Obesity Interventions for Older Adults: Diet as a Determinant of Physical Function

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ABSTRACT

Throughout the world, a high prevalence of obesity in older populations has created a new phenotype of frailty: the obese, functionally frail older adult. The convergence of the obesity epidemic with global graying will undoubtedly increase the prevalence of this concern. Barriers to treatment include ambiguities about the appropriate level of obesity that should trigger an intervention, due to age-related physiologic changes and a lack of consensus on specific criteria and cutoffs. Moreover, obesity interventions for this population have been limited by concerns about negative effects on lean mass, bone mineral density, and even mortality. However, newly reported approaches for restoring physical function by obesity reduction have shown good short-term efficacy. Because the majority of these interventions have used exercise as part of the treatment, this review focuses specifically on current understanding of the discrete effects of dietary interventions for geriatric obesity with regards to functional outcomes on tests including the Short Physical Performance Battery, the Physical Performance Test, and the Western Ontario and McMaster Universities Osteoarthritis Index. The literature showed roughly equal benefits to function from a weight reduction diet or exercise regimen, although neither modality was as efficacious alone as the 2 combined. Only 1 of 3 studies of protein intake during weight loss showed a positive effect of protein on function, but findings to date are too limited to prove or disprove a protein benefit. We conclude that although diet and exercise should be combined whenever possible, it remains important to further investigate the beneficial and likely unique effects that calorie restriction and/or nutrient modification can provide, particularly for obese and functionally frail older populations. Adv Nutr 2018;9:151–159.

Keywords: calorie restriction, obesity reduction, older adults, function

Introduction

A global epidemic of obesity has combined with an unprecedented “graying” of the population to threaten the health and functional independence of future cohorts of older adults. Already, almost 40% of US adults aged ≥60 y have a BMI (in kg/m²) exceeding 30 (1). Increases in obesity are also being recorded globally, with rates of 10–15% in the developing world (2). The combination of obesity with age-related elevations in metabolic and functional risk contributes to physical limitations and reduced independence, as well as a host of chronic cardiometabolic disorders (3). The impact of obesity on health, independence, and quality of life in older adults is multifaceted, but the primary focus of this review is on the impact of diet interventions on physical function outcomes in obese older individuals. The deterioration of functional status severely impacts quality of life for obese older adults, increasing their risk of falls and other injuries and enhancing the likelihood of institutionalization (4–6). Unless effective obesity interventions can be found, the functionally disabled, obese older adult may become the “most commonly encountered phenotype of frailty” in the near future (7). This concern has begun to be addressed in a number of obesity intervention trials aimed at lessening associated comorbidities, preserving lean mass, and/or improving function, many of which have been recently reviewed (8–13). The majority of these interventions have emphasized exercise as an essential modality of treatment and focused on lean mass preservation as an outcome; very few have been designed to examine the discrete effects of diet interventions on physical function as an outcome. While the benefits of exercise for cardiovascular health and muscle strength are robust and well substantiated (14, 15), the role of diet in obesity treatment is equally
crucial but under-studied. Following a discussion of the upsurge of obesity prevalence in older adults and its implications for health and physical function, the intent of this narrative review is to summarize current understanding of the effects of diet apart from exercise with regards to physical function outcomes in obese older adults.

**The Convergence of Global Graying with the Obesity Pandemic**

Thanks to lower birth rates and tremendous strides in treatment and prevention of infectious diseases, “global graying” is now occurring in rapid fashion. In the United States, the population of adults aged ≥65 y will nearly double to almost 83 million by 2050, up from ~43 million in 2012 (16). Globally, demographic milestones are rapidly being realized. For the first time in recorded history, adults aged >65 y will soon outnumber those aged ≤5 y; this “crossing over” is unprecedented in recorded human history and it will continue into 2050, when there will be twice as many older adults as children aged ≤5 y (17).

Another dramatic global trend is obesity in later life, which was rare until recently but has become an important harbinger of nutritional risk in many older persons (1). This trend is driven by an overall pandemic of obesity (2). Worldwide obesity has more than doubled since 1980, with >600 million adults (13%) being obese. In much of the world, being overweight or obese now contributes more to mortality than being underweight (18).

**Indicators of obesity in older adults**

In order to understand the impact of obesity in later life, it is important to note the limitations of current approaches to assessment of excess adiposity in this population. Typically, BMI measurement is used to classify obesity, despite the well-known limitations of this index for use in older persons. BMI does not fully capture the extent of adiposity because as adults age, they accumulate a greater proportion of body weight as fat compared with lean tissue (19). Additionally, BMI does not capture the tendency of older adults to accumulate more intra-abdominal than subcutaneous or whole body fat and the commonly observed loss of height with aging due to vertebral body compression and spinal kyphosis can also distort the BMI measurement. The use of waist circumference as an indicator of visceral adiposity has been suggested (>102 cm in men and >88 cm in women), although there are no age-specific recommendations (20). It should also be noted that ethnic differences in BMI cutoffs associated with detrimental health changes have been noted, although these differences have not been well described in older adults (21, 22).

Another way to classify detrimental changes in body composition in older adults is by the diagnosis of sarcopenic obesity. Broadly speaking, sarcopenic obesity refers to the common phenomenon wherein sarcopenia (decreased muscle mass and function) co-occurs with obesity (excess body fat mass) (20). Sarcopenic obesity is linked with a host of metabolic health problems as well as disabilities, falls, and mobility limitations (20). It makes surgery and other medical treatments riskier and hastens the need for institutionalization due to loss of functional independence. Functionally frail, obese older adults have a much greater likelihood of getting admitted to a nursing home than do nonobese elders (23). Yet, studies of potential interventions are hampered due to the lack of consensus on the specific criteria most indicative of sarcopenic obesity. Thus, estimated rates of prevalence of sarcopenic obesity range widely depending upon the definition employed (24), with findings of ≤84% in men and 94% in women in an analysis of DXA results from the NHANES (National Health and Nutrition Examination Survey) of 1999–2004.

**Impact of obesity in later life on physical function**

The negative impact of sarcopenic obesity on health and functional independence underscores the importance of identifying interventions that reverse physical deficits; it also explains why this review focuses on studies of physical function outcomes rather than on intervention effects on lean mass per se. Some terms commonly used to describe the quality and performance of muscle, along with descriptions of functional tests discussed in this paper, are shown in Table 1. In Figure 1, we see that both aging and obesity are consistently associated with poor muscle quality (25) and resulting deterioration of muscle function (26). With aging, sarcopenia, a progressive loss of muscle mass and strength, almost inevitably occurs (27, 28). Lean muscle mass declines from ~50% of total body weight in young adults to ~25% at 75–80 y of age (29). This progressive deterioration of muscle quantity and quality leads to slower movement, a decline in strength and power, and increased risk for falls (30). Through different mechanisms, obesity is also strongly associated with deterioration of muscle quality and loss of physical function. Adiposity favors the accumulation of lipids between and within muscles (reduced muscle quality), as well as a persistent low-grade inflammation (due to chronic activation of the innate immune system) that also leads to muscle depletion by enhancing protein breakdown and impairing myogenesis (11, 31). In addition, with the reduced ability to be physically active as a result of both obesity and aging, progressive muscle atrophy due to disuse takes place (32). Thus, the convergence of obesity with aging dramatically accelerates functional decline and results in a marked threat to independence for present and future cohorts of older adults.

**The Controversial Nature of Obesity Interventions for Older Adults**

Given the many adverse effects of obesity on health and well-being in older adults, it would seem logical to advocate for more interventions targeting weight reduction for this population. In fact, specific recommendations for obesity treatment in older adults have advised a cautious approach (33). Weight reduction can be difficult to achieve in older adults, who have lower basal metabolic rates, calorie requirements, and physical activity (34–36) and may have greater reductions in energy expenditure during weight loss (37). Moreover, efforts to reduce body weight in obese older adults raise...
### TABLE 1  Glossary of muscle physiology descriptors and functional tests applied in older adults

<table>
<thead>
<tr>
<th>Terminology</th>
<th>Description</th>
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<tr>
<td><strong>Muscle physiology</strong></td>
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<tr>
<td><strong>Muscle strength</strong></td>
<td>The ability of a muscle or muscle group to develop maximal contractile force against a resistance in a single contraction. Muscle strength may be measured using a one-repetition maximum, which is the sum of the maximal weights lifted in the biceps curl, bench press, seated row, knee extension, knee flexion, and leg press exercises.</td>
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<tr>
<td><strong>Muscular endurance</strong></td>
<td>The ability of a muscle or muscle group to exert submaximal force for extended periods of time. Exercises such as running illustrate muscular endurance as they require multiple repetitions of an exercise.</td>
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<td><strong>Muscle quality</strong></td>
<td>Typically defined as muscle strength or power per unit of muscle mass, muscle quality is a complex characteristic determined by a variety of attributes, including muscle size and architecture, fiber type, contractile properties, aerobic capacity, and intermuscular adipose tissue (25).</td>
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<td><strong>Sarcopenia</strong></td>
<td>The loss of muscle mass and muscle strength that is associated with aging; features include decreased muscle mass and muscle cross-sectional area and infiltration of muscle with fat and connective tissue (28).</td>
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<tr>
<td><strong>Muscle wasting</strong></td>
<td>A degree of muscle atrophy associated with clinically important impairments in functional capacity and/or increased risk of morbidity or mortality. Also referred to as myopenia (32), it is a distinct condition from sarcopenia.</td>
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<td><strong>Functional tests</strong></td>
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<td><strong>Short Physical Performance Battery</strong></td>
<td>The SPPB (74) is a performance-based test designed to assess mobility in older adults by measuring 3 categories scored on a scale of 0 to 4—balance, strength, and gait speed. There are 3 different standing balance tests (side-by-side, semi-tandem, and tandem), 5 chair stands, and a 4-meter walk. Performance in each category is scored on a scale of 0 to 4 with a total score ranging from 0 to 12.</td>
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<tr>
<td><strong>Physical Performance Test</strong></td>
<td>The PPT assesses performance of tasks that simulate activities of daily living. It includes 7 standardized tasks (walking 50 ft, putting on and removing a coat, picking up a penny, standing up from a chair, lifting a book, climbing 1 flight of stairs, and performing a progressive Romberg test) plus 2 additional tasks (climbing up/down 4 flights of stairs and performing a 360-degree turn). The score for each task ranges from 0 to 4; a perfect score is 36 (52).</td>
</tr>
<tr>
<td><strong>Western Ontario and McMaster Universities Osteoarthritis Index</strong></td>
<td>The WOMAC Index is a widely used set of standardized questionnaires originally designed to assess symptoms and physical disability in individuals with osteoarthritis of the hip and/or knee (53). It includes assessment of pain, stiffness, and physical function.</td>
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Strong concerns about the concomitant loss of lean body mass. Of total weight lost, \( \geq 25\% \) is likely to be lost as lean mass (38). Any loss of lean mass in older individuals is a concern for future functional status, as well as for glucose uptake and tolerance (39). The inclusion of an exercise program with weight reduction treatment can help minimize the loss of lean mass, although the long-term impact of various weight-loss strategies in this population is not well understood.

![Figure 1](https://academic.oup.com/advances/article-abstract/9/2/151/4969261)  
**FIGURE 1** Both aging and obesity are associated with poor muscle quality and a reduction of muscle function. Decreased muscle endurance, elevated pro-inflammatory cytokines, and infiltration of fat into muscle combine with muscle disuse to reduce overall muscle quality and worsen physical function.
characterized. Furthermore, not all obese older adults are able or willing to sustain a regular program of exercise. As subsequently discussed, another concerning observation during obesity reduction in older adults is a slight loss of bone mineral density; this occurs as a consequence of weight loss in all ages and its long-term impact on fracture risk is unknown (40).

The well-characterized “obesity paradox” is yet another concern related to the controversy about obesity reduction in later life. Several chronic health conditions associated with aging have the potential to progress to conditions of wasting, also known as cachexia (41). The “reverse epidemiology” of obesity or “obesity paradox” has been observed in such individuals, meaning that often those with a higher BMI survive longer than those with a lower BMI. This phenomenon has been confirmed in the case of cancer cachexia (42), end stage renal disease (43), and chronic heart failure (44), as well as a number of other common chronic conditions. The availability of larger body stores of both energy (fat) and lean mass, as well as a better nutritional state overall is thought to contribute to increased survival in obese older individuals (45). While this potential benefit of obesity on mortality is well recognized, the fact remains that severe decrements in function because of obesity could translate into years of disability during an extended lifetime (20). For all these reasons, and as emphasized in a 2016 review by Locher et al. (8), the overall safety of weight-loss interventions for those aged ≥65 y remains controversial and yet in great need of study because of the pervasiveness of the obesity problem.

**Findings on Obesity Reduction and Function Outcomes: Diet-based Interventions**

The effectiveness of exercise as part of obesity interventions in older adults has been investigated and confirmed in a number of trials. Almost all recent studies of weight reduction in this population have included exercise in all treatment arms, with the best results being reported in study arms that combined exercise with a calorie-restricted diet (12, 46). The results of these studies have been recently summarized (8, 10, 11, 38).

**Calorie-restricted weight-loss diets**

**Weight-loss outcomes.** In head-to-head studies of diet compared with exercise, calorie-restricted diet regimens almost always result in more weight loss than do exercise-alone treatments (14). As shown in Table 2, exercise treatments without a diet component typically result in little or no weight loss, while calorie-restricted diets achieve mean reductions in baseline body weight of 5% to almost 10%. Other benefits may accrue: in the recently reported CROSSROADS (Calorie Restriction in Overweight SeniorS: Response of Older Adults to a Dieting Study) trial, Ard et al. (46) found that an exercise regimen plus weight-loss diet was more successful at reducing body fat and improving cardiometabolic risk factors than exercise alone.

**Function.** To date, only a few trials of obesity reduction in older adults that included a diet-alone arm have reported function as an outcome. As shown in the first 3 studies on Table 2, these trials range from 12 to 18 mo in duration (14, 47–51). Villareal et al. (14) explored the independent and combined effects of a weight management diet and an exercise treatment in older adults aged ≥65 y. Physical Performance Test (PPT) (52) scores were best in the combination group, while improvements in the diet-only group for PPT were similar to those of the exercise-only treatment group. Functional Status Questionnaire (FSQ) improvements were greater in the combination group compared with the diet-only group. In the Arthritis, Diet, and Activity Promotion Trial (ADAPT) including overweight and obese older adults with osteoarthritis, Messier et al. (48) compared long-term (18 mo) exercise and diet-induced weight loss separately or in combination with a healthy lifestyle control group with regards to physical function and mobility. The diet plus exercise group improved in both the 6-min walk distance and stair climb, while the exercise-only group improved in the 6-min walk distance compared with the healthy lifestyle control group. The diet-only group did not improve in either mobility measure compared with the healthy lifestyle control group. In another trial by these investigators, the Intensive Diet and Exercise for Arthritis (IDEA) trial, Messier et al. (47) again studied overweight and obese older adults with osteoarthritis over an 18-mo duration. The IDEA trial assessed function and mobility as secondary outcomes of an intensive diet-induced weight loss with or without exercise. These investigators found a better Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) score (53) in the combination group than in the diet-only and exercise-only groups; the diet-only and exercise-only groups improved but did not differ from each other. The 6-min walk distance results were better for both the combination and the exercise group than for the diet group. The combination group had faster walking speeds compared with the exercise-only group; there was no difference between the diet-only and exercise-only groups for walking speed.

**Higher-protein weight-loss diets**

There is a strong consensus that the protein requirement of older adults exceeds the RDA of 0.8 g protein · kg body weight⁻¹ · d⁻¹, with the suggestion for intakes ranging ≤1.5 g protein · kg body weight⁻¹ · d⁻¹ or more in high-risk situations (54, 55). Protein intakes exceeding the RDA amounts have been linked with better preservation of lean mass (56, 57) and recent findings from the Framingham study have confirmed the benefits of high-quality (animal) protein for protection of appendicular lean mass (58), preservation of grip strength (59), and decreased risk of function decline in the long term (60). Muscle becomes more resistant to anabolic stimulation with age, but there is encouraging evidence that generous and balanced intakes of high-quality (complete) protein can offset age-related anabolic resistance in the aging muscle (61–63). As confirmed in several short-term studies, essential amino acids, especially leucine,
### Table 2: Randomized controlled trials of obesity reduction with a diet treatment arm: weight loss and function-related outcomes

<table>
<thead>
<tr>
<th>Study reference</th>
<th>Population</th>
<th>Interventions tested</th>
<th>Findings</th>
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<tr>
<td><strong>Calorie restriction</strong></td>
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<tr>
<td>Messier et al. (2013) (IDEA trial) (47)</td>
<td>n = 454</td>
<td>Arms: Diet Ex</td>
<td>Weight: Diet loss (9.5%) and Diet + Ex (11.4%) were significantly greater than Ex loss (2.0%) (P &lt; 0.001). Function: WOMAC function score significantly increased in Diet + Ex compared with Diet (P = 0.003) and Ex (P &lt; 0.001). For the 6MWT, Diet + Ex arm walked significantly farther than both Diet arm (P &lt; 0.001) and Ex arm (P = 0.005). The Ex arm walked significantly farther than the Diet arm (P = 0.009). Walking speeds significantly increased in Diet + Ex compared with Ex (P = 0.003), no difference was found between Diet + Ex and Diet arms.</td>
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<tr>
<td>Villareal et al. (2011) (14)</td>
<td>n = 107</td>
<td>Arms: Diet Control</td>
<td>Weight: Diet loss (10%) and Diet + Ex loss (9%) were significantly greater than Ex loss (1%) and Control loss (&lt;1%) (P &lt; 0.001). Function: PPT score significantly increased in all 3 intervention arms at 12 mo (P &lt; 0.001). PPT score increased significantly more in the Diet + Ex arm compared with Diet arm (P &lt; 0.001) and Ex arm (P = 0.04). Following 12 mo, FSQ significantly increased in all 3 intervention arms (P &lt; 0.01). Diet + Ex FSQ score increased significantly more than Diet FSQ score (P = 0.04).</td>
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<tr>
<td>Messier et al. (2004) (ADAPT trial) (48)</td>
<td>n = 316</td>
<td>Arms: Diet Control</td>
<td>Weight: Diet loss (4.9%) and Diet + Ex loss (5.7%) were significantly greater than Control (1.2%) (P &lt; 0.05). Function: Diet + Ex arm significantly improved more in both 6MWT and stair climb time compared with Control (P &lt; 0.05). Ex group significantly improved in 6MWT compared with Control (P &lt; 0.05). No difference between Diet and Control arms for either mobility measure.</td>
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<td><strong>Calorie restriction plus nutrient modification</strong></td>
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<td>Porter Starr et al. (2016) (MEASUR-UP trial) (49)</td>
<td>n = 67</td>
<td>Arms: Control (NP Diet) HP Diet</td>
<td>Weight: Total body weight significantly decreased for both arms (P &lt; 0.001). Control (7.5%) and HP Diet (8.1%) losses were not different (P = 0.52). Function: SPPB scores significantly increased in HP Diet more than in Control (P &lt; 0.05). Hand grip strength was unchanged for both arms (P = 0.53).</td>
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<tr>
<td>Bales et al. (2017) (POWR-UP trial) (50)</td>
<td>n = 80</td>
<td>Arms: Control (NP Diet) HP Diet</td>
<td>Weight: Total body weight significantly decreased for both arms (P &lt; 0.001). Control (6.3%) and HP Diet (6.2%) losses were not different (P = 0.92). Function: 6MWT distance increased in Control (P &lt; 0.01) and HP Diet (P &lt; 0.001) with no difference between groups. SPPB and 8-ft-up-and-go significantly improved in both arms (P &lt; 0.01) with no group difference. 30-s chair stand significantly improved in HP Diet (P &lt; 0.01), but no between-group difference was found.</td>
</tr>
<tr>
<td>Backx et al. (2016) (51)</td>
<td>n = 61</td>
<td>Arms: Control (NP Diet) HP Diet</td>
<td>Weight: Total body weight significantly decreased for both arms (P &lt; 0.01). Control (−8.9 kg) and HP Diet (−9.1 kg) losses were not different (P = 0.58). Function: 1-RM leg press significantly decreased in both arms (P &lt; 0.01). No change in SPPB score for either arm. 1-RM leg extension significantly decreased in Control (P &lt; 0.01), but no between-group difference was found. Hand grip strength significantly decreased in HP Diet (P &lt; 0.01), but no between-group difference was found. 400-m walking velocity increased in HP Diet (P &lt; 0.01), but no between-group difference was found.</td>
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*ADAPT, Arthritis, Diet, and Activity Promotion Trial; Diet, Calorie-restricted diet with no exercise treatment; Ex, exercise of any type; FSQ, Functional Status Questionnaire; HP, high-protein diet; IDEA, Intensive Diet and Exercise for Arthritis; MEASUR-UP, Measuring Eating, Activity, and Strength: Understanding the Response—Using Protein; NP, normal protein diet; OA, osteoarthritis; POWR-UP, Protein Optimization in Women Enables Results—Using Protein; PPT, Physical Performance Test; SPPB, Short Physical Performance Battery; WOMAC, The Western Ontario and McMaster Universities Osteoarthritis Index; 6MWT, 6-min walk test.*
initiate the mTOR signaling pathway and stimulate muscle protein synthesis (64–66). These short-term studies support a balanced, generous intake of protein throughout the day for optimal protein synthesis in the aging muscle (67, 68). There is a refractory period during which muscle protein synthesis stimulated by amino acid influx cannot be stimulated again, the so-called “muscle full” phenomenon (26, 69), so that balanced protein intake, rather than skewing most of the protein intake to an evening meal, has been associated with better outcomes.

It has been hypothesized that higher protein intake during obesity reduction may reduce the risk of physical frailty by increasing muscle anabolism; improvements in muscle quality may also result (25, 56, 68, 70, 71). Recommendations for obesity reduction in older adults have long included advice for a protein intake of 1.0 g protein · kg body weight\(^{-1}·\)d\(^{-1}\) (36), albeit without a strong body of high-quality supporting evidence. A recent systematic review and meta-analysis addressed the impact of dietary protein intake on body composition in overweight and obese older adults (13). The results indicated a small but significant preservation of lean mass with high protein intake during weight loss. The review did not address function as an outcome. Additionally, of the 19 papers included, only 2 trials studied populations with a mean age of ≥ 60 y; of these, one study (72) did not measure function as an outcome and the other (73) did not include a diet-alone arm. We are aware of only 3 weight-loss studies that have investigated protein intakes exceeding the current RDA of 0.8 g protein · kg body weight\(^{-1}·\)d\(^{-1}\) with assessment of functional outcomes. The second section of Table 2 describes these studies. Porter Starr et al. (74) studied obese men and women who were aged ≥ 60 y and with a suboptimal Short Physical Performance Battery (SPPB) score, testing a 6-mo diet intervention that compared generous servings of high-quality protein products at each meal with a normal-protein weight-loss diet (49). Weight loss was achieved equally well in each group and the SPPB score (primary outcome) improved in both groups, with a significantly greater increase (\(P = 0.02\)) in SPPB score in the high protein (+2.4 ± 1.7 units) compared with the normal protein (+0.9 ± 1.7 units) arm. Backx et al. (51) also studied protein intake (1.7 compared with 0.9 g protein · kg body weight\(^{-1}·\)d\(^{-1}\)) during a calorie-restricted diet in older women and men. The trial was of shorter duration (12 wk) and included overweight as well as obese participants. Weight loss was successful in both study arms and both arms showed improvement in 400-m walking speed with no group difference. However, leg strength decreased in both groups with no group difference. Using the same protocol as the Porter Starr et al. trial of enhanced meal intake of high-quality protein (49), Bales et al. (50) compared normal- and high-protein intake–weight-loss regimens in obese women aged ≥ 45 y (mean age = 60 ± 8.2 y) during a 6-mo intervention. Weight loss was achieved in both groups with no group difference. The distance walked in 6 min (primary outcome) increased in both the normal (\(P < 0.01\)) and high (\(P < 0.001\)) protein diets, with no group difference. While 30-s chair stand score significantly improved in the high protein group (\(P < 0.01\)), no group difference from the normal protein treatment was detected. Other functional improvements included increases in SPPB and 8-ft-up-and-go results in both the normal and high protein groups, with no group difference.

**Weight-loss diets with other nutrient modifications**

Studies of weight loss with manipulation of nutrients other than protein are rare, and none were identified that studied diet apart from exercise effects. Second to protein, vitamin D is the nutrient of most interest with regards to function. Inadequate vitamin D intake has been associated with reduced muscle mass and strength, reduced balance, gait impairments, and increased risk of falling (20, 75, 76). Thus, vitamin D has begun to be explored as an adjunct to obesity treatment, although none of the studies we reviewed had a diet-alone arm. Verreijen et al. (77) found a beneficial effect of a whey protein-, leucine-, and vitamin D–enriched regimen for appendicular lean mass compared with an iso-caloric control (both groups also performed resistance exercise). Function-related outcomes were not reported. Mason et al. (78) studied vitamin D supplementation (2000 IU/d compared with placebo) in obese postmenopausal women with insufficient concentrations of serum 25-hydroxyvitamin D during a 12-mo weight-loss trial that included moderate-to vigorous-intensity aerobic exercise in both groups. The vitamin D supplementation did not provide any added protection for lean mass or bone mineral density and was associated with decreased leg strength measured by one-repetition strength testing. One suggested explanation for this unexpected outcome was the possibility that some participants exerted inconsistent amounts of effort on the leg-strength test at the end of the study compared with baseline (78).

**Summary of findings on diet to date**

The findings from the trials shown in Table 2 permit only preliminary conclusions. Although the trials are of high quality, the limited number of studies and differences in the target populations and primary outcomes measured for function reduce the ability to draw conclusions about diet effects. Generally, the findings for effects of calorie-restricted diets on function were positive and not significantly different from the functional benefits yielded by exercise alone. Study findings for high compared with normal protein intake were also too limited to prove or disprove a benefit. Only 1 of the 3 studies, Porter Starr et al. (49), showed a clear protein benefit. However, the 2 trials showing no group effect had a lower baseline age (60 ± 8.2 and 63.0 ± 4.8 y compared with 68.3 ± 5.6 y in Porter Starr et al.) and the Bales et al. trial studied only women; thus, it is possible that age and/or sex might influence the potential that higher protein intake would be advantageous. Based on the strong evidence in other literature supporting a protein benefit to function in older adults, further studies in obese individuals aged ≥ 65 y, sufficiently powered to detect differences by sex, are warranted. Regarding other nutrients that might be linked with better function, very little is known. Initial findings with vitamin D have yielded mixed results but are too limited to answer questions about benefit. Even
less is known about other nutrients but a recent systematic review has examined the possible role of essential minerals in prevention and treatment of sarcopenia, including outcomes for muscle strength and physical performance (79).

Comments on Bone Health and Obesity
While beyond the scope of this review and under-studied for long-term impact, the potential threat of weight reduction to bone mineral density needs to be assessed and accounted for. Fractures and fear of falling greatly increase the risk of functional frailty in seniors. The conventional wisdom that obesity is protective of bone has recently been challenged by evidence that it is associated with lessened bone quality, raising the possibility that small losses of bone during obesity reduction could lead to subsequent fractures (80). Von Thun et al. (81) assessed 42 postmenopausal women 2 y after they started a 6-mo weight-loss trial and reported that they had not recovered bone mineral density at that follow-up, irrespective of whether or not weight regain had occurred. While exercise helps to preserve bone, bone-supporting nutrients may also be critically important. In a study of very low calorie diets in obese adults aged ≥65 y, Haywood et al. (82) reported small but significant losses of total bone density, despite a supervised exercise program thrice weekly. However, the value of good nutrition for bone quality during calorie restriction over time has also been reported (83).

Summary
This literature review provided indications that weight-loss diets may benefit function in this high-risk population of obese older adults. It is clear that a reduced calorie intake is necessary to achieve physiologically important losses of body weight and, while concerns about loss of lean mass remain, functional benefits do result when weight loss is achieved. Certainly, a striking shortage of published research prevents clinical application at this juncture. Evidence of a protein benefit apart from exercise is even more limited, although there is strong support in the literature for further study. Despite our limited understanding to date, it is likely that diet interventions provide valuable benefits to physical function and independence in obese older adults. And, while combining diet with exercise whenever possible is optimal, it remains important to understand the beneficial and likely unique effects that calorie restriction and/or nutrient modification can provide. The influence of diet composition in this context is woefully under-studied and future trials with study designs that allow the separate examination of exercise and diet effects, especially targeting nutrients likely to be key for physical function, are of critical importance. Moreover, both diet and exercise interventions need to be studied over the long term (e.g., ≥2 y) to evaluate their lasting impact on functional independence and health-related quality of life.

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