By Melissa J. Benton, PhD, MSN, GCNS-BC, FACSM, Maria D. Whyte, DHSc, MSN, APRN, and Brenda W. Dyal, DNP, MSN, FNP-BC

Sarcopenic Obesity: Strategies for Management

Increased protein intake and resistance training can counter muscle loss in older adults.

Overview: Sarcopenia is the age-related loss of muscle mass. Sarcopenic obesity, which describes the process of muscle loss combined with increased body fat as people age, is associated with loss of strength and function, reduced quality of life, and early death. This article describes the clinical significance of sarcopenia and sarcopenic obesity, their pathophysiology, and management strategies for healthy older adults. Both diet and exercise are essential for preventing and reversing loss of muscle and gains in fat. Dietary approaches include protein supplementation and a high protein diet. Exercise strategies promote resistance training in order to maintain muscle mass and maximize energy expenditure.

Nurses should be knowledgeable about this condition and its management and routinely educate older patients on the benefits of resistance training and dietary protein to prevent or reverse sarcopenia and sarcopenic obesity.

Keywords: aging, high-protein diet, obesity, resistance training, sarcopenia, sarcopenic obesity

Obesity continues to grow in prevalence in the United States and is associated with numerous health concerns. Although nurses are knowledgeable about the health implications and management of obesity, they may know less about sarcopenic obesity. This condition, often seen in older adults, represents a significant health risk.

Sarcopenia is a clinical term that's been increasingly used during the last two decades to identify the age-related loss of muscle mass. Sarcopenia should be differentiated from *wasting*, which refers, more broadly, to involuntary loss of body mass (both muscle mass and fat).[1]

Discussions of the pathophysiology of obesity traditionally focus on accretion of fat mass.[2,3] The currently agreed-upon clinical definition of obesity is a body mass index (BMI) equal to or greater than 30. Since BMI is calculated as weight (kg) divided by height (m^2), it doesn't actually provide a direct measure of fatness—body composition (the relative amounts of fat and lean tissue) can be highly variable between people who have similar BMIs. Using BMI as the criterion for evaluating obesity doesn't, in fact, provide information regarding lean mass.

Sarcopenic obesity is an alternate model of obesity characterized by loss of muscle and a concomitant increase in fat.[4] Unfortunately, there's no universal phenotype for sarcopenic obesity. In general, it's often seen in sedentary patients, whether obese or not,

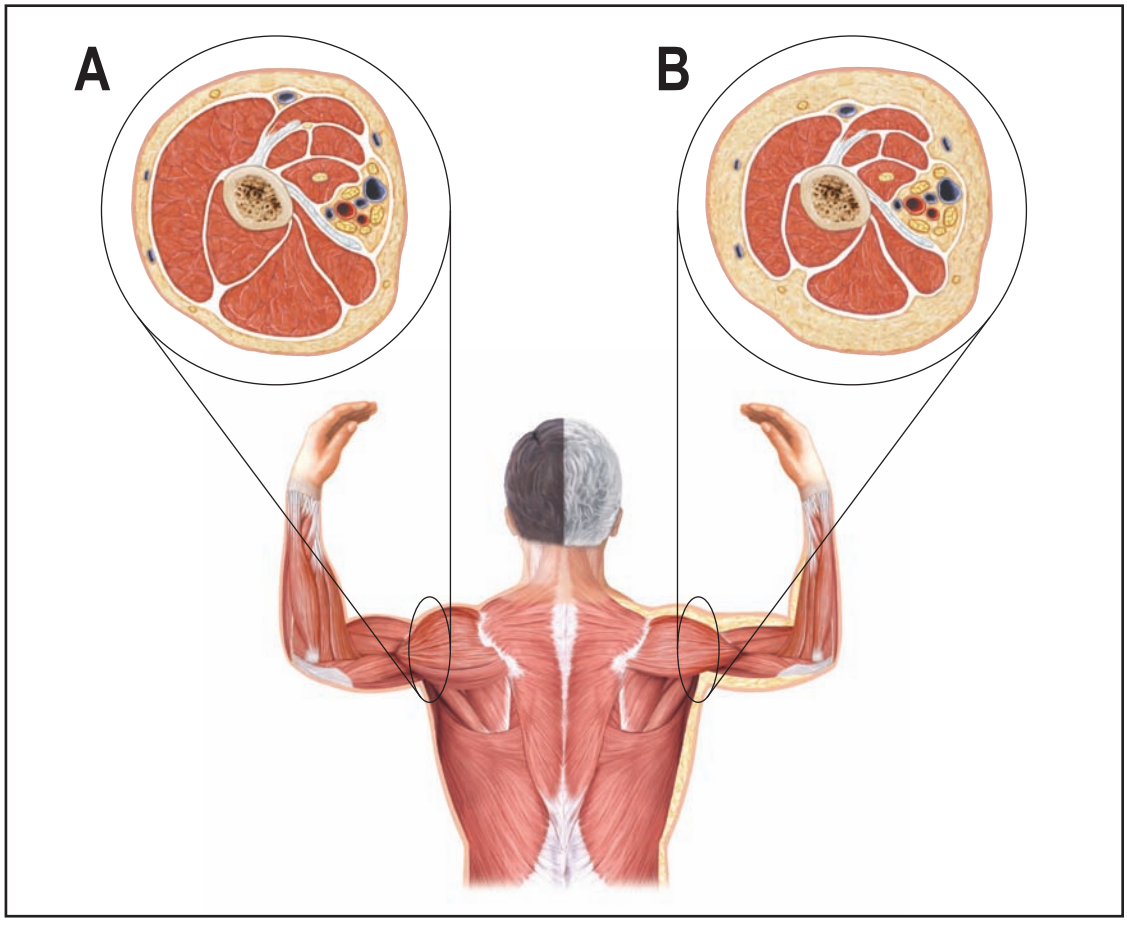
or in those who've experienced deconditioning, caused by, for example, fatigue, poor activity tolerance, or weakness. Because of their pivotal role in promoting health, nurses working with older adults should be knowledgeable in the pathophysiology of sarcopenic obesity, as well as in strategies for its management.

BODY COMPOSITION AND SARCOPENIC OBESITY

The relative components of body mass are generally categorized as fat and lean mass, with lean mass being predominantly composed of muscle tissue. Changes in body composition can easily be masked when increases in one type of tissue are compensated for by decreases in another. Typically, fat mass increases over the life span while lean mass decreases. In many cases, substantial increases in body fat and decreases in muscle mass aren't clinically evident if a person maintains a relatively stable body weight. As a result, obesity isn't diagnosed until fat mass increases to such an extent that total body mass also increases. Given this clinical presentation, it's not surprising that the focus of obesity management has traditionally been on decreasing weight rather than increasing muscle.

The model of sarcopenic obesity is consistent with age-related changes in body composition. While both men and women exhibit decreases in lean mass during middle age, their body weight may remain relatively stable, reflecting a compensatory increase in body fat. In fact, data from the New Mexico Aging Process Study and the New Mexico Elder Health Survey demonstrate that sarcopenia, with its loss of muscle mass, occurs even when absolute amounts of body fat remain constant over time.[5] As a result, despite an overall decrease in body weight that may be reassuring to the clinician, the relative amount of fat actually increases in comparison to lean tissue, a critical step in the development of sarcopenic obesity.

Figure 1. Body Composition Changes with Sarcopenic Obesity. As people age they lose the lean muscle mass gained in young adulthood (A), resulting in a higher proportion of fat mass (B), even if the absolute amounts of body fat remain constant. This can lead to sarcopenic obesity—a loss of muscle and a concomitant increase in fat, often while body weight remains stable or even decreases. Illustration by Anne Rains.



Although sarcopenic obesity is primarily associated with aging, it's also influenced by gender.[6] Men tend to achieve greater peak muscle mass during early adulthood than women do. This provides them a greater "safety net" for muscle loss with age and may delay the onset of sarcopenic obesity until later in life. Data from adolescents and men and women between 12 and 80 years of age, gathered from 1988 through 1994 by the Third National Health and Nutrition Examination Survey, support this model.[7] Overall body weight and lean mass increase during adolescence, although at a much steeper rate in men than women. Furthermore, at all ages men have greater lean and total body mass than women, while women consistently have higher levels of absolute and relative body fat.[7] During young adulthood the rate of muscle deposition tapers off for both genders, although men continue to increase lean mass at a greater rate than women, until in their mid-40s both men and women begin to lose muscle.[7] There's a strong inverse relationship between fat and lean mass, with fat deposition mirroring muscle loss with or without changes in body weight.

Metabolic rate. Decreases in resting metabolic rate (RMR) also accompany decreases in physical activity. Lean muscle mass is the principal determinant of RMR and energy expenditure. As muscle mass increases, so does RMR. Unsurprisingly, as age increases, RMR decreases. Women have a lower metabolic rate than men across all age groups. RMR is the strongest determinant of 24-hour energy expenditure.[13] As RMR decreases, total energy expenditure also decreases, resulting in an increased risk of fat deposition.

Diet and the role of protein. Dietary issues have been widely discussed as a factor in obesity, but are less well recognized in relation to the development of sarcopenia. Unlike physical activity and RMR, caloric intake doesn't typically decline over the life span. The resulting caloric imbalance ultimately leads to fat deposition and increased fat mass.

Protein intake may also be a significant factor in the development of sarcopenia. Findings of a study by Pitkanen and colleagues of 72 healthy men and women between the ages of 23 and 92 suggest that protein intake may decrease with age in adults, especially women.[14] This decrease in protein is associated with decreased levels of serum amino acid, including essential and branched-chain amino acids necessary for the maintenance of muscle mass. However, when amino acids are administered intravenously, muscle protein synthesis is significantly increased, even in people over age 70.[15] Moreover, in healthy older adults (69 ± 2 years) oral administration of only the essential amino acids is sufficient to stimulate an anabolic response.[16]

Inadequate dietary protein, even over a short period of time, can result in loss of muscle mass, despite adequate energy intake. In one small study, Campbell and colleagues provided healthy men and women, 55 to 77 years of age, with a eucaloric diet containing 0.8 g/kg of protein per day, the recommended dietary allowance (RDA) for adults.[17] In only three months, thigh muscle cross-sectional area was reduced by 1.7%. Furthermore, in malnourished older adults (69 to 90 years), even 10 days of oral protein supplementation containing 30 g of casein was found to increase protein synthesis, resulting in a 1.2-kg gain in lean mass.[18] It's probable that both the quantity and quality of

Although decreases in muscle and increases in fat mass are considered part of the natural course of aging, to a great extent they're probably the results of inactivity and sedentary behaviors.

PATHOPHYSIOLOGY

Physical activity influences body composition directly through its effect on caloric expenditure and indirectly through its stimulatory effect on muscle growth. Levels of physical activity decrease over the life span,[8, 9] with children the most active segment of the population. It's not coincidental that decreases in muscle mass accompany decreases in physical activity. Although decreases in muscle and increases in fat mass are considered part of the natural course of aging, to a great extent they're probably the results of inactivity and sedentary behaviors.

Disuse syndrome is a classic pattern of muscular deconditioning and atrophy resulting from inactivity or immobilization. *Disuse atrophy* is characterized by reductions in muscle fiber size. On a cellular level, these changes can be manifested as either a reduction in both type I muscle fibers (needed for endurance) and type II muscle fibers (needed for strength) or a preferential reduction in type II fibers alone.[10] Atrophic changes begin in the mid-20s and accelerate with age,[11] resulting in a decrease in overall muscle cross-sectional area in both men and women.[12]

dietary protein contribute to the loss of muscle mass seen with age.

Inflammation is an area of growing interest. Data from the Framingham Heart Study demonstrate that insulin-like growth factor and the inflammatory cytokine interleukin-6 (IL-6) predict loss of muscle and sarcopenia in men and women between the ages of 72 and 92.[19] Not surprisingly, IL-6 and tumor necrosis factor-α (TNF-α) have been positively related to fat deposition in healthy men and women ages 65 to 80, as well as in those with type 2 diabetes.[20] The inflammatory process reflected by the activities of IL-6 and TNF-α represents a catabolic stimulus that continues over time as people age.[21] Stimulation of catabolism in the absence of an anabolic environment (diminished physical activity and inadequate dietary protein) may play a key contributory role in sarcopenia and the development of sarcopenic obesity.

CLINICAL IMPLICATIONS

Sarcopenia is strongly associated with increased disability, functional impairment, physical frailty, and diminished quality of life.[5, 22, 23] Leg strength is significantly reduced and the risk of functional limitation significantly increased in the presence of sarcopenia or sarcopenic obesity.[24] Moreover, strength losses and the development of sarcopenia in older adults are associated with significantly increased mortality rates.[25, 26]

MANAGEMENT

Management strategies for obesity commonly favor diet changes and aerobic exercise in order to reduce levels of body fat. However, this approach doesn't address the loss of muscle mass that may occur during weight loss and contribute to sarcopenia. It's of critical importance that management strategies focus on maintenance or accretion of muscle mass as well as fat loss in order to maintain strength, function, and RMR. Resistance exercise is the most appropriate strategy to achieve these goals.

Resistance training. In older adults, resistance training can improve body composition without the need for weight loss. Resistance training, also known as weight or strength training, consists of exercises using free weights, machines, or elastic bands, during which skeletal muscles shorten against a counterweight (the resistance). More than 20 years ago, Fiatarone and colleagues demonstrated that an eight-week resistance training program could significantly increase muscle mass in even frail, institutionalized 90-year-old men and women.[27] Subsequent research has demonstrated that weight training three days a week without dietary restriction increases muscle mass and decreases fat mass in healthy men and women between 50 and 75 years of age, although body weight remains unchanged.[28, 29] Furthermore, increases in muscle mass are accompanied by commensurate increases in RMR.

A resistance training program can also induce changes in muscle fiber characteristics in healthy men and women 60 years of age and older. In as little as 12 weeks, resistance training two or three days a week can result in muscle hypertrophy and increased cross-sectional area of both type I and type II fibers essential for both muscular endurance and strength.[30-32] Most importantly, the stimulus to the muscle resulting from resistance training increases fiber size to that of young, untrained adults.[30, 32] Even in the frail elderly

Table 1. High-Quality Protein Sources

Foods	Quantity	Protein
Beef		
Flank steak, broiled	3 oz (85 g)	25 g
Hamburger patty (90% lean), broiled	3 oz (85 g)	22 g
Top sirloin steak, broiled	3 oz (85 g)	26 g
Dairy		
Egg, whole	1 large	6 g
Egg, white only	1 large	4 g
Milk, low fat (1% fat)	8 oz (1 cup)	8 g
Milk, nonfat	8 oz (1 cup)	8 g
Pork		
Pork loin (boneless), broiled	3 oz (85 g)	25 g
Poultry		
Chicken breast, roasted with skin	3 oz (85 g)	27 g
Chicken breast, roasted without skin	3 oz (85 g)	28 g
Chicken thigh, roasted with skin	3 oz (85 g)	23 g
Chicken thigh, roasted without skin	3 oz (85 g)	22 g
Seafood		
Halibut, broiled	3 oz (85 g)	19 g
Salmon, broiled	3 oz (85 g)	22 g
Trout, broiled	3 oz (85 g)	23 g
Tuna (light, canned in water), drained	3 oz (85 g)	22 g
Soy		
Soy protein isolate	1 oz (28 g)	25 g
Tofu (firm), uncooked	3 oz (85 g)	13 g

Adapted from U.S. Department of Agriculture, Agricultural Research Service. 2010. USDA National Nutrient Database for Standard Reference, Release 23. Nutrient Data Laboratory Home Page: www.ars.usda.gov/ba/bhnrc/ndl.

Table 2. Resistance Training Recommendations for Healthy Older Adults

Exercises	Frequency	Volume	Intensity	Precautions
Include at least 8 exercises designed to stimulate all major muscle groups. Use free weights or exercise machines. Chest • front press Back • pulldown • row Shoulders • overhead press Arms • extension • flexion (curl) Legs • seated or incline press • extension • flexion (curl)	Exercise 3 nonconsecutive days/wk to achieve muscle hypertrophy. *Although some benefits will accrue with 2 days/wk, 3 days/wk is preferable.* Allow at least 24 hours rest between training sessions to allow muscle groups to recover.	At least 2–3 sets for each exercise at each training session. Include an additional warm-up set for each exercise, using about 50% of the target weight (load) to be used for subsequent sets.	8–12 repetitions per set using a weight that causes fatigue at the end of each set or that would be described as "somewhat hard" to "very hard" (6–8 on a 10-point scale). Weight (load) should be increased when 10–12 repetitions can be achieved in all sets of an exercise.	To minimize transient increases in blood pressure, patient education should stress the need to avoid the Valsalva maneuver when force is exerted. Breathing patterns should emphasize • exhalation during exertion (pushing with presses and extensions, pulling with pulldowns, rows, flexion, and curls) • inhalation during relaxation (returning to the starting position)

Sources: American College of Sports Medicine. Position stand: exercise and physical activity for older adults. *Med Sci Sports Exerc* 2009;41(7):1510-30; American College of Sports Medicine. Position stand: progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 2009;41(3):687-708.

(over 85 years of age), three months of resistance training can selectively increase type II fibers that are preferentially lost with age by as much as 20%.[33] Although often considered to be a normal part of aging, muscle loss may be not only preventable but also reversible with an appropriate exercise prescription.

Even during severe caloric restriction, resistance training can be beneficial. Weight loss usually includes a reduction in both fat and lean mass. However, when resistance exercise is prescribed in addition to caloric restriction, a muscle-sparing effect is observed that is characterized by enhanced loss of fat, blunted loss of muscle, and maintenance of RMR in middle-aged (30 to 50 years) and elderly (70 to 80 years) men and women.[34, 35] As a result, body composition changes minimize the development of sarcopenia by maintaining lean mass. Not surprisingly, decreases in fat mass in the presence of stable amounts of muscle mass manifest as an overall decrease in body fat percentage and a reduced risk of obesity.

Protein supplementation, in combination with resistance exercise, enhances muscle protein synthesis and improves body composition by increasing lean mass in relation to fat mass.[36] In men and women 25 to 35 years of age, 6 g of essential amino acids ingested immediately before a single bout of resistance exercise resulted in significant increases in muscle protein synthesis, primarily due to increased delivery of amino acids to working muscles.[37] In one small study, during a 12-week resistance training program, 10 g of whole protein ingested five minutes after exercise by healthy older men (70 to 80 years) resulted in a 1% to 2% increase in lean mass, compared with a 1% to 2% decrease when supplementation was delayed by two hours.[38] By comparison, 12 weeks of resistance training plus twice-a-day consumption of a protein supplement containing 17 g of essential amino acids by healthy young men (20 to 25 years) stimulated an approximately 80% greater gain in lean mass compared with resistance training alone.[39] Finally, during four weeks of bed rest, administration of 15 g of essential amino acids to healthy middle-aged men (30 to 55 years of age), in combination with a resistance training program, attenuated the loss of muscle and gains in fat normally seen during immobilization.[40]

Dietary protein. Even without the stimulus provided by resistance exercise, a high protein diet may in itself provide an anabolic environment that can promote retention or accretion of muscle over time. A study by Solerte and colleagues found that in older

men and women 64 to 84 years of age with evidence of sarcopenia, oral supplementation with 16 g per day of essential amino acids was sufficient to increase lean mass in as little as eight months.[41] This effect persisted over time and was accompanied by a decrease in TNF-α, which has been associated with the sarcopenic process.

Protein supplementation may also spare muscle during times of caloric restriction. A study by Frestedt and colleagues found that use of a commercial protein supplement to increase daily protein intake to the RDA for adults of 0.8 g/kg per day during a 12-week weight-loss diet increased fat loss by 75% and blunted muscle loss by 50% in obese but otherwise healthy adults between the ages of 25 and 50.[42]

Increasing daily protein intake to above recommended levels may also be beneficial. In obese, nondiabetic men and women 45 to 50 years of age, a very high protein (2.2 g/kg per day) weight loss diet for 12 weeks not only maintained muscle but also increased fat loss (but not overall weight loss) by more than 60% compared with a moderately high protein (1.1 g/kg) diet.[43] Finally, a study of 24 obese women 55 to 65 years of age found that a high protein diet providing 1.2 to 1.5 g/kg of protein per day promoted weight loss and the retention of 20% greater lean mass over a 20-week period compared with a low protein diet.[44]

RECOMMENDATIONS

Any person beginning a diet or exercise program should first consult with a primary care provider. Although dietary protein may pose a risk for those with impaired renal function, a 2005 review by Martin and colleagues found no evidence that a high protein diet negatively affects kidney function in healthy individuals.[45] A review by Wolfe and colleagues likewise found that "concerns about potential detrimental effects of increased protein intake on bone health, renal function, neurological function and cardiovascular function are generally unfounded."[46] The authors also argue that, to counter the risks of sarcopenia and sarcopenic obesity, healthy older adults should have a dietary intake of 1.5 g/kg of protein per day. This is nearly twice the RDA of 0.8 g/kg per day set by the Food and Nutrition Board of the U.S. National Academy of Sciences. To optimize the amino acid profile of dietary proteins, high-quality sources such as lean meat, fish, nonfat dairy, and soy should be emphasized (see Table 1). Unfortunately, cost may be a barrier for people on a limited budget, making these foods difficult to obtain regularly.

Public health recommendations for resistance training in healthy adults suggest that it be performed at least two days per week; however, for maintenance of lean mass, three days a week should be encouraged.[47] Age alone is not an exclusionary criterion for a resistance training program, although the rate of progression (increases in load or resistance) should be gradual, especially in those with hypertension, arthritis, cardiovascular disease, or any condition limiting physical function.[48] Resistance training guidelines for both healthy adults and older adults are summarized in Table 2. Additional educational resources can be found on the Web site of the National Institute on Aging, which provides exercise and physical activity guidelines: http://1.usa.gov/f0xGH.

THE NURSES' ROLE

Management of sarcopenic obesity should focus on increasing muscle mass and strength rather than decreasing fat mass. If muscle mass increases, then RMR will increase, resulting in an increase in energy expenditure. Long-term increases in energy expenditure can potentially decrease fat mass without severe caloric restriction. Although resistance training alone or protein intake alone may be effective in maintaining muscle mass, appropriate management will ideally involve both strategies. Once muscle is lost with aging or inactivity, it's much more difficult to build it back up. Prevention cannot be emphasized enough. Nurses should routinely educate healthy adult and older adult patients on the benefits of resistance training and dietary protein to prevent or reverse sarcopenia and sarcopenic obesity. ▼

For 13 additional continuing nursing education articles on physical assessment/diagnostic topics, go to nursingcenter.com/ce.

Melissa J. Benton is an associate professor, and Maria D. Whyte and Brenda W. Dyal are assistant professors, at Valdosta State University College of Nursing, Valdosta, GA. Contact author: Melissa J. Benton, mjbenton@valdosta.edu. *Melissa J. Benton participated in a program sponsored by Abbott Nutrition, a maker of nutritional products, and received an honorarium for her participation. The other authors have disclosed no potential conflicts of interest, financial or otherwise.* AJN*'s peer review process has determined this article to be objective and free of commercial bias.*

REFERENCES

1. Roubenoff R, et al. Standardization of nomenclature of body composition in weight loss. *Am J Clin Nutr* 1997;66(1):192-6.
2. Bays HE, et al. Pathogenic potential of adipose tissue and metabolic consequences of adipocyte hypertrophy and increased visceral adiposity. *Expert Rev Cardiovasc Ther* 2008;6(3):343-68.
3. Bray GA. Obesity is a chronic, relapsing neurochemical disease. *Int J Obes Relat Metab Disord* 2004;28(1):34-8.
4. Roubenoff R. Sarcopenic obesity: does muscle loss cause fat gain? Lessons from rheumatoid arthritis and osteoarthritis. *Ann N Y Acad Sci* 2000;904:553-7.
5. Baumgartner RN. Body composition in healthy aging. *Ann N Y Acad Sci* 2000;904:437-48.
6. Sorensen MB. Changes in body composition at menopause—age, lifestyle or hormone deficiency? *J Br Menopause Soc* 2002;8(4):137-40.

7. Chumlea WC, et al. Body composition estimates from NHANES III bioelectrical impedance data. *Int J Obes Relat Metab Disord* 2002;26(12):1596-609.
8. Bradley CB, et al. Changes in common activities of 3rd through 10th graders: the CHIC study. *Med Sci Sports Exerc* 2000;32 (12):2071-8.
9. Schutzer KA, Graves BS. Barriers and motivations to exercise in older adults. *Prev Med* 2004;39(5):1056-61.
10. Lexell J, et al. Distribution of different fiber types in human skeletal muscles: effects of aging studied in whole muscle cross sections. *Muscle Nerve* 1983;6(8):588-95.
11. Lexell J, et al. What is the cause of the ageing atrophy? Total number, size and proportion of different fiber types studied in whole vastus lateralis muscle from 15- to 83-year-old men. *J Neurol Sci* 1988;84(2-3):275-94.
12. Frontera WR, et al. Skeletal muscle fiber quality in older men and women. *Am J Physiol Cell Physiol* 2000;279(3): C611-C618.
13. Campbell WW, et al. Increased energy requirements and changes in body composition with resistance training in older adults. *Am J Clin Nutr* 1994;60(2):167-75.
14. Pitkanen HT, et al. Serum amino acid concentrations in aging men and women. *Amino Acids* 2003;24(4): 413-21.
15. Volpi E, et al. Exogenous amino acids stimulate net muscle protein synthesis in the elderly. *J Clin Invest* 1998;101(9): 2000-7.
16. Volpi E, et al. Essential amino acids are primarily responsible for the amino acid stimulation of muscle protein anabolism in healthy elderly adults. *Am J Clin Nutr* 2003;78(2): 250-8.
17. Campbell WW, et al. The recommended dietary allowance for protein may not be adequate for older people to maintain skeletal muscle. *J Gerontol A Biol Sci Med Sci* 2001; 56(6):M373-M380.
18. Bos C, et al. Short-term protein and energy supplementation activates nitrogen kinetics and accretion in poorly nourished elderly subjects. *Am J Clin Nutr* 2000;71(5):1 129-37.
19. Payette H, et al. Insulin-like growth factor-1 and interleukin 6 predict sarcopenia in very old community-living men and women: the Framingham Heart Study. *J Am Geriatr Soc* 2003;51(9):1237-43.
20. Pedersen M, et al. Circulating levels of TNF-alpha and IL-6-relation to truncal fat mass and muscle mass in healthy elderly individuals and in patients with type-2 diabetes. *Mech Ageing Dev* 2003;124(4):495-502.
21. Roubenoff R. Catabolism of aging: is it an inflammatory process? *Curr Opin Clin Nutr Metab Care* 2003;6(3): 295-9.
22. Janssen I, et al. Low relative skeletal muscle mass (sarcopenia) in older persons is associated with functional impairment and physical disability. *J Am Geriatr Soc* 2002;50(5): 889-96.
23. Villareal DT, et al. Physical frailty and body composition in obese elderly men and women. *Obes Res* 2004;12(6): 913-20.
24. Zoico E, et al. Physical disability and muscular strength in relation to obesity and different body composition indexes in a sample of healthy elderly women. *Int J Obes Relat Metab Disord* 2004;28(2):234-41.
25. Krakauer JC, et al. Body composition profiles derived from dual-energy X-ray absorptiometry, total body scan, and mortality. *Prev Cardiol* 2004;7(3):109-15.
26. Metter EJ, et al. Skeletal muscle strength as a predictor of all-cause mortality in healthy men. *J Gerontol A Biol Sci Med Sci* 2002;57(10):B359-B365.
27. Fiatarone MA, et al. High-intensity strength training in nonagenarians. Effects on skeletal muscle. *JAMA* 1990;263(22): 3029-34.
28. Pratley R, et al. Strength training increases resting metabolic rate and norepinephrine levels in healthy 50- to 65-yr-old men. *J Appl Physiol* 1994;76(1):133-7.
29. Kerksick C, et al. Effects of a popular exercise and weight loss program on weight loss, body composition, energy expenditure and health in obese women. *Nutr Metab (Lond)* 2009;6:23.
30. Hikida RS, et al. Effects of high-intensity resistance training on untrained older men. II. Muscle fiber characteristics and nucleo-cytoplasmic relationships. *J Gerontol A Biol Sci Med Sci* 2000;55(7):B347-B354.
31. Verdijk LB, et al. Skeletal muscle hypertrophy following resistance training is accompanied by a fiber type-specific increase in satellite cell content in elderly men. *J Gerontol A Biol Sci Med Sci* 2009;64(3):332-9.
32. Kosek DJ, et al. Efficacy of 3 days/wk resistance training on myofiber hypertrophy and myogenic mechanisms in young vs. older adults. *J Appl Physiol* 2006;101(2):531-44.
33. Kryger AI, Andersen JL. Resistance training in the oldest old: consequences for muscle strength, fiber types, fiber size, and MHC isoforms. *Scand J Med Sci Sports* 2007;17(4):422-30.
34. Bryner RW, et al. Effects of resistance vs. aerobic training combined with an 800 calorie liquid diet on lean body mass and resting metabolic rate. *J Am Coll Nutr* 1999;18(2): 115-21.
35. Frimel TN, et al. Exercise attenuates the weight-loss-induced reduction in muscle mass in frail obese older adults. *Med Sci Sports Exerc* 2008;40(7):1213-9.
36. Kerksick C, et al. International Society of Sports Nutrition position stand: nutrient timing. *J Int Soc Sports Nutr* 2008; 5:17.
37. Tipton KD, et al. Timing of amino acid-carbohydrate ingestion alters anabolic response of muscle to resistance exercise. *Am J Physiol Endocrinol Metab* 2001;281(2): E197-E206.
38. Esmarck B, et al. Timing of postexercise protein intake is important for muscle hypertrophy with resistance training in elderly humans. *J Physiol* 2001;535(Pt 1):301-11.
39. Kraemer WJ, et al. Effects of amino acids supplement on physiological adaptations to resistance training. *Med Sci Sports Exerc* 2009;41(5):1111-21.
40. Brooks N, et al. Resistance training and timed essential amino acids protect against the loss of muscle mass and strength during 28 days of bed rest and energy deficit. *J Appl Physiol* 2008;105(1):241-8.
41. Solerte SB, et al. Nutritional supplements with oral amino acid mixtures increases whole-body lean mass and insulin sensitivity in elderly subjects with sarcopenia. *Am J Cardiol* 2008;101(11A):69E-77E.
42. Frestedt JL, et al. A whey-protein supplement increases fat loss and spares lean muscle in obese subjects: a randomized human clinical study. *Nutr Metab (Lond)* 2008;5:8.
43. Treyzon L, et al. A controlled trial of protein enrichment of meal replacements for weight reduction with retention of lean body mass. *Nutr J* 2008;7:23.
44. Gordon MM, et al. Effects of dietary protein on the composition of weight loss in post-menopausal women. *J Nutr Health Aging* 2008;12(8):505-9.
45. Martin WF, et al. Dietary protein intake and renal function. *Nutr Metab (Lond)* 2005;2:25.
46. Wolfe RR, et al. Optimal protein intake in the elderly. *Clin Nutr* 2008;27(5):675-84.
47. Haskell WL, et al. Physical activity and public health: updated recommendation for adults from the American College of Sports Medicine and the American Heart Association. *Circulation* 2007;116(9):1081-93.
48. American College of Sports Medicine. American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 2009; 41(3):687-708.