elderly is scanty. It is widely distributed in foods, and there is no agreement on whether the elderly have an adequate pantothenic acid intake (145). Total blood pantothenic acid and protein-bound pantothenic acid have been reported to decline with age (85), but others have reported no age-related change in blood pantothenic acid (145). In rats there is a significant decline of serum pantothenate with age (148). Data about changes in urinary pantothenic acid excretion with age are contradictory (145). Because of the limited nature of the reported studies, no conclusion can be drawn about the requirements for pantothenic acid by the elderly.

NUTRITIONAL STATUS OF THE ELDERLY

Evidence from Surveys

The frequency of malnutrition in a population or a subgroup can be obtained by a combination of food intake measurements and biochemical measurements on blood or urine, or through function tests (e.g. transketolase for thiamin status), and finally by clinical evaluation. Two successive rounds of HANES surveys (71) made on a representative group of Americans provide some indication of the frequency of malnutrition, but include only the elderly up to 74 years of age. The importance of assessing the clinical status of the elderly individuals being surveyed is illustrated by a representative survey of the British population (34). Among 365 men and women 70 years and older, 26 were identified as suffering from some form of malnutrition. The incidence of malnutrition was 6% for men and 5% for women between 70 and 79 years old, and 12% and 8% respectively from 80 years of age onward. In most of the 26 subjects, malnutrition was secondary to diseases likely to precipitate it through reduced appetite and increased requirements, diseases such as chronic emphysema, bronchitis, dementia, and mental depression. This raises the dilemma of whether to exclude cases of malnutrition secondary to chronic disease, the answer to which will depend on whether one is assessing the frequency of malnutrition from all causes or is measuring the occurrence of suboptimal nutrition in healthy elderly.

In addition to such national surveys, specific groups have been examined. For example, a survey of elderly people in New Jersey living either at home or in nursing homes (11) can be compared with a similar survey in Belfast, Northern Ireland, which included hospitalized elderly in addition to the other two groups (165). In both surveys, biochemical analysis of blood for selected vitamins showed that the percentage of unacceptably low values varied according to whether the elderly person was at home, in a nursing home, or in hospital. In addition, the relative frequencies of low values varied in the two geographical locations. The impact of vitamin supplementation on biochemical values has been dealt with in surveys of free-living elderly in New Mexico (53, 54) and in Boston (111).

Exton-Smith (42) has divided factors contributing to malnutrition into a series of primary and secondary causes. He lists primary factors as (*a*) ignorance of the need for a balanced diet; (*b*) financial restrictions on the range of food purchased; (*c*) a similar restriction from physical disability (e.g. arthritis) causing the old person to be house-bound; (*d*) social isolation giving rise to a lack of incentive to eat; and (*e*) mental disorders that are often incompatible with the provision of a well-balanced diet. To these we can add the effect of diseases such as chronic bronchitis, which, as noted above, are frequently associated with malnutrition. His secondary causes of malnutrition include (*a*) malabsorption from intestinal disease and from achlorhydria; (*b*) alcoholism, which affects the nutritional status of the elderly when substituted for nutrient-rich caloric sources, and which interferes with absorption of some nutrients, notably folic acid; and (*c*) use of certain therapeutic drugs that interfere with absorption and metabolism of nutrients.

Drug-Nutrient Interactions

Therapeutic drugs can be significant factors in the nutrition of the elderly. A survey of Boston elderly (111) showed that 47% were using medications, often several. Roe (128) provided a recent comprehensive analysis of how drugs can affect nutritional status. First, a number of drugs depress appetite. Second, some medications interact with absorption of specific nutrients. Thus folic acid absorption is reduced by binding to cholestyramine, by reduction in intestinal acidity with antacids, and by inhibition of mucosal folate enzymes by sulfasalazine. Cholestyramine also binds vitamins A and K and thus reduces their absorption, while tetracycline chelates calcium. Finally, the metabolism of some nutrients can be altered by drugs. The uptake of folate into red cells is inhibited by salicylates, and its catabolism is accelerated by phenytoin. Phenytoin and phenobarbital increase catabolism of vitamin D, while the hydroxylation of this vitamin is inhibited by isoniazid, which also affects vitamin B_6 metabolism by inhibiting pyridoxal kinase. Finally, several drugs inhibit the action of vitamin K in prothrombin carboxylation. For individuals on phenytoin, Roe (128) recommends an increase in the daily intakes of vitamin D (20–30 μg), vitamin K (2–5 mg), and folic acid (0.8–1.2 mg). The same increased intake of folic acid is recommended for those on sulfasalazine and on colestipol, while increased intake of vitamin A (5,000–10,000 IU) should be prescribed for those on cholestyramine.

Nutrition Intervention Strategies

Finally, in view of the number of elderly who, for one or another of the reasons listed above, consume insufficient diets causing poor nutritional status, it is important to recognize that food intervention programs are available in the US. The effectiveness of these was recently reviewed by Kohrs (93). From studies in Missouri, she demonstrates how adequacy of intake varies between elderly women living alone in different types of housing, and what services are available to them, whether through congregate feeding, meal deliveries, or food stamps. Much of the benefit of congregate food programs stemmed from the social interaction of such occasions. Nevertheless, three surveys comparing food program participants with nonparticipants found that intakes of energy and protein were increased, as were intakes of vitamins and minerals, notably calcium. Evaluations of meal programs, while confirming the general nutritional adequacy of the meals served, demonstrated that their content of zinc was low, and it is likely that folic acid was also underrepresented. These are, of course, features of the zinc and folate consumptions of the general population as compared with the much larger recommended dietary allowances (126).

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