

Effect of protein intake on bone and muscle mass in the elderly

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The aging process is frequently characterized by an involuntary loss of muscle (sarcopenia) and bone (osteoporosis) mass. Both chronic diseases are associated with decreased metabolic rate, increased risk of falls/fracture, and, as a result, increased morbidity and loss of independence in the elderly. The quality and quantity of protein intake affects bone and muscle mass in several ways and there is evidence that increased essential amino acid or protein availability can enhance muscle protein synthesis and anabolism, as well as improve bone homeostasis in older subjects. A thorough evaluation of renal function is important, since renal function decreases with age. Finally, protein and calcium intake should be considered in the prevention or treatment of the chronic diseases osteoporosis and sarcopenia.

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INTRODUCTION

The aging process is characterized by an involuntary loss of muscle (sarcopenia) and bone (osteoporosis) mass. This degenerative loss of skeletal muscle occurs at a rate of 3–8% per decade after the age of 30 and accelerates with advancing age.¹ There is also evidence that bone loss starts in the third and fourth decades of life, and in women, the annual rates of bone loss increase by more than 1% after menopause.² Lifetime risk of any osteoporotic fracture is very high, with ranges of 40–50% being reported for women and 13–22% for men.³ Sarcopenia and osteoporosis are associated with decreased metabolic rate, increased risk of falls and fracture, and, as a result, increased morbidity and loss of independence.⁴

The main amino acid reservoir in the body is skeletal muscle, which contains 50–75% of all proteins in the human body.⁵ In addition, loss of skeletal muscle and lower protein intake are closely related and play an important role in both sarcopenia and osteoporosis, since they affect both bone metabolism and muscle anabolism, as shown in Tables 1 and 2, respectively.⁶

Based on the results of all available studies that have estimated the minimum protein intake necessary to avoid a progressive loss of lean body mass determined by nitro-

gen (N) balance, the Food and Nutrition Board recommends that protein intake under normal conditions equate to 0.6 g/kg per day according to the estimated average requirements (EAR) and 0.8 g/kg per day according to the recommended dietary allowance (RDA). It is emphasized that intake must be accompanied by an adequate energy supply to achieve optimal protein utilization and it should account for 10–35% of total energy consumed.⁷

Campbell et al.⁸ assessed the effect of age on the EAR and RDA for protein and observed that there was no difference between the mean protein requirement for younger subjects (0.61 g protein/kg/d) and that for older subjects (0.58 g protein/kg/d), suggesting that the requirement for total dietary protein is no different for healthy older adults or for younger adults and that the allowance estimate does not differ statistically from the RDA.

On the other hand, EAR and RDA could be greater than assumed in malnourished or elderly ill subjects and protein turnover value per kilogram of body weight might be higher as a result of a hyper-catabolic state when compared to elderly healthy persons.⁹ Additionally, consumption of less than the EAR has been observed in elderly Americans. The National Health and Nutrition Examination Study III observed that the percentage of men

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Table 1 Characteristics and outcomes of studies evaluating the effect of protein intake on bone mass.

Reference	Subjects	Nutritional characteristics	Outcomes
Effect of quantity of protein intake on bone mass			
Hannan et al. (2000) ¹⁸	Elderly women and men	Protein 68 g/day (16% of energy)	Protective against spinal and femoral bone loss
Kestetter et al. (2000) ¹⁹	Postmenopausal women	Protein > 75 g/day	Positive association between protein intake and total bone mineral density
Munger et al. (1999) ²⁰	40,000 postmenopausal women	High protein intake	69% reduction in risk of hip fracture
Wengreen et al. (2004) ²¹	2,500 women and men (50–69 y)	High protein intake (17.4–30.8% of energy intake)	65% reduction in risk of hip fracture
Hunt et al. (2009) ²⁴	Healthy postmenopausal women	High dietary protein (10–20% of energy intake)	Decreased urinary deoxypyridinoline and increased serum IGF-1
Kestetter et al. (2005) ²⁵	10 women (55–70 y)	Moderate (1.0 g/kg/d) or high (2.1 g/kg/d) protein intake	The high-protein diet caused a significant reduction in urinary calcium and a nonsignificant reduction in the rate of bone turnover.
Feskanich et al. (1996) ²⁶	85,900 women (53–59 y)	More than 95 g/d and low calcium intake (≤ 541 mg/day)	Increase in forearm fracture risk (RR 1.22 [95% CI 1.04–1.43])
Dargent-Molina et al. (2008) ²⁷	2,408 women	Lowest quartile of calcium and high protein intake	Increase in fracture risk (RR1.51 [95% CI 1.17–1.94])
Meyer et al. (1997) ²⁸	Elderly women and men	Protein intake (20.6 g/d) + low calcium intake (435 mg/d)	Double the risk of hip fracture (RR1.96, CI 95% 1.09–3.56)
Effect of quality of protein intake on bone mass			
Evans et al. (2007) ²⁹	572 women; 388 men (55–92 y)	For every 15 g/day increase in animal protein	Hip BMD increased by 0.016 g/cm ² , at the femoral neck 0.012 g/cm ² , at the spine 0.015 g/cm ² , and total body 0.010 g/cm ² .
Larsson et al. (2005) ³⁰	226 free-living healthy men (42–76 y)	Consumption of red meat (31.2 g)	Positive correlation between IGF-1 and consumption of red meat ($P = 0.05$)
Roughead et al. (2003) ³¹	15 postmenopausal women	High-meat diet (117 g of protein) vs low-meat diet (45 g of protein)	Controlled high-meat diets do not affect calcium retention or indices of bone status in healthy postmenopausal women
Lau et al. (1998) ³²	Vegetarian Chinese women	Vegetable protein	Decrease in hip bone mineral density
Promislow et al. (2002) ³³	Postmenopausal women	Soy protein intake	No impact on bone mineral density
Kenny et al. (2009) ³⁴	131 healthy women (60 y)	Soy protein + isoflavone	No effect on BMD (either alone or together)
Spenc et al. (2005) ³⁵	Postmenopausal women	Vegetable-based protein	Less urinary calcium excretion
Koh et al. (2009) ³⁶	63,257 Chinese	Soy protein + isoflavone	Second to fourth quartiles exhibited 21–36% reduction of hip fracture
Appleby et al. (2007) ³⁷	7,947 men and 26,749 women (20–89 y)	Fish eaters, vegetarians, and vegans; diet + low calcium intake (< 525 mg/d)	Fracture risk with low calcium intake + vegan diet (RR 1.30 [95% CI 1.02–1.66])
Darling et al. (2009) ³⁸	Meta-analysis	Total protein intake	Positive association between BMD and BMC and protein intake. Protein intake explains 1–2% of BMD

BMD, bone mineral density; BMC, bone mineral content.

Table 2 Characteristics and outcomes of studies evaluating the effect of protein intake on muscle mass.

Reference	Subjects	Nutritional characteristics	Outcomes
Effect of quantity of protein intake on muscle mass Houston et al. (2008) ³⁹	2,000 individuals (70–79 y)	Protein intake (91.0 g/d)	40% less loss in lean body mass
Bos et al. (2001) ⁴¹	Malnourished hospitalized patients	Protein intake 1.0, 1.5, and 2.0 g/kg/d	Greater rates of whole-body protein synthesis and improved nitrogen balance
Chevalier et al. (2003) ⁴²	Frail women	Protein intake 0.87–1.23 g/kg/d	Increase in net endogenous protein balance and positive nitrogen balance
Thalacker-Mercer et al. (2007) ⁴³	Older adults	0.5 g/kg/d and 1.2 g/kg/d	Muscle wasting compared to high-protein intake
Effect of quality of protein intake on muscle mass Boersheim et al. (2008) ⁴⁸	Healthy elderly people	Oral administration of 30 g EAAs	Increase in lean body mass, strength, and functional test scores
Volpi et al. (1999) ⁴⁹	Healthy young and elderly subjects	Oral administration of AA mixture and infusion of phenylalanine	Phenylalanine transport into the muscle, muscle protein synthesis, and net balance increased significantly ($P < 0.01$)
Baier (2009) ⁵⁰	Elderly women (76 y)	Supplement of beta-hydroxy-beta-methylbutyrate, L-arginine, and L-lysine	The rates of protein turnover were significantly increased by 12% in one year
Rieu et al. (2006) ⁵¹	Elderly men	Leucine supplementation	Improved muscle protein synthesis
Katsanos et al. (2005) ⁵⁵	Elderly	7 g EAAs	Inefficient at stimulating protein synthesis
Katsanos et al. (2006) ⁵⁶	Elderly	6.7 g EAAs – 41% of leucine (2.79 g)	EAAs can reverse an attenuated response of muscle protein synthesis
Symons et al. (2007) ⁵⁷	Elderly men and women	113 g serving of an intact protein (lean beef)	Increased muscle protein synthesis by approximately 50%
Pannemans et al. (1998) ⁵⁸	Elderly women	Animal protein and vegetable protein	Less net protein synthesis in the high-vegetable protein diet than in the high-animal protein diet
Lord et al. (2007) ⁵⁹	Elderly women	Animal protein intake	Animal protein intake was the only independent predictor of muscle mass index ($r^2 = 0.19$; $P = 0.008$)

EAAs, essential amino acids.

between 51 and 70 years old who consumed less than the EAR for protein was less than 3% and for men above 71 years of age, it was 5.6%. In women between 51 and 70 years of age, the rate was 4.4%, and 5.9% of women above 71 years old consumed less than the EAR for protein.¹⁰

Protein intake seems to be very important for providing some benefit in managing chronic diseases such as osteoporosis and sarcopenia. This review intends to discuss the effect of protein intake on muscle and bone mass and provide an overview of the current status of research in these areas.

POTENTIAL ROLE OF PROTEIN INTAKE ON BONE AND MUSCLE MASS

There are several potential mechanisms by which protein intake affects bone metabolism. It has been observed that

increased protein intake could improve bone matrix collagen protein.¹¹ One-third of bone volume is composed of 50% of protein, which is critical for the synthesis of type I collagen that involves post-translational modifications of amino acids, including hydroxylation of lysine and proline, and many other non-collagen proteins in the bone matrix.¹²

A potential effect of protein intake on bone mass involves the production and action of insulin-like growth factor-1 (IGF-1).¹³ It is an essential factor for longitudinal bone growth and induces an anabolic effect on bone mass during adulthood. It also has pluripotent effects on calcium and phosphate metabolism, including enhanced calcitriol synthesis and stimulated renal phosphate reabsorption. IGF-1 selectively stimulates the plasma membrane uptake of inorganic phosphate in osteoblastic cell lines to promote matrix mineralization.¹³ In an

experimental study with protein-restricted adult female rats, a marked decrease of 29–34% in plasma IGF-1 was shown, while trabecular bone mineral density (BMD) was decreased and accompanied by an increased urinary deoxypyridinoline excretion without any change in osteocalcin levels, suggesting an uncoupling between resorption and formation.¹⁴ In humans practicing calorie restriction with reduced protein intake from an average of 1.67 g/kg of body weight per day to 0.95 g/kg of body weight per day for 3 weeks, a reduction was observed in serum IGF-1 from 194 ng/mL to 152 ng/mL. In addition, for undernourished elderly individuals with hip fracture, protein supplementation of 20 g/d could increase IGF-1 production and attenuation of proximal femur bone loss.¹⁵

Protein intake, especially amino acids such as leucine and IGF-1, are anabolic stimuli for muscle metabolism. Evidence suggests that amino acid availability is a potent regulator of muscle protein synthesis and an increase can enhance muscle protein synthesis and anabolism in older subjects.¹⁶ Both anabolic stimuli for muscle share a common pathway of action via activation of mammalian target of rapamycin (mTOR) signaling cascade.¹⁷ Stimulation of muscle protein synthesis in humans after feeding is accompanied by enhanced phosphorylation and activity of the mTOR signaling pathway, including the 70-kDa ribosomal protein S6 kinase (S6K1) and its target ribosomal protein S6 (rpS6). In addition, rates of protein synthesis are tightly regulated by the activity of the guanine nucleotide exchange factor eukaryotic initiation factor 2B (eIF2B), which is responsive to amino acid intake and is controlled by glycogen synthase kinase-3b.¹⁷

EFFECT OF DIETARY PROTEIN ON BONE MASS

Effect of quantity of protein intake on bone mass

Recent evidence supports the hypothesis that dietary protein is also critical for bone health and fracture reduction, and the quantity of protein intake may be important for preserving bone mass in later years. Epidemiological studies have observed that the quantity of protein influences bone metabolism and BMD.^{18–21} The Framingham Osteoporosis Study was carried out on a large cohort of elderly women and men who were prospectively followed over 4 years. It was observed that the highest levels of protein intake (84–152 g/day) were correlated with protection against spinal and femoral bone loss in both genders when compared to the lowest quartile (17–51 g/day).¹⁸ Also, dietary protein intake above 75 g/day and total BMD for the hip were positively associated in postmenopausal women in the Third National Health and Nutrition Examination Survey.¹⁹ Similarly, in a prospec-

tive study of approximately 40,000 women in Iowa, higher protein intakes were associated with a 69% reduction in risk of hip fracture.²⁰ In addition, a case-control study of 2,500 men and women in Utah demonstrated a negative relationship between protein intake and hip fracture incidence in men and women between the ages of 50 and 69 years. In the highest quartile of protein intake (17.4–30.8% of energy intake), hip fracture incidence was reduced by 65%.²¹

Protein intake also has an effect on calcium balance. Previous studies observed a decrease in renal tubular reabsorption of calcium and an increase in urinary calcium excretion with high protein intake. It was assumed that the additional calcium loss is entirely from bone, leading to the hypothesis that high-protein diets are detrimental to the skeleton.^{22,23}

However, recent studies evaluating a moderate increase in dietary protein, from 10% to 20%, and calcium balance through calcium isotopes, observed that the increase in urinary calcium excretion is due to improved intestinal calcium absorption, thereby improving bone health by decreased urinary deoxypyridinoline and increased serum IGF-1 without affecting parathyroid hormone, osteocalcin, bone-specific alkaline phosphatase, or tartrate-resistant acid phosphatase; there was also no negative effect on skeletal calcium balance.²⁴ Another study that evaluated high levels of protein intake (2.1 g/kg/d) and calcium balance by stable calcium isotopes observed that intestinal calcium absorption increased with the high-protein diet in comparison with the moderate diet (26.2% versus 18.5%, $P < 0.0001$) as did urinary calcium (5.23 versus 3.57 mmol/d, $P < 0.0001$). The high-protein diet caused a significant reduction in the fraction of urinary calcium of bone origin and a non-significant trend toward a reduction in the rate of bone turnover. There were no protein-induced effects on net bone balance.²⁵ These data directly demonstrate that, at least in the short term, high-protein diets are not detrimental to bone health.

The negative effect of high protein intake observed in some studies might be attributed to low calcium intake and not necessarily to high protein intake. During 12 years of follow-up in the Nurse's Health Study, protein intake greater than 90 g/d was associated with an increased risk of forearm fracture (OR = 1.22, 95% CI 1.04–1.43) in a cohort of 85,900 women aged 35–59 years. However, women with high-protein (>90 g/day) diets that were also high in calcium had a relative risk of 1.15 (95% CI 0.84–1.58) for forearm fracture, while a more elevated risk of 1.31 (95% CI 0.94–1.82) was observed among women with high-protein but low-calcium (≤ 541 mg/day) diets; this suggests the risk of forearm fracture with higher intakes of protein may be exacerbated by low calcium intake.²⁶ Also, in the

epidemiological study E3N (Etude Epidémiologique de femmes de la Mutuelle Générale de l'Education Nationale) with 2,408 women who reported a fracture, women who had a high protein intake and were in the lowest quartile of calcium intake (<400 mg/1,000 kcal) were observed to have an associated significant increase in fracture risk (RR 1.51 for the highest versus lowest quartile; 95% CI 1.17–1.94).²⁷ Similarly, Meyer et al.²⁸ observed that subjects with the combination of high protein intake (20.6 g/d, highest quartile bound) and low calcium intake (435 mg/d, lowest quartile bound) were at approximately double the risk of hip fracture (RR 1.96, 95% CI 1.09–3.56) when compared with other subjects in the study. The results of these studies suggest that calcium intake may, in fact, influence the impact of dietary protein on the skeleton.

Effect of quality of protein intake on bone mass

Protein sources may also have different effects on bone metabolism and BMD. Studies have observed that animal protein intake (meat and dairy products) is associated with higher BMD and also a better effect on bone and calcium metabolism, while vegetable protein intake (soy food) has not been linked with an effect on BMD.

In a community-dwelling cohort of 572 women and 388 men aged 55–92 years, multiple linear regression analyses adjusted for standard osteoporosis covariates showed a positive association with animal protein consumption. For every 15 g/day increase in animal protein intake, BMD increased by 0.016 g/cm² at the hip ($P = 0.005$), 0.012 g/cm² at the femoral neck ($P = 0.02$), 0.015 g/cm² at the spine ($P = 0.08$), and 0.010 g/cm² for the total body ($P = 0.04$). Conversely, a negative association between vegetable protein and BMD was observed in both sexes.²⁹ Larsson et al.³⁰ observed that the consumption of red meat ($P = 0.05$) and fish and seafood ($P = 0.07$) was modestly positively associated with IGF-1 concentrations. In a randomized study with healthy postmenopausal women, it was observed that consuming a high-meat diet (117 g of protein per day or 1.62 g/kg/d) did not affect calcium excretion and biochemical markers of bone formation and resorption when compared with a low-meat diet (45 g/d of meat and 68 g of protein).³¹

Investigating the differences between animal and vegetable protein intake in BMD, a community-based study observed that hip BMD of 76 vegetarian Chinese women (age 70–89 years) was lower when compared to omnivorous control subjects.³² Furthermore, in a 9-month intervention with 61 postmenopausal women, soy protein intake showed no impact on bone mineral density.³³ Similarly, a randomized, double-blind, placebo-controlled clinical trial in 131 healthy ambulatory women aged 60 years were randomly assigned into one of four

intervention groups: soy protein (18 g) + isoflavone tablets (105 mg), soy protein + placebo tablets, control protein (18 g) + isoflavone tablets, and control protein + placebo tablets. It was observed that soy protein and isoflavones (either alone or together) did not affect BMD.³⁴

On the contrary, some studies support the idea that vegetable protein could have a positive effect on calcium and bone metabolism. A study evaluating calcium metabolism in postmenopausal women observed that urinary calcium excretion was significantly lower ($P < 0.01$) with consumption of either of the soy diets (i.e., soy protein isolate enriched with isoflavones [65 mg] and soy protein isolate devoid of isoflavones [3.1 mg]) than with consumption of casein-whey protein isolate (control diet).³⁵ In addition, a significant association of soy protein and isoflavones with hip fracture risk in women was observed in a prospective cohort of 63,257 Chinese. Those in the second to the fourth quartiles exhibited 21–36% reductions in risk of hip fracture (all $P = 0.036$).³⁶

Calcium intake should also be taken into consideration when evaluating the effect of the source of protein on bone health. Comparing fracture rates in four diet groups (meat eaters, fish eaters, vegetarians, and vegans) in the Oxford cohort of the European Prospective Investigation into Cancer and Nutrition (EPIC-Oxford), Appleby et al.³⁷ observed over an average of 5.2 years of follow-up that, in comparison with meat eaters, the fracture incidence rate ratios in men and women (combined and adjusted for sex, age, and non-dietary factors) were 1.01 (95% CI 0.88–1.17) for fish eaters, 1.00 (95% CI 0.89–1.13) for vegetarians, and 1.30 (95% CI 1.02–1.66) for vegans. After further adjustment for dietary energy and calcium intake, the incidence rate ratio among vegans compared with meat eaters was 1.15 (95% CI 0.89–1.49). Among subjects consuming at least 525 mg/d calcium, the corresponding incidence rate ratios were 1.05 (95% CI 0.90–1.21) for fish eaters, 1.02 (95% CI 0.90–1.15) for vegetarians, and 1.00 (95% CI 0.69–1.44) for vegans. The higher fracture risk in the vegans appeared to be a consequence of their considerably lower mean calcium intake.

Finally, in a recent meta-analysis, no significant effect was observed for total protein on the relative risk of fractures in the highest compared with the lowest quintile/quartile of total protein intake (RR 0.75 [95% CI 0.47–1.21, $P = 0.24$]), animal protein (RR 0.83 [95% CI 0.54–1.30, $P = 0.42$]), and vegetal protein (RR 1.21 [95% CI 0.82–1.79, $P = 0.34$]). However, in cross-sectional surveys, all pooled r -values for the relation between protein intake and BMD or bone mineral content at the main clinically relevant sites were significant and positive; protein intake explained 1–2% of BMD.³⁸

EFFECT OF DIETARY PROTEIN ON MUSCLE MASS

Effect of quantity of protein intake on muscle mass

The recent report of the Health Aging and Body Composition Study confirms the importance of protein intake in preserving lean body mass on a large population basis. Changes in body composition were determined over a 3-year period in more than 2,000 individuals aged 70–79 years. After adjustments were made for potentially confounding covariates, individuals in the highest quintile of protein intake (56.0 g/d or 0.8 g/kg/d) had 40% less loss of lean body mass over the 3-year period than those in the lowest quintile of protein intake (91.0 g/d or 1.2 g/kg/d).³⁹

Low protein intake may cause depletion of protein stores, essentially muscle mass, leading to an impairment of overall condition and increasing risk of disability and falls.⁴⁰ In malnourished and frail elderly subjects, Bos et al.⁴¹ and Chevalier⁴² observed that increasing dietary protein intake from 0.5 to 2.0 g protein/kg/day resulted in progressively greater rates of whole-body protein synthesis and improved nitrogen balance at the end of the diet period. Also, Thalacker-Mercer et al.⁴³ reported that low protein intake (0.5 g/kg/day) by older adults results in muscle wasting when compared to older adults consuming greater amounts of dietary protein (1.2 g/kg/day).

However, concerns exist regarding high protein intake, mainly in the elderly. It is agreed that evidence shows that high protein intake (up to 2.0 g/kg/d) could increase risk for impaired kidney function in healthy men and women.⁴⁴ A recent study in healthy elders showed that an increase in daily protein intake (0.9–2.1 g/kg/d) for 10 days resulted in changes of 57.7% in the glomerular filtration rate (GFR) when compared to younger participants. Also the cohort of the Nurse's Health Study observed that in women with mild renal insufficiency, high-protein diets (>1.3 g/kg/d) may lead to glomerular hyperfiltration.⁴⁵

Furthermore, there is general agreement that moderately increasing daily protein intake beyond 0.8 g/kg/d may enhance muscle protein anabolism and provide a reduction in the progressive loss of muscle mass with age. On the other hand, initial screening and subsequent monitoring of renal function and creatinine clearance may also be prudent for older individuals.⁴⁶

Effect of source of protein intake on muscle mass

In addition to the quantity of protein, the source of protein has to be considered since there are differences in the essential amino acid (EAA) content of proteins, which are required to avoid negative nitrogen (N)

balance and acutely improve muscle protein balance in the elderly.⁴⁷ Boersheim et al.⁴⁸ and Volpi et al.⁴⁹ observed that an oral administration of an EAA mixture to healthy elderly subjects resulted in an increased transport of phenylalanine into the leg muscle and also increased lean body mass, strength, and functional test scores. Another randomized study of an orally administered special mixture of amino acids (AAs) observed a significant increase in protein turnover rates of 8% and 12% in the supplemented group, while rates of protein turnover decreased 11% and 9% in the control subjects at 3 and 12 months, respectively.⁵⁰

Also, there is a dose-dependent response of muscle protein synthesis to EAA intake. Recent studies⁵¹ have shown that the maximal stimulation of muscle protein synthesis is achieved with approximately 35 g of high-quality protein that contains 15 g of all EAAs. Among the EAAs, the branched-chain amino acid (BCAA) leucine has been shown to be a key regulator of muscle protein synthesis.^{52–54}

Katsanos et al.⁵⁵ showed that a small bolus of essential amino acids (EAAs; 7 g) was insufficient to stimulate muscle protein synthesis in elderly subjects, whereas the same authors in another study observed that while both a 26% (1.72 g leucine) and a 41% (2.79 g leucine) bolus of leucine EAA increased muscle protein synthesis in young men, only a 41% leucine EAA bolus was effective in the elderly.⁵⁶

Also, recent data suggests that a moderate 113 g serving of protein (lean beef) contains sufficient amino acids (30 g total; 10 g EAAs) to increase muscle protein synthesis by approximately 50% in elderly men and women.⁵⁷ In addition, a study has been conducted on elderly women who consumed three diets differing in both the quantity and source of protein (diet A: 5.3% of energy intake provided by animal protein and 5.0% by vegetable protein; diet B: 14.5% of energy provided by animal protein and 5.1% by vegetable protein; diet C: 5.0% of energy provided by animal protein and 15.1% by vegetable protein). Subjects on these diets were followed for 2 weeks, and there were 2-week intervals between the diets. There was no effect of feeding on protein synthesis.

However, with a diet high in vegetable protein, protein breakdown in the absorptive state was not inhibited to the same extent as it was with the diet high in animal protein, resulting in less net protein synthesis during the high-vegetable-protein diet than during the diet with high intake of animal protein.⁵⁸ Lord et al.⁵⁹ observed an association between muscle mass index and animal protein intake in older women, and a stepwise regression analysis showed that animal protein intake was the only independent predictor of muscle mass index ($r^2 = 0.19$; $P = 0.008$).

Finally, including a serving of protein with high biological value should be considered in an adequate diet due to its positive effect on muscle protein anabolism.

CONCLUSION

In conclusion, aging is associated with a progressive loss of bone and muscle mass, in part due to protein and amino acid homeostasis. There is reasonable evidence indicating that protein intake levels higher than the RDA (0.8 g/kg/day) might be required for the elderly. Therefore, ensuring that the elderly, in particular, have an adequate dietary protein intake with high-quality proteins and adequate calcium intake is essential for preserving bone and muscle mass. However, evaluating renal function, which decreases with aging, is also important. Finally, protein and calcium intake should be considered in the prevention or treatment of the chronic diseases osteoporosis and sarcopenia.

Acknowledgments

Declaration of interest. The authors have no relevant interests to declare.

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