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Dietary protein and muscle in older persons

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Abstract

Purpose of Review—To highlight recent advances in nutrition and protein research that have the potential to improve health outcomes and status in aging adults.

Recent Findings—The beneficial effects of dietary protein on muscle health in older adults continue to be refined. Recent research has bolstered support for moderately increasing protein consumption beyond the current RDA by adopting a meal-based approach in lieu of a less specific daily recommendation. Results from muscle protein anabolism, appetite regulation and satiety research support that contention that meeting a protein threshold (approximately 30 g/meal) represents a promising strategy for middle-aged and older adults concerned with maintaining muscle mass while controlling body fat.

Summary—Optimizing dietary protein intake to improve health requires a detailed consideration of topics including muscle protein anabolism, appetite control and satiety. While each area of research continues to advance independently, recent collaborative and translational efforts have highlighted broad, translational consistencies related to the daily distribution and quantity of dietary protein.

Keywords

aging; sarcopenia; nutrition; satiety; strength

Overview

Higher protein diets continue to gain scientific support as a strategy to preserve lean mass, promote weight loss, prevent weight-regain following weight loss, or to simply maintain a healthy weight throughout the lifespan. The effectiveness of these diets appears to be driven, in part, by improvements in protein anabolism, daily appetite control and satiety. This brief synopsis will first summarize the state of the research regarding the effects of increased protein consumption on changes in body weight/composition during controlled-feeding trials and in free-living older adult populations. Recent conceptual and mechanistic advances in protein synthesis, energy expenditure, and the regulation of food intake will also be explored. Finally, the impact of protein quantity and timing of consumption will be addressed.

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Sarcopenia and protein recommendations

A reduction in muscle mass and functional capacity is a largely inevitable consequence of aging. The uncomplicated progression of sarcopenia results in a 3-8% reduction in muscle mass per decade, starting in the fourth or fifth decade of life. During this early period, small decrements in muscle mass or function may be readily masked by subtle lifestyle adaptations. However, advanced sarcopenia is synonymous with physical frailty and associated with an increased risk of falls and impairment in the ability to perform routine activities of daily living (1, 2).

The Recommended Dietary Allowance (RDA) for protein (i.e., 0.8 g protein/kg/day) describes the quantity of protein required daily to prevent deficiency for all adults, irrespective of age. In recent years, there has been increased support for the contention that the current RDA for protein is insufficient to promote optimal health. To this end, several recent reviews and consensus statements have suggested that a protein intake between 1.0 and 1.5 g/kg/day may confer health benefits beyond those afforded by simply meeting the minimum (3-8).

Analysis of large data sets such as the National Health and Nutrition Examination Survey (NHANES), suggests that many adult populations already consume a moderate-to-high protein diet (i.e., 1.3 g protein/kg/day), (9, 10). Unfortunately, older adults generally consume less protein and energy than their younger peers (6). Approximately one third of adults over 50 years of age fail to meet the RDA for protein, while approximately 10% of older women fail to meet even the Estimated Average Requirement (EAR) for protein (0.66 g protein/kg/day) (3, 11). For a 65 kg adult, the EAR represents a paltry 40 g of protein/day. Increasing and optimizing protein intake may be particularly important for older populations experiencing catabolic stressors such as illness, physical inactivity or injury (6, 12-14). In circumstances where the capacity or ability to exercise is limited, nutrition, and protein consumption in particular, represents one of the few remaining options to improve muscle protein anabolism and ultimately preserve muscle mass and function.

While there are compelling arguments supporting the role of higher protein diets for muscle health, it is equally clear that a growing proportion of the population chronically exceed their daily energy requirements (10, 15). In older adults, the outwardly paradoxical increase in the incidence of sarcopenic obesity highlights the need to look beyond the quantity of protein and energy consumed daily (16-18). Recent research efforts have clearly established the benefits of increased dietary protein within an energy controlled diet for weight management (16, 19). However, relatively few studies have examined issues such as protein distribution (20-22), or adopted an integrated approach to examine the concomitant effects of increased protein on a broad, cross-disciplinary array of outcomes/themes such as: protein metabolism, cell signaling, body composition, satiety, glucose regulation, and overall macronutrient consumption.

Body Weight/Composition

Three recent meta-analyses examined the effects of higher protein diets on changes in body weight and body composition. Wycherley et al. (23) analyzed 24 randomized controlled trials that compared higher protein or standard protein energy-restriction diets of 12.1 ± 9.3 weeks in duration in 1063 overweight and obese individuals between 18-80 years of age. The higher protein diets contained between 27-35% of daily energy intake as protein (1.07-1.60 g protein/kg/day), whereas the standard protein diets contained 16-21% protein (0.55-0.88 g protein/kg/day) (23). Across this broad age spectrum, the higher protein diets led to greater weight loss (mean difference: −0.79 kg; CI: −1.50, −0.08; $p<0.03$) and fat loss (mean difference: −0.87 kg; CI: −1.26, −0.48; $p<0.001$) compared to the standard protein diets (23). Of particular importance for middle-aged and older adults, the higher protein diets were also associated with greater lean mass retention (during energy restriction) (mean difference: +0.43 kg; CI: 0.09, 0.78; $p<0.01$) compared to the standard protein diets (23).

Similar findings were also reported in a meta-analyses of studies involving 418 middle-aged adults (46-63 y) with Type 2 Diabetes (24). In this analysis, the higher protein diets, containing 25-32% protein, led to greater weight loss (mean difference: −2.08 kg; CI: −3.25, −0.90 kg) compared to diets containing 15-20% protein (24). Santesso et al. (25) extended these findings to encompass 74 randomized controlled trials comparing higher protein (16-45%) vs. standard protein diets (5-23%). Irrespective of factors such as total energy consumption, health status and age, higher protein diets facilitated greater weight loss (mean difference: −0.36 kg; CI: −0.56, −0.17; $p<0.001$), reductions in BMI (mean difference: −0.37 kg/m^2; CI: −0.56, −0.19; $p<0.001$) and reductions in waist circumference (mean difference: −0.43 cm; CI: −0.69, −0.16; $p<0.001$) compared to the standard protein diets. The magnitude of change, while modest, has clear clinical relevance in light of the on-going obesity epidemic as well as the increased prevalence of type 2 diabetes, metabolic syndrome, sarcopenia and sarcopenic obesity.

Muscle loss and inactivity: Is 50 the new 70?

Establishing healthy exercise and nutrition behaviors should not be viewed as a switch that can be turned on at a particular age or in response to a health scare. Age-related conditions such as osteoporosis and sarcopenia do not develop acutely. Rather, they are insidious conditions whose onset may be accelerated by less than optimal lifestyle practices in early-middle age (26). Nevertheless, middle-aged adults (i.e., 40-65 y) are comparatively under-represented in research, falling between the typical age-based group assignments of: “young” (20-40y) or “elderly” (65y +).

In a compilation of studies examining the effects of physical inactivity/bed rest on skeletal muscle, we nominally compared the rate and magnitude of muscle loss in young (27) and older adults (28) to a recently completed study in middle-aged adults (29) (Table 1.).

While controlled experimental conditions are certainly needed to confirm these data, it appears that, while healthy middle age adults often have “normal” or “youthful” physiological responses during acute muscle metabolism studies (31, 32), a metabolic perturbation or catabolic insult (e.g., inactivity, injury, malnutrition) may facilitate anabolic resistance or an aging phenotype, increasing the rate of muscle loss.

These observations are consistent with the “Catabolic Crisis” model of muscle loss we recently put forward (13) and suggest that prevention and treatment strategies targeting older adults could be extended to middle-aged adults who may also be at increased risk of accelerated muscle loss during periods of physiological stress (33, 34).

Regulation of Protein Intake

Ingestive behavior is a complex system comprised of both physiological eating and reward-driven (i.e., hedonic) eating. Physiological eating occurs in response to acute and/or chronic fluctuations in energy balance during times of fasting, meal omission, and weight loss, whereas hedonic eating typically occurs in response to external (environmental) signals that stimulate memories and thoughts of food for enjoyment and/or reward. In the current, food-centric obesogenic environment, many support the premise that hedonic eating is the most significant factor in terms of overweight and weight gain; however, during weight loss (or following weight loss), the physiological signals that control hunger and satiety play a pivotal role. Thus, it is critical to identify the effects of dietary interventions on both types of eating. Recent evidence suggests that increased dietary protein modulates both systems.

Results from the majority of acute single-meal studies illustrate significant post-prandial reductions in perceived hunger and increased perceived fullness following the consumption of higher versus standard protein meals (35). These responses are accompanied by hormonal responses including reductions in the hunger-stimulating hormone ghrelin and increases in the satiety-stimulating hormones PYY and GLP-1 (35, 36). Although these findings are more physiological in nature, recent data from our lab also illustrates that the consumption of higher protein meals significantly impacts reward-driven eating behavior. Using functional magnetic resonance imaging (fMRI), we have identified neural activation in response to rewarding food stimuli prior to subsequent eating occasions. Compared to standard protein meals, the higher protein versions leads to reduced activation in select cortico-limbic brain regions, including the insula, hippocampus, parahippocampus, and/or middle pre-frontal cortex which control food motivation, reward, and cravings as well as executive function (37, 38). Collectively, these data support the beneficial effect of dietary protein to modulate appetite control, satiety, and food motivation/reward.

It is important to note that studies examining the regulation of food intake have been performed almost exclusively in young to middle-age men and women. Due to the well-documented anorexic effect of aging, the consumption of higher protein meals might exert an even larger reduction in appetite in the elderly. However, it is also possible that older individuals will be insensitive to increased protein consumption due to their already blunted, ‘non-responsive’ appetite signaling. A retrospective analysis comparing the post-meal appetite responses following standard protein versus higher protein meals across the lifespan is shown in Table 2. Although the older individuals experienced blunted appetite compared to their younger counterparts, the consumption of higher protein meals led to greater reductions in perceived appetite compared to a standard protein meal in all age groups (Table 2; all, $p<0.05$).

However, irrespective of age, consumption of moderately higher protein meals still led to reduced post-prandial appetite responses compared to standard protein versions. While muscle protein metabolism research consistently demonstrates the benefits of a moderately higher dietary protein intake, they do not address complex behavioral issues such as the drive to eat. Studies examining the acute and chronic effects of increased dietary protein on physiological and hedonic eating are needed in the elderly to better understand the anorexia of aging to establish specific, age-appropriate protein recommendations.

Protein Quantity

One of the remaining overarching questions in the field of protein research centers on the quantity of protein required to optimize muscle protein anabolism, appetite control and body weight management. The difficulty in answering this question lies with the multiple ways in which protein consumption can been quantified. The dietary guideline recommendations are reported as grams of protein/kg of body weight per day with a minimal quantity of 0.8 g protein/kg/day established as the quantity to prevent deficiencies. The dietary guidelines also include an acceptable macronutrient distribution range (AMDR). The AMDR for protein represents 10%-35% of an individual's total daily energy intake and is defined as "the range of intake for a particular energy source (i.e., protein) that is associated with reduced risk of chronic disease while providing intakes of essential nutrients". Unfortunately, the prescriptive usefulness of the AMDR is diminished by the overly-restrictive and generous quantities of protein represented by both ends of the range. Nevertheless, the protein meta-analyses presented in this synopsis suggest that the quantity of protein necessary to promote improvements in body composition falls between 1.2-1.6 g protein$\cdot$kg$^{-1}\cdot$d^{-1} (i.e., ~25-30% of daily intake as protein) (40). This is well within the acceptable macronutrient range for protein and allows for the ability to meet the recommendations for other requirements including fruits, vegetables, dairy, and fiber.

Many mechanistic studies and clinical trials examining protein synthesis, appetite control and satiety, focus on meal-specific protein consumption and not total daily intake. For some outcome measures, this may be a critical point. For example, the human body has limited capacity to temporarily store excess protein from a single large meal and use it to acutely stimulate muscle protein anabolism at a later date. In several recent studies and reviews, there is general agreement that approximately 30 g of protein/eating occasion is required to elicit an optimal or measureable change in a number of outcome variables (6, 41-44). For example, Figure 1 shows the 2 h post-prandial fullness response following the consumption of 350 kcal meals containing varying quantities of dietary protein (unpublished data, composite from previous studies with similar populations and experimental designs).

Although the consumption of all meals led to an immediate rise in fullness, the meal containing 30 g of protein elicited a larger (and more sustained) increase over the 2 h post-prandial period compared to the other quantities. Thus, these data support a within-meal protein threshold to elicit increases in satiety. If 3-4 meals containing 30 g of protein/meal are consumed throughout the day, the total amount of protein equates to the quantities shown to elicit body weight/body composition changes described above (22). Ingestion of larger protein meals may be justified for adults with increased energy demands or high protein turnover (e.g., athletes, some patient populations), but any potential benefit should be weighed against the risk of exceeding daily energy requirements.

Timing and Distribution of Consumption

Current diet trends continue to focus on the concept of eating frequency to promote optimal weight loss/body composition changes. Ironically, these trends cross the gamut of eating frequency with some advocating small ‘mini’ meals spread through the day, while others emphasis intermittent fasting which includes meal omission, particularly breakfast. However, based on the previous discussion, the quantity and distribution of protein embedded within this eating pattern may significantly impact the outcomes.

In older adults, two recent studies have focused on changes in muscle mass associated with protein distribution patterns (20, 21). Bollwein et al (20) performed a cross-sectional analysis of groups of frail, pre-frail and non-frail adults over the age of 75 y. They noted that while total daily protein consumption was similar in all groups, non-frail older adults consumed an evenly distributed protein diet (i.e., moderate amounts of protein at each meal). In contrast, frail and pre-frail cohorts followed a more skewed protein ingestion pattern, consuming the bulk of their total daily protein during the midday meal.

A recent clinical trial asked a similar question, but found quite different results. Bouillanne et al. (21), conducted a 6-week randomized trial in hospitalized, older adults (avg. 85 y). They reported that patients were provided with a “pulsed” protein diet (8am: 4.5 g, noon: 47.8 g, 4pm: 2.3 g, 7pm: 10.9 g) experienced a significant improvement in lean mass compared to the “spread” protein diet (8am: 12.2 g, noon: 21 g, 4pm: 13.5 g, 7pm: 21.2 g) that provided the same total amount of protein each day (i.e., 1.31 g protein/kg/day). Methodological differences aside, it is difficult to immediately reconcile the apparent discrepancy in the results of these studies. However, an obvious area for further investigation centers on the threshold amount of protein per meal required by various aging populations (healthy and clinical) to elicit a meaningful increase in muscle protein anabolism. In the case of the Bouillanne study, one could suggest that each of the spread protein meals (12-21 g protein) failed to meet the threshold required to optimally stimulate muscle protein anabolism (6, 41-44), whereas the noon meal in the pulsed protein likely had more than enough protein (~48 g) to elicit a single, robust anabolic response (41).

We previously examined whether 6 small meals (i.e., 350 kcal/meal) consumed every 2 h improves daily appetite and satiety responses compared to the standard 3 larger meals (i.e., 700 kcal/meal) (45, 46). Protein quantity was also varied within each meal pattern. Overall, we found that protein quantity had a more robust effect on satiety than eating frequency. Higher protein meals led to greater feelings of fullness and PYY concentrations throughout the day compared to the normal protein meals. These data refute claims that consuming ‘mini’ meals and/or frequent snacking throughout the day is beneficial in controlling appetite and satiety. Further, these data support the ‘protein threshold’ concept of ≥30 g protein to elicit satiety responses as the meals containing < 30 g protein, as was the case for the 6 small high protein meal and the 3 large normal protein meal patterns, led to the smallest satiety response.

A recent longer-term study by Arciero et al. (47) extended these findings to examine the effects of increased protein intake and meal frequency on changes in body weight and body composition. In this study, the higher protein diet groups, regardless of eating frequency, led to greater fat loss, particularly abdominal fat, compared to the normal protein diet. The higher protein diets also led to increased lean mass and reduced daily hunger vs. normal protein versions. The protein meal pattern in this study contained approximately 30 g of protein/eating occasion.

At the other end of the eating frequency spectrum is the concept of meal omission/skipping. Although intermittent fasting, which is a type of reduced eating frequency, is gaining traction in the lay press, limited data exist to support this dietary pattern. On the other hand, meal omission, particularly the breakfast meal, has been strongly associated with increased BMI, unhealthy weight gain, and obesity (48). We recently found that the consumption of breakfast led to increased appetite control, satiety, and reduced reward-driven eating behavior throughout the day compared to skipping the morning meal (38). However, a protein-rich breakfast, containing 35 g of protein, led to further improvements through greater increases in satiety throughout the day along with greater reductions in food motivation/reward compared to a normal protein breakfast containing only 13 g protein. Further, only the higher protein breakfast reduced unhealthy, evening snacking on high fat snacks by approximately 200 kcal compared to skipping breakfast or consuming a normal protein breakfast. These data suggest that substantial protein intake at the breakfast meal appears to have immediate and sustained effects throughout the day. Previous data from our lab further support these findings by illustrating that protein at the morning meal leads to greater immediate and sustained satiety throughout the day compared to protein at lunch or dinner (49).

Conclusions

Sarcopenia has debilitating consequences for the elderly community and considerable impact on health-care systems. The benefits of moderate protein diets for young and older adults have been well established and many ongoing research efforts seek to refine and incrementally add to our understanding. However, it is increasingly clear that multidisciplinary research efforts are needed to provide practical, translatable data on the regulation of body composition and maintenance of muscle mass and function during aging. A compilation of data from recent muscle protein anabolism, appetite regulation and satiety studies suggest that meeting a protein threshold (approximately 30 g/meal) represents a promising strategy or dietary-framework for middle-aged and older adults concerned with maintaining muscle mass while controlling body fat.

Extended Data

Table 1

Comparison of leg lean mass loss per day during bed rest for young (27), middle-aged (29) and older adults (30).

	Bed Rest (days)	Age (y)	Muscle Loss (kg)	Rate of Loss (g/day)
Young	28	38±8	−0.40±0.10	−14
Middle-age	14	52±4	−1.16±0.14	−83

	Bed Rest (days)	Age (y)	Muscle Loss (kg)	Rate of Loss (g/day)
Elderly	10	67±5	−0.95±0.15	−95

Table 2

Age-related appetite responses following standard vs. high protein meals (39)

	Age (y)	4-h Post-meal Appetite following a Standard Protein Meal	4-h Post-meal Appetite following a High Protein Meal
Young	38 ± 2	7878 ± 1310	6071 ± 1145*
Middle-aged	50 ± 1	6065 ± 1205	5432 ± 1053*
Elderly	64 ± 2	5551 ± 1254†	4646 ± 1096*†

*High Protein vs. Standard Protein, p<0.05

†Old vs. Young, p<0.05

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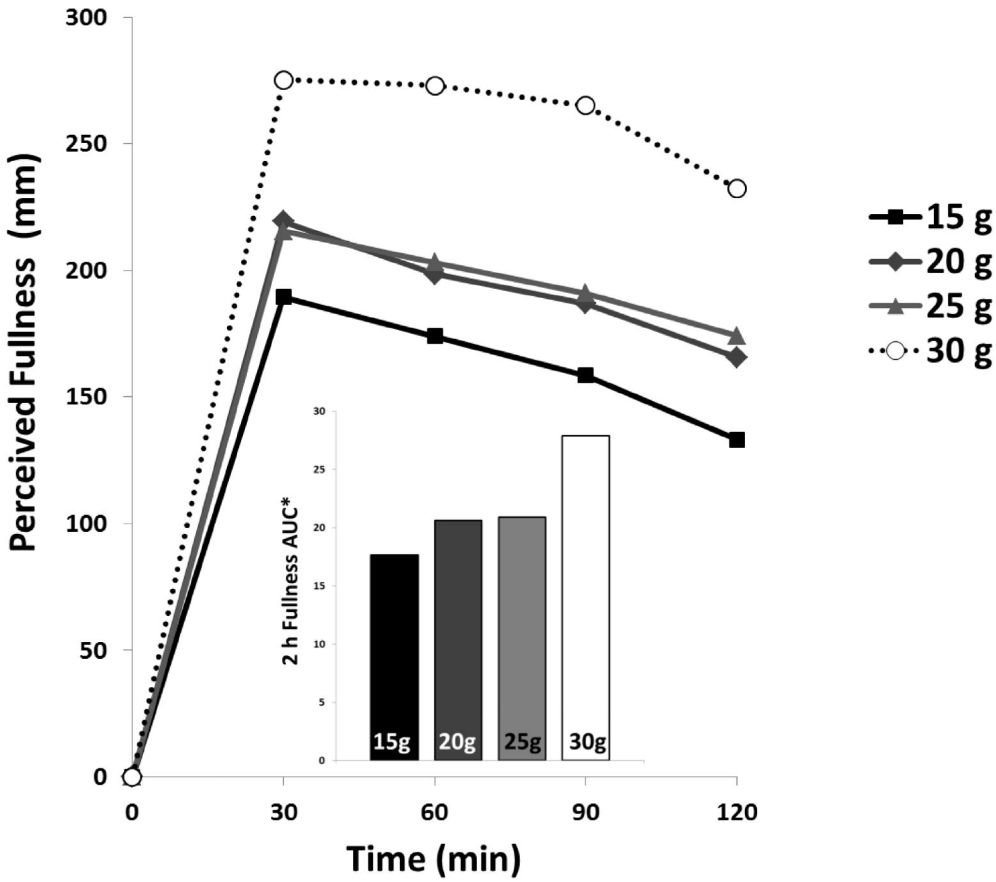
Key Points

- Sarcopenia has debilitating consequences for the elderly community and considerable impact on health-care systems.
- Moderate protein diets for young and older adults have led to greater weight loss, fat loss, and preservation of lean mass compared to standard protein diets.
- Potential protein-related mechanism(s)-of-action include the increase in protein anabolism, appetite regulation, and satiety.
- Meeting a protein threshold (approximately 30 g/meal) represents a promising strategy or dietary-framework for middle-aged and older adults concerned with maintaining muscle mass while controlling body fat.
- Multidisciplinary research efforts are needed to provide practical, translatable data on the regulation of body composition and maintenance of muscle mass and function during aging.



*AUC: Area Under the Curve (mm*120 min^{-10})

Figure 1.

Post-prandial fullness responses following 350 kcal meals varying in protein content

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Table 1

Comparison of leg lean mass loss per day during bed rest for young (27), middle-aged (29) and older adults (30).

	Bed Rest (days)	Age (y)	Muscle Loss (kg)	Rate of Loss (g/day)
Young	28	38±8	−0.40±0.10	−14
Middle-age	14	52±4	−1.16±0.14	−83
Elderly	10	67±5	−0.95±0.15	−95

Table 2

Age-related appetite responses following standard vs. high protein meals (39)

	Age (y)	4-h Post-meal Appetite[1] following a Standard Protein Meal (Area Under the Curve; mm*240 min)	4-h Post-meal Appetite[1] following a High Protein Meal (Area Under the Curve; mm*240 min)
Young	38 ± 2	7878 ± 1310	6071 ± 1145[*]
Middle-aged	50 ± 1	6065 ± 1205	5432 ± 1053[*]
Elderly	64 ± 2	5551 ± 1254[†]	4646 ± 1096[*†]

[1] Appetite was measured from 100 mm visual analog scales assessing perceived hunger as ‘how strong is your feeling of hunger’, with end anchors of ‘extremely’ to ‘not at all.’ Questionnaires completed every 30 min throughout the 4-h period.

[*] High Protein vs. Standard Protein, p<0.05

[†] Old vs. Young, p<0.05