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Lifestyle Behavioral Strategies for Weight Loss in Older Adults

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ABSTRACT

There is a rising prevalence of both obesity (defined as a body mass index of > 30.0 kg/m^2) and the number of individuals over the age of 60 years. Currently ~40% of older adults are obese and the number of individuals over the age of 65 is expected to reach 82 million by 2050. Obesity is also estimated to affect 50% of older adults in next few decades. This combination makes this a very concerning health issue. While intentional weight loss benefits young- to middle- aged adults, this is not so clear with older adults. Due to the loss of fat free mass, including skeletal muscle and bone mineral density, there is an increased risk of impaired physical function, fractures, and even mortality in this older cohort. Complicating whether to advise older adults to attempt to lose weight or not is the fact that about 1 in 5 individuals rescind and gain back most if not all of lost weight. This weight regain is mostly as fat and it is deposited into ectopic fat depots, potentially making cardiometabolic risk worse. Caloric restriction using a variety of diet patterns and macronutrient distributions can be successful, at least in the short-term. Additionally, combining resistance and aerobic exercise training with caloric restriction seems to provide the best results with regards to protecting loss of skeletal muscle and bone mineral density. Finally, time restricted eating is a novel approach for combating the detrimental effects of obesity and aging.

Background

Obesity, defined as a body mass index (BMI) ≥ to 30.0 kg/m^2, is a chronic condition affecting individuals across nearly all lifespan stages, from early childhood to older adults. In essence, nearly all organs are negatively impacted by the excess fat mass accompanying obesity, leading to increased morbidity from numerous health conditions, most notably cardiovascular disease, diabetes, certain types of cancer, and poor health related quality of life; many of these are responsible for the leading causes of death in the United States[1]. Unfortunately, the prevalence of obesity in the United States continues to rise, reaching over 40% of older adults (≥60 years of age)[2]. Of particular concern is that obesity is estimated to affect 50% of older adults in next few decades[3]. Additionally, there is a projected 47% increase in the number of individuals over the age of 65, reaching 82 million by 2050. Globally, 900 million people were ≥ 60 years of age in 2015 and it is estimated to reach 2.1 billion by the year 2050[4]. The combination of the rise in obesity and a greater number of older adults makes identification of obesity treatment and/or prevention strategies among this cohort a significant public health priority.

Body mass index was shown to increase annually by 0.12 kg/m^2 for men and 0.18 kg/m^2 for women between the ages of 45 to 65 years[5]. This is a result of an increase in fat mass since fat free mass decreases in men and stays the same in women over these two decades. A statistically significant association was observed between changes in adiposity and changes in cholesterol that are inducive of worsening heart disease risk[5]. This is consistent with others who observed an unfavorable redistribution of body fat, from subcutaneous depots to the viscera, liver, skeletal and cardiac muscles, and bone marrow[6]. Others found a 2% decrease in fat free mass per decade and a 7.5% increase in fat mass per decade with aging[7]. As a person ages, body composition changes lead to adverse metabolic profiles, increasing the risk of insulin resistance, type 2 diabetes mellitus and the development of cardiovascular disease (CVD)[8]. While diabetes affects nearly all ages, almost half of the population with diabetes is over the age of 65 years with the peak prevalence at 24% in older people aged 75–79 years[9]. Similarly, to diabetes, there is an increase in the prevalence of CVD with aging. In the 40-59 year old age group, 54% of individuals have CVD, and this goes up to 78% in the 60-79 year olds and 90% in those above 80 years old[10]. Disability, morbidity, mortality occur with obesity and advancing age[11,12]. For older adults, obesity exacerbates the age-related decline in muscle mass and physical function causing frailty, an increase in institutionalization rates, and greater health care costs[13].

The shifts in body composition are likely the combination of a reduction in energy expenditure from lower physical activity, and decreased secretion of sex and anabolic hormones, reducing muscle mass and shifting fat from subcutaneous to visceral locations[14,15]. The observed decline in fat free mass was greater in the least fit compared with the more fit older adult[7]. The decrease in fat free mass with aging is particularly an issue as it relates to a reduction in bone mineral density and declines in physical function[16]. Low bone mineral density is a major predictor of bone fractures[17] and physical frailty is associated with a low relative proportion of body weight as fat free mass, as well as poor muscle quality[18]. While the premise has been that obese older adults are more protected from low bone mineral density, Nielson et al found the hazard ratio for nonspine fractures in men was 1.29 for class I obesity (BMI 30.0-34.9 kg/m2) and 1.94 for class II obesity (BMI 35.0-39.9 kg/m2) as compared to normal BMI[19]. Interestingly, this was apparent when bone mineral density was held constant. Over an 11 year follow-up period, there was a 40% increase in frailty fractures in the intensive lifestyle intervention of Look AHEAD compared to the weight control group[20].

Further contributing to the health comorbidities of obesity and aging are that both are characterized by chronic low-grade inflammation, contributing to reduced muscle quality[21] as well as diminished muscle anabolic responses[22]. Oxidative stress and inflammation as indicated by higher circulating levels of interleukin 6 (IL-6) and tumor necrosis factor alpha (TNFα) are present and this causes further molecular changes, including an increase in telomere shortening[23]. Independently, obesity induces epigenetic alterations, accelerating age-related dysfunction[24].

Thus, obesity in older adults is a public health burden. While weight loss interventions have proven successful in improving health related metabolic outcomes in young- and middle-aged adults, there has been some hesitation to promote weight loss in older adults. Currently, strategies to treat obesity in older adults consider lifestyle interventions (diet and physical activity strategies) to be the initial approach and the gold standard of treatment. This treatment strategy will be the focus for this narrative review. However, it is recognized that pharmacological and surgical interventions are implemented in a stepwise approach. Briefly, anti-obesity medications are initiated when obesity treatment is not successful to lifestyle interventions. While incretin therapy of GLP-1 agonists provide weight loss of greater than 20%, their safety and efficacy profile is based on younger adults. With the potential for drug-drug interactions and the polypharmacy practice apparent in many older adults and the extensive weight loss, the safety of these medications in older adults needs further study. Furthermore, metabolic surgeries to treat those at the higher spectrum of obesity (BMI ≥ 40.0 kg/m^2) produce weight loss of over 30%. While many of the chronic conditions present with obesity are improved or resolved in the vast majority of older adults following metabolic surgery, there appears to be more complications and less weight loss in older vs. younger adults[25]. In contrast, after one-year of post-surgery follow-up, others concluded metabolic surgery had similar surgery-risk and complication rates between older and younger adults, but the younger group had greater losses in weight and fat free mass[26]. This is likely related to greater weight loss overall. Importantly though, about 22% of weight loss was from fat free mass[26]. While metabolic surgery shows success in long-term weight loss, the restriction for surgery to be limited to those with a BMI ≥ 40.0 kg/m^2

and its cost makes it unavailable for many individuals. Thus, anti-obesity medications and metabolic surgery will not be further discussed.

Guidelines for the management of obesity state weight loss interventions for older adults (≥ 65 years) remains controversial and further research is needed[27]. This is based on the premise that weight loss programs result not only in the loss of fat mass, but also fat free mass. Caloric restriction alone improves measurable outcomes of physical function and quality of life, however it also consistently decreases lean body mass and bone mineral density[28]. The loss of lean body mass and bone mineral density is a concern since it can further exacerbate sarcopenia and increase fracture risk[29]. In a study on overweight or obese women and men ranging in age from 30 to 70 years[30], participants followed a low-calorie diet consisting of either high-protein or average protein and underwent bone density testing to measure hip and spine composition six months and two years after the study's commencement. Premenopausal women lost bone density in the hip while postmenopausal women risked both hip and spine bone density loss. Decreasing bone mineral density could potentially result in a further increase in fracture risk. Reducing fat free mass, including skeletal muscle may exacerbate impairments in physical function, increasing the risk for frailty and loss of independent living[31–33]. Wu and colleagues[34] present results showing caloric restriction of 500 kcals/day with and without exercise achieved similar loss in body weight and body fat, however the caloric restriction with 90 minutes of aerobic exercise per week attenuated the loss of fat free mass compared to caloric restriction alone. A combination of enhanced protein intake and resistance exercise attenuates some, but not all of the loss of lean body mass during weight loss[35]. There remains a concerning dearth of knowledge regarding the best approaches for managing body weight and treating obesity in older adults[28], especially for sarcopenic obese individuals who suffer the worst of both conditions- low bone mineral density and low fat free mass[36]. Thus, there is an essential need for successful protocols to induce fat mass loss while preserving muscle and bone mass to reduce aging- and obesity-related cardiometabolic and cognitive deterioration and prevent frailty.

Several observational studies in middle-aged and older adults report an association between weight loss and increased mortality[37,38] even though weight loss interventions in overweight and obese older adults have beneficial effects on risk factors for mortality, such as inflammation (IL-6)[39–41], blood pressure[42], fasting plasma glucose [43], mobility disability (gait speed)[44–46], and cardiorespiratory fitness[45,47,48]. Recently, a meta-analysis of 15 randomized controlled trials showed a 15% lower all-cause mortality risk from lifestyle-based weight loss interventions[49]. More than 17,000 were included in these trials with a mean age of 52 years. The BMI ranged between 30-46 kg/m^2 with 18 months set as a minimum follow-up time criteria, although the max follow-up period was 12.6 years and a mean of 27 months. Across all studies, the mean weight loss was 5.5 ± 4.0 kg. There was a 15% lower all-cause mortality risk as determined by the 264 deaths in the weight loss groups and 310 in non-weight loss groups. Further analysis in this study by selecting only participants at least 55 years old at randomization produced similar results. These findings support an earlier meta-analysis from 2009 assessing prospective studies (instead of randomized controlled trials) with intentional weight loss[50]. However, Harrington found an increase in mortality when weight loss was self-reported as unintentional. Interestingly, several observational studies observed an increased risk of mortality, even with self-reported intentional weight loss. These conflicting findings indicates intentionality is unreliable and intentional and unintentional weight loss may occur simultaneously in some individuals. However, due to the lack of clarity among the various research, the obesity paradox has caused a reluctance to recommend weight loss in older adults by some clinicians[51].

Unfortunately, less than 20% of individuals are successful at long-term weight loss when defined as losing at least 10% of initial body weight and keeping the weight off for at least one year[52,53]. In fact, a meta-analysis reported more than half of lost weight was regained within two years, and by five years more than 80% of lost weight was regained[53]. Several factors responsible for either resistance to weight loss or inability of weight loss maintenance have been identified and described by Dabas and colleagues[54]. These are classified into 5 separate categories: biological, medical, intervention, lifestyle, and environmental. A few examples for each include:

1. Biological: genetics; anthropometry; metabolic adaptations
2. Medical: hypothyroidism; polycystic ovary syndrome; medications
3. Interventional: dietary adherence; macronutrients-based diets
4. Lifestyle: sleep deprivation; circadian rhythm; alcohol
5. Environmental: stress; social support; pollutants

Unfortunately, this failure to maintain weight loss may predispose individuals to a worsening of conditions seen in obesity and aging. Specifically, weight regain in older adults is primarily as fat mass vs. fat free mass and this includes a reduction in muscle mass and bone mineral density[55–59]. This predisposes them to an increased risk for fractures and mobility disability and frailty. However, a slightly promising finding is increasing age is a strong predictor of adherence to lifestyle interventions in men and women[60,61].

This review presents brief synopsis of behavioral lifestyle programs utilizing dietary and exercise interventions for weight loss in older adults. The dietary programs are based on altering macronutrient intake, dietary patterns, and timing of eating. Much of this research is limited by few studies exclusively focused on older adults. The different exercise modalities and intensity of exercise training, and how they affect body composition, including lean body mass and bone mineral density, during weight loss programs are covered. Taken together, calorie restriction in combination with exercise may provide additional benefits besides weight loss as they have been shown to slow biological aging by protecting against the molecular and cellular damages that occur in obesity and aging[62–64].

Diet Focused Weight Loss Programs

ALTERED MACROMOLECULE INTAKE

Low Fat and Low Carbohydrate Diets (Keto Diet)

A meta-analysis of weight loss trials on popular dietary approaches found that the most significant weight loss results were induced by low-carb and low-fat diets[65]. This finding is supported by the results of a particular study comparing low-fat and low-carb weight-loss interventions in obese adults at different intervals over a one year period. A significant reduction in weight after twelve months was observed, however, the low-carb diet induced a greater weight loss and potential cardiovascular biomarker benefits[66]. Although both have been shown effective in weight loss, the shift in macronutrient composition may have other effects. Low carbohydrate diets are often followed to combat insulin sensitivity by avoiding foods with a high glycemic load and to promote weight loss by inducing lipolysis through ketone production[67]. Low fat diets are often followed to decrease lipid levels and blood cholesterol and may also have positive effects on insulin sensitivity[68].

High Protein Diet

High protein diets are often used as an approach with aged populations, in conjunction with resistance exercise, to maintain lean mass during weight loss[69]. In patients with metabolic syndrome, a standard protein diet and high protein diet both resulted in significant decreases in waist circumference, glucose, insulin and triglycerides. After six months, the high protein diet showed 7% weight loss while standard protein diet showed 5.1% weight loss ($p< 0.05$)[70]. Although inducing positive weight loss results, a high protein low carbohydrate diet has been shown to cause kidney damage in rats which may apply to humans as well[71].

A daily protein intake of at least 1.2 g protein/kg body weight/day has been advocated for older adults based on prior evidence suggesting that skeletal muscle in the elderly has a blunted anabolic response to dietary protein[72,73]. However, in a randomized clinical trial in men with moderate limitations in physical function found no improvement in lean body mass, muscle strength, or physical function when daily protein intake was increased from 0.8 to 1.3 g protein/kg body weight/day[74]. As mentioned earlier, combining a high protein diet with resistance exercise training during caloric restriction reduced loss of lean body mass, but did not prevent it totally[35]. Approximately 1.6 g protein/kg of body weight, along with resistance training may be necessary to overcome the anabolic resistance of aging[73,75,76].

Potential nutritional health of altering reducing or cutting out a macronutrient is the inevitable shift in ingested sources of fiber. A low-carbohydrate diet suggests a decrease in whole grains, a high fiber food, and when compared to a 12-month low-fat diet intervention, showed a larger decrease in fiber intake over time. The low-fat diet intervention of this study actually increased their fiber intake by 1 g/day while the low carbohydrate diet decreased fiber intake by 3.3 g/day over a twelve month period[77]. Another hesitation in adjusting macronutrient intakes is that decreased dietary diversity will have a negative impact on gut microbiota[78]. It has been shown that gut microbiota plasticity and diversity can be an important factor for sustainable weight loss[79].

DIETARY PATTERNS

Mediterranean Diet

In contrast to altering specific nutrients, other approaches for promoting weight loss are focused on adhering to dietary patterns, which are emphasized in the Dietary Guidelines[80]. These dietary approaches promote a balance of macronutrients and mimic the food consumption of a cultural lifestyle. The Mediterranean diet is a western interpretation of food available in Mediterranean cuisine, and focuses on plant-based, natural foods and healthy fats, including whole grains, vegetables, lentils, nuts, fish, yogurt, olive oil, wine and very little refined sugar and red meat. In a comparative study of the Mediterranean diet with a very low calorie ketogenic diet, participants on the ketogenic diet lost 5% of their body weight after one month ($7.21 \pm 1.57\%$), while Mediterranean diet participants took longer and needed three months to lose 5% of their body weight ($7.68\pm 2.52\%$). Although weight loss was seen after a longer duration, the Mediterranean diet group saw a greater reduction in waist circumference (-6.86 ± 3.3 cm vs. -5.74 ± 2.07 cm) and fat mass percentage (-3.15 ± 2.49 vs. -2.17 ± 2.14 %) (Di Rosa et al., 2022). Therefore, the Mediterranean diet weight loss might have more substantial health benefits. This is evident in a separate study where adherence to the Mediterranean Diet demonstrated positive cardiovascular effects[81]. As chronic diseases are often age-related, the positive CVD effects of the Mediterranean Diet are important in this demographic. The extent of the long-term and combined cardiovascular and weight loss effects of the Mediterranean diet are highlighted in a yearlong study comparing the Mediterranean diet with a control group. After 12 months, the Mediterranean diet group lost an average of 3.2 kg vs. 0.7 kg in the control group. Cardiovascular effects seen in the Mediterranean diet group included improved waist circumference, fasting glucose, triglycerides and high density lipoprotein cholesterol, insulin resistance, HbA1c, MCP-1 and circulating leptin. Therefore, the Mediterranean diet has benefits towards chronic disease prevalent in aged adults such as diabetes, obesity and cardiovascular disease[82].

Paleo

Similar to the Mediterranean Diet, the paleolithic, or hunter-gatherer diet, is a rounded, lifestyle diet that incorporates fruits, vegetables, lean meat, fish and avoids dairy and grain[83]. Compared to an American Diabetes Association approved diet of non-paleolithic type foods containing grains and dairy, the paleolithic diet showed greater metabolic improvements, in measures such as insulin sensitivity and lipid profiles in obese patients with type 2 diabetes[84]. Weight loss between both groups was also significantly different (American Diabetes Association Diet: -2.1 ± 1.9, Paleo Diet: -2.4 ± 0.7). Similar results were found in overweight, post-menopausal women. After a two-year paleo diet intervention, a reduction in body weight (-7.8 ± 4.5 kg), improvement in insulin sensitivity and decrease in circulating triglycerides was observed in comparison to a control diet. The gene expression mechanism behind these observations was explored, and it was found that both diet groups showed decreased expression of lipogenic enzymes that reduce stores of triglycerides[85].

INTERMITTENT FASTING

Intermittent fasting (IF) is a dietary approach that restricts the food consumption period throughout the day rather than the food quantity or composition[86]. Inducing a period of fasting elicits a change from glucose-metabolism to ketone-metabolism and activates pathways that defend against oxidative stress and inflammation[87]. Therefore, IF has been shown to be effective in combating chronic diseases such as obesity, cardiovascular disease and neurodegenerative diseases.

Research in intermittent fasting is difficult due to the wide variety of fasting schedules and the suggested differences dependent on life stage. IF is a general term but often refers to the 5-2 eating pattern in which only one meal is eaten two out of the seven days of the week and a normal diet pattern is followed for the other five days[86]. Energy restriction for 2/7 days of the week for just eight weeks has been shown to have significant effects on anthropometric measurements such as body composition but no effect on blood pressure, glucose metabolism or lipid measures[88].

In addition to the 5-2 approach, the other two most common IF approaches in research include time restricted eating (TRE), in which food consumption only occurs during 8/24 hours each day, and alternate day fasting (ADF), which is similar to 5-2, but only 1 meal (about 600 calories) is eaten every other day[89]. Both approaches have shown a significant decrease in waist circumference, BMI and body weight in just three weeks, and similar results post-intervention at a three month follow-up[89]. Similar results have been found in TRE, six week interventions in overweight, aged adults, however, males may respond more to this approach as there was a significantly larger reduction in visceral fat and waist circumference in men than women[90]. TRE continued to be effective in promoting weight loss in obese women with metabolic syndrome, however, blood markers such as HDL, LDL and cholesterol were unchanged[91].

Therefore, intermittent fasting has shown promising and consistent effects on weight loss, and potential to increase cardiometabolic parameters. Because IF has been shown to be effective in attenuating chronic disease symptoms and risk factors as well as promote weight loss, future studies are need to focus on aged, obese adults, who are more susceptible and affected by chronic disease, to observe the effects of IF on life stage.

TIME RESTRICTED EATING

Time restricted eating is a lifestyle dietary intervention that aligns food consumption with a person's circadian rhythm. The circadian clock regulates neural and endocrine pathways[92]. This type of eating pattern typically allows eating for 8-10 hours a day with > 14 hours of fasting, which includes overnight sleep. This timing of ingesting food coincides with nutrient-seeking behavior and nutrient absorption. It is not necessarily a calorie restricted diet like intermittent fasting. A number of health benefits are attributed this alignment of eating with circadian rhythms in cellular physiology. The body's circadian rhythms are driven within a 24-hour period by more than 12 regulators of transcription[92]. These regulators are in tune with predictable daily events, including feeding, sleeping, and fasting and control metabolic pathways involved with anabolism and catabolism. The rhythms are involved in preparing the brain and peripheral metabolic systems for these daily events, including in skeletal muscle and bones[93]. Disruption of circadian rhythms occurs with irregular eating and sleeping patterns, as well as with aging[94]. It has been propositioned that many of the alterations with aging involving the musculoskeletal system are related to disruption of the circadian rhythms[93]. In an observational study that compared shift-workers with a regular schedule, shift-workers with an irregular schedule, and non-shift-workers, the odds ratio for sarcopenia for the shift work group with a regular schedule was 1.7, whereas the odds ratio for sarcopenia for shift-workers with an irregular schedule was 1.8, as compared to non-shift-workers[95].

There is extremely limited clinical research in this area, but it could be an approach to counteract alterations in body composition with aging. In one 12-month study, time restricted eating plus resistance training reduced fat mass and inflammatory markers, and improved insulin sensitivity and blood lipid profile as compared to a normal diet plus resistance training[96]. Groups were originally matched for total calories consumed, but the time restricted eating group showed a spontaneous decrease in total daily calorie intake. Additionally, there were no group differences in lean body mass. In animal experiments, evidence suggests time restricted feeding improves skeletal muscle myofibrillar and mitochondria function, both of which are disrupted with aging and obesity[97]. This is an exciting line of research where more clinical trials are warranted.

Exercise Programs

EFFECT OF EXERCISE MODALITY ON BONE FRAGILITY

As established, losing weight is often associated with healthy living, rapid weight loss can cause detriments to bone density. This is due to the decrease in mechanical stress of the bones coupled with increased calcium loss due to weight loss. Exercise type plays a role in maintenance of body composition during weight loss in older overweight and obese individuals. Studies have shown that resistance exercise in comparison with aerobic training influences the nature of bone mineral density and muscle mass as the body undergoes weight changes, and both aerobic and resistance exercise influence the effectiveness and safety of weight loss differently. In a recent clinical trial the effectiveness of exercise mode in reverse frailty and preventing reduction in bone mass and muscle mass was investigated[98]. As measured by the Physical Performance Test, weight loss measures plus combined aerobic and resistance exercise was the most effective in improving physical and functional status of obese older adults (21% increase) compared to weight loss plus aerobic exercise or resistance training (14% increase for each). Although scores of body composition among all groups increased more in the combination group, all treatment groups showed positive changes compared to the control group, indicating general exercise, at the very least, is useful to combating frailty in obese older adults undergoing weight loss. With this, participant strength increased most in the combination group (18% increase) and resistance exercise group (19% increase) compared to that of the aerobic exercise group (4% increase). This emphasizes the positive impact of mechanical loading on bones and on the human body generally, especially during periods of weight loss.

Although the previous study identifies the short-term changes in bone mineral density and composition due to exercise type, the long-term effects of different exercise modalities play a strong role in the effectiveness of maintaining physical function in obese older adults. A study by Beavers et al. in 2017 discusses the long-term effects of exercise modality during weight loss on body composition and its relationship to physical function, showing weight loss plus resistance training results in less loss of lean mass and helps to conserve bone mineral density and strength[99]. When weight loss was combined with exercise, there was a significant increase in total body mass lost in the weight loss plus aerobic training group (-8.5 ± 0.7 kg) and weight loss plus resistance training group (-8.7 ± 0.7 kg). Total body fat mass loss was significantly greater in the weight loss plus aerobic exercise group (-6.8 ± 0.6 kg) and weight loss plus resistance exercise group (-7.8 ± 0.5 kg) compared to that of the weight loss group (-4.8 ± 0.6 kg). Although aerobic exercise enhances the loss of body mass, which promotes weight loss, it may have negative implications for body composition in terms of bone strength, density, and frailty.

EFFECT OF EXERCISE MODALITY ON FAT LOSS

Exercise alone, either with aerobic endurance training and/or progressive resistance training does not result in significant weight loss in the absence of CR, but it does exert positive effects on body composition, physical function, muscle strength, and quality of life in aging adults with obesity[28]. In that excessive adiposity is a risk factor to cardiometabolic diseases and significantly contributes to functional limitations in old age, the relationship between exercise and fat loss is important to promote healthy weight loss. Intramuscular tissue, found between muscle fibers or muscle groups, contrasts with visceral adipose tissue, which is predominantly found around the organs in the abdominal cavity. Both intermuscular and visceral adipose tissue decrease more when individuals practice both aerobic and resistance training in combination with dieting intended for weight loss when compared to individuals who engaged in solely aerobic or resistance exercise (intramuscular adipose tissue: -41% vs 28% and -23%, respectively and visceral adipose tissue: -36% vs -19% and -21% respectively)[100]. This suggests a weight loss program with a combination of aerobic and resistance exercise is the most effective in terms of fat loss.

Both resistance and aerobic forms of training can provide beneficial effects of body composition in different ways. With limited time and a focus on loss of body weight and fat mass, aerobic training is optimal[6]. Despite this, resistance exercise has been shown to offer benefits beyond aerobic training, as previously discussed, by better preserving bone mineral density amidst weight loss in obese older adults.

Alternatively, yoga has become a more mainstream form of exercise, as holistic medical options have become more popular[101]. Several observational and randomized controlled trial studies have shown that yoga results in a reduction in body weight and body fat while providing an increase in lean body mass. Few adverse effects have been found to be associated with yoga, and patients have shown high levels of adherence, as yoga is easily practiced at home. This suggests lifestyle modifications may enhance maintenance of proper body composition during weight loss.

EFFECT OF EXERCISE INTENSITY ON WEIGHT LOSS

Intensity of the exercise program influences energy expenditure and subsequently, weight loss. In a randomized controlled trial of patients with obesity, participants were assigned either to a 24-week moderate-intensity continuous training (MICT) program or a combined MICT with high-intensity interval training (HIIT/MICT) program[102]. Energy expenditure along with resting metabolic rate, cardiorespiratory fitness, and body composition were measured. No difference was found in energy expenditure between groups although the HIIT/MICT lost more weight than those in the MICT group (5 kg and 2 kg, respectively). This suggests higher intensity training may aid in achieving weight loss. It is important to consider the biomechanical effects of quick weight loss in terms of aforementioned risks for body composition.

EFFECT OF DIETARY RESTRICTION COMBINED WITH EXERCISE

As previously discussed, intentional weight loss in obese older adults may not result in all positive health benefits. In order to combat muscle loss during caloric restriction weight loss, a high protein diet, along with resistance exercise, has been investigated and has been shown to preserve fat free mass[69]. Caloric restriction and exercise both individually improve physical function and quality of life, however, their combination provides better outcomes than either intervention alone[45]. Furthermore, the addition of exercise to caloric restriction may to some extent attenuate loss of lean body mass, including bone mineral density. Consuming a hypocaloric diet high in protein combined with participating in resistance exercise significantly increased fat free mass percentage over a 10-week weight loss program (+0.6 ± 1.3 kg). A high protein diet did not significantly affect changes in fat free mass when combined with modest weight loss programs. Similar results were found when a high protein diet and resistance exercise were assessed independently in terms of changes in fat free mass.

Altering the ratio of carbohydrates and protein is also important for the safety and efficacy of exercise and weight loss programs in obese adults. In obese women who were assigned to either a no exercise and no diet control group, an exercise and no diet group, or one of four diet and exercise groups it was shown that exercise alone had minimal impact on body composition, resting energy expenditure, and muscular fitness[103]. When resistance-based exercise was combined with a hypoenergetic diet, positive effects were shown in these categories. All groups showed significant reductions in waist circumference over a 14-week period; however, improved results were shown when carbohydrates were replaced with protein.

Summary

Based on the most recent research, obese older adults undertaking caloric restriction should participate in both aerobic and resistance training. This is consistent with the physical activity recommendations

Conflicts of Interest Statement

The authors have no conflicts of interest to declare

References

1. Massetti GM, Dietz WH, Richardson LC. Excessive Weight Gain, Obesity, and Cancer: Opportunities for Clinical Intervention. *JAMA*. 2017;318(20):1975-1976. Doi;10.1001/jama.2017.15519
2. National Health Statistics Reports, Number 158, June 14, 2021. 2021;(158).
3. Flegal KM, Kruszon-Moran D, Carroll MD, et al. Trends in Obesity Among Adults in the United States, 2005 to 2014. *Jama*. 2016;315(21):2284-2284. Doi;10.1001/jama.2016.6458
4. Ageing and health. Accessed June 1, 2024. https://www.who.int/news-room/fact-sheets/detail/ageing-and-health
5. Siervogel RM, Wisemandle W, Maynard LM, et al. Serial changes in body composition throughout adulthood and their relationships to changes in lipid and lipoprotein levels. The Fels Longitudinal Study. *Arterioscler Thromb Vasc Biol*. 1998;18(11):1759-1764. Doi;10.1161/01.atv.18.11.1759
6. Kuk JL, Saunders TJ, Davidson LE, Ross R. Age-related changes in total and regional fat distribution. *Ageing Res Rev*. 2009;8(4):339-348. Doi;10.1016/j.arr.2009.06.001
7. Hughes VA, Frontera WR, Roubenoff R, Evans WJ, Singh MA. Longitudinal changes in body composition in older men and women: role of body weight change and physical activity. *AmJClinNutr*. 2002;76(2):473-481.
8. Colleluori G, Villareal DT. Aging, obesity, sarcopenia and the effect of diet and exercise intervention. *Exp Gerontol*. 2021;155:111561. Doi;10.1016/j.exger.2021.111561
9. Sun H, Saeedi P, Karuranga S, et al. IDF Diabetes Atlas: Global, regional and country-level diabetes prevalence estimates for 2021 and projections for 2045. *Diabetes Res Clin Pract*. 2022;183:109119. Doi;10.1016/j.diabres.2021.109119
10. Tieland M, Dirks ML, van der Zwaluw N, et al. Protein supplementation increases muscle mass gain during prolonged resistance-type exercise training in frail elderly people: a randomized, double-blind, placebo-controlled trial. *J Am Med Dir Assoc*. 2012;13(8):713-719. Doi;10.1016/j.jamda.2012.05.020
11. Rejeski WJ, Marsh a. P, Chmelo E, Rejeski JJ. Obesity, intentional weight loss and physical disability in older adults. *ObesRev*. 2010;11(9):671-685. Doi;10.1111/j.1467-789X.2009.00679.x
12. Houston DK, Nicklas BJ, Zizza C a. Weighty Concerns: The Growing Prevalence of Obesity among Older Adults. *J Am Diet Assoc*. 2009;109(11):1886-1895. Doi;10.1016/j.jada.2009.08.014
13. Agha M, Agha R. The rising prevalence of obesity: part A: impact on public health. *Int J Surg Oncol*. 2017;2(7):e17. Doi;10.1097/IJ9.0000000000000017
14. Doucet E, St Pierre S, Alméras N, Mauriège P, Richard D, Tremblay A. Changes in energy expenditure and substrate oxidation resulting from weight loss in obese men and women: is there an important contribution of leptin? *J Clin Endocrinol Metab*. 2000;85(4):1550-1556. Doi;10.1210/jcem.85.4.6500
15. Sowers M, Zheng H, Tomey K, et al. Changes in body composition in women over six years at midlife: ovarian and chronological aging. *J Clin Endocrinol Metab*. 2007;92(3):895-901. Doi;10.1210/jc.2006-1393
16. Villareal DT, Apovian CM, Kushner RF, Klein S. Obesity in older adults: technical review and position statement of the American Society for Nutrition and NAASO, The Obesity Society. *ObesRes*. 2005;13(11):1849-1863. Doi;10.1038/oby.2005.228
17. Cummings SR, Black DM, Nevitt MC, et al. Bone density at various sites for prediction of hip fractures. The Study of Osteoporotic Fractures Research Group. *Lancet Lond Engl*. 1993;341(8837):72-75. Doi;10.1016/0140-6736(93)92555-8
18. Villareal DT, Banks M, Siener C, Sinacore DR, Klein S. Physical Frailty and Body Composition in Obese Elderly Men and Women. *Obes Res*. 2004;12(6):913-920. http://www.obesityresearch.org/cgi/content/abstract/12/6/913
19. Nielson CM, Marshall LM, Adams AL, et al. BMI and fracture risk in older men: the osteoporotic fractures in men study (MrOS). *J Bone Miner Res Off J Am Soc Bone Miner Res*. 2011;26(3):496-502. Doi;10.1002/jbmr.235
20. Johnson KC, Bray GA, Cheskin LJ, et al. The Effect of Intentional Weight Loss on Fracture Risk in Persons With Diabetes: Results From the Look AHEAD Randomized Clinical Trial. *J Bone Miner Res*. 2017;32(11):2278-2287. Doi;10.1002/jbmr.3214
21. Wu H, Ballantyne CM. Skeletal muscle inflammation and insulin resistance in obesity. *J Clin Invest*. 2017;127(1):43-54. Doi;10.1172/JCI88880
22. Burd NA, Gorissen SH, van Loon LJC. Anabolic resistance of muscle protein synthesis with aging. *Exerc Sport Sci Rev*. 2013;41(3):169-173. Doi;10.1097/JES.0b013e318292f3d5
23. Mundstock E, Sarria EE, Zatti H, et al. Effect of obesity on telomere length: Systematic review and meta-analysis. *Obes Silver Spring Md*. 2015;23(11):2165-2174. Doi;10.1002/oby.21183
24. Salvestrini V, Sell C, Lorenzini A. Obesity May Accelerate the Aging Process. *Front Endocrinol*. 2019;10:266. Doi;10.3389/fendo.2019.00266
25. Susmallian S, Barnea R, Weiss Y, Raziel A. Outcome of bariatric surgery in older patients. *Surg Obes Relat Dis*. 2018;14(11):1705-1713. Doi;10.1016/j.soard.2018.08.007
26. Aryannezhad S, Khalaj A, Hosseinpanah F, Mahdavi M, Valizadeh M, Barzin M. One-year outcomes of bariatric surgery in older adults: a case-matched analysis based on the Tehran Obesity Treatment Study. *Surg Today*. 2021;51(1):61-69. Doi;10.1007/s00595-020-02079-3
27. Jensen MD, Ryan DH, Apovian CM, et al. 2013 AHA/ACC/TOS Guideline for the Management of Overweight and Obesity in Adults. *J Am Coll Cardiol*. 2014;63(25):2985-3023. Doi;10.1016/j.jacc.2013.11.004
28. Batsis JA, Gill LE, Masutani RK, et al. Weight Loss Interventions in Older Adults with Obesity: A Systematic Review of Randomized Controlled Trials Since 2005. *J Am Geriatr Soc*. 2017;65(2):257-268. Doi;10.1111/jgs.14514

29. Locher JL, Goldsby TU, Goss AM, Kilgore ML, Gower B, Ard JD. Calorie restriction in overweight older adults: Do benefits exceed potential risks? *Exp Gerontol*. 2016;86:4-13. Doi;10.1016/j.exger.2016.03.009
30. Tirosh A, de Souza RJ, Sacks F, Bray GA, Smith SR, LeBoff MS. Sex Differences in the Effects of Weight Loss Diets on Bone Mineral Density and Body Composition: POUNDS LOST Trial. *J Clin Endocrinol Metab*. 2015;100(6):2463-2471. Doi;10.1210/jc.2015-1050
31. Colleluori G, Villareal DT. Weight strategy in older adults with obesity: calorie restriction or not? *Curr Opin Clin Nutr Metab Care*. 2023;26(1):17-22. Doi;10.1097/MCO.0000000000000879
32. Chaston TB, Dixon JB, O'Brien PE. Changes in fat-free mass during significant weight loss: a systematic review. *Int J Obes 2005*. 2007;31(5):743-750. Doi;10.1038/sj.ijo.0803483
33. Gielen E, Beckwée D, Delaere A, et al. Nutritional interventions to improve muscle mass, muscle strength, and physical performance in older people: an umbrella review of systematic reviews and meta-analyses. *Nutr Rev*. 2021;79(2):121-147. Doi;10.1093/nutrit/nuaa011
34. Wu X, Zhang C, Liang Z, Liang Y, Li Y, Qiu J. Exercise Combined with a Low-Calorie Diet Improves Body Composition, Attenuates Muscle Mass Loss, and Regulates Appetite in Adult Women with High Body Fat Percentage but Normal BMI. *Sports*. 2024;12(4):91. Doi;10.3390/sports12040091
35. Beavers KM, Beavers DP, Martin SB, et al. Change in Bone Mineral Density During Weight Loss with Resistance Versus Aerobic Exercise Training in Older Adults. *J Gerontol Ser A*. 2017;72(11):1582-1585. Doi;10.1093/gerona/glx048
36. Martínez-Amat A, Aibar-Almazán A, Fábrega-Cuadros R, et al. Exercise alone or combined with dietary supplements for sarcopenic obesity in community-dwelling older people: A systematic review of randomized controlled trials. *Maturitas*. 2018;110:92-103. Doi;10.1016/j.maturitas.2018.02.005
37. Frank LL, Sorensen BE, Yasui Y, et al. Effects of exercise on metabolic risk variables in overweight postmenopausal women: a randomized clinical trial. *Obes Res*. 2005;13(3):615-625. Doi;10.1038/oby.2005.66
38. Wannamethee SG, Shaper AG, Walker M. Weight change, weight fluctuation, and mortality. *Arch Intern Med*. 2002;162(22):2575-2580. Doi;10.1001/archinte.162.22.2575
39. Volpato S, Guralnik JM, Ferrucci L, et al. Cardiovascular disease, interleukin-6, and risk of mortality in older women: the women's health and aging study. *Circulation*. 2001;103(7):947-953. Doi;10.1161/01.cir.103.7.947
40. Messier SP, Mihalko SL, Legault C, et al. Effects of intensive diet and exercise on knee joint loads, inflammation, and clinical outcomes among overweight and obese adults with knee osteoarthritis: the IDEA randomized clinical trial. *JAMA*. 2013;310(12):1263-1273. Doi;10.1001/jama.2013.277669
41. Beavers KM, Ambrosius WT, Nicklas BJ, Rejeski WJ. Independent and combined effects of physical activity and weight loss on inflammatory biomarkers in overweight and obese older adults. *J Am Geriatr Soc*. 2013;61(7):1089-1094. Doi;10.1111/jgs.12321
42. Whelton PK, Appel LJ, Espeland MA, et al. Sodium reduction and weight loss in the treatment of hypertension in older persons: a randomized controlled trial of nonpharmacologic interventions in the elderly (TONE). TONE Collaborative Research Group. *JAMA*. 1998;279(11):839-846. http://www.ncbi.nlm.nih.gov/pubmed/9515998
43. Espeland MA, Rejeski WJ, West DS, et al. Intensive weight loss intervention in older individuals: results from the Action for Health in Diabetes Type 2 diabetes mellitus trial. *J Am Geriatr Soc*. 2013;61(6):912-922. Doi;10.1111/jgs.12271
44. Studenski S, Perera S, Patel K, et al. Gait speed and survival in older adults. *JAMA*. 2011;305(1):50-58. Doi;10.1001/jama.2010.1923
45. Villareal DT, Chode S, Parimi N, et al. Weight Loss, Exercise, or Both and Physical Function in Obese Older Adults. *N Engl J Med*. 2011;364(13):1218-1229. Doi;10.1056/NEJMoa1008234
46. Messier SP, Loeser RF, Miller GD, et al. Exercise and dietary weight loss in overweight and obese older adults with knee osteoarthritis: the Arthritis, Diet, and Activity Promotion Trial. *Arthritis Rheum*. 2004;50(5):1501-1510. http://www.ncbi.nlm.nih.gov/pubmed/15146420
47. Lee JS, Kritchevsky SB, Tylavsky FA, et al. Weight-loss intention in the well-functioning, community-dwelling elderly: associations with diet quality, physical activity, and weight change. *Am J Clin Nutr*. 2004;80(2):466-474. http://www.ajcn.org/cgi/content/abstract/80/2/466
48. Rejeski WJ, Brubaker PH, Goff Jr. DC, et al. Translating weight loss and physical activity programs into the community to preserve mobility in older, obese adults in poor cardiovascular health. *ArchInternMed*. 2011;171(10):880-886. Doi;10.1001/archinternmed.2010.522
49. Kritchevsky SB, Beavers KM, Miller ME, et al. Intentional Weight Loss and All-Cause Mortality: A Meta-Analysis of Randomized Clinical Trials. Wu WCH, ed. *PLOS ONE*. 2015;10(3):e0121993. Doi;10.1371/journal.pone.0121993
50. Harrington M, Gibson S, Cottrell RC. A review and meta-analysis of the effect of weight loss on all-cause mortality risk. *Nutr Res Rev*. 2009;22(1):93-108. Doi;10.1017/S0954422409990035
51. Bales CW, Buhr G. Is obesity bad for older persons? A systematic review of the pros and cons of weight reduction in later life. *JAmMedDirAssoc*. 2008;9(5):302-312. http://www.ncbi.nlm.nih.gov/pubmed/18519110
52. Wing RR, Phelan S. Long-term weight loss maintenance. *Am J Clin Nutr*. 2005;82(1 Suppl):222S-225S. Doi;10.1093/ajcn/82.1.222S
53. Anderson JW, Konz EC, Frederich RC, Wood CL. Long-term weight-loss maintenance: a meta-analysis of US studies. *Am J Clin Nutr*. 2001;74(5):579-584. Doi;10.1093/ajcn/74.5.579
54. Dabas J, Shunmukha Priya S, Alawani A, Budhrani P. What could be the reasons for not losing weight even after following a weight loss program? *J Health Popul*

Nutr. 2024;43(1):37. Doi;10.1186/s41043-024-00516-4
55. Paintin J, Cooper C, Dennison E. Osteosarcopenia. *Br J Hosp Med Lond Engl 2005*. 2018;79(5):253-258. Doi;10.12968/hmed.2018.79.5.253
56. Kirk B, Zanker J, Duque G. Osteosarcopenia: epidemiology, diagnosis, and treatment-facts and numbers. *J Cachexia Sarcopenia Muscle*. 2020;11(3):609-618. Doi;10.1002/jcsm.12567
57. Beavers KM, Lyles MF, Davis CC, Wang X, Beavers DP, Nicklas BJ. Is lost lean mass from intentional weight loss recovered during weight regain in postmenopausal women? *AmJClinNutr*. 2011;94(3):767-774. Doi;10.3945/ajcn.110.004895
58. Chmelo EA, Beavers DP, Lyles MF, Marsh AP, Nicklas BJ, Beavers KM. Legacy effects of short-term intentional weight loss on total body and thigh composition in overweight and obese older adults. *Nutr Diabetes*. 2016;6(4):e203. Doi;10.1038/nutd.2016.8
59. Kammire DE, Walkup MP, Ambrosius WT, et al. Effect of Weight Change Following Intentional Weight Loss on Bone Health in Older Adults with Obesity. *Obes Silver Spring Md*. 2019;27(11):1839-1845. Doi;10.1002/oby.22604
60. Mitchell NS, Furniss AL, Helmkamp LJ, Van Pelt RE. Factors Associated with Achievement of Clinically Significant Weight Loss by Women in a National Nonprofit Weight Loss Program. *J Womens Health 2002*. 2017;26(8):911-917. Doi;10.1089/jwh.2016.6264
61. Burgess E, Hassmén P, Pumpa KL. Determinants of adherence to lifestyle intervention in adults with obesity: a systematic review. *Clin Obes*. 2017;7(3):123-135. Doi;10.1111/cob.12183
62. Speakman JR, Mitchell SE. Caloric restriction. *Mol Aspects Med*. 2011;32(3):159-221. Doi;10.1016/j.mam.2011.07.001
63. Villareal DT, Smith GI, Shah K, Mittendorfer B. Effect of Weight Loss on the Rate of Muscle Protein Synthesis During Fasted and Fed Conditions in Obese Older Adults. *Obesity*. 2012;20(9):1780-1786. Doi;10.1038/oby.2011.280
64. Ho E, Qualls C, Villareal DT. Effect of Diet, Exercise, or Both on Biological Age and Healthy Aging in Older Adults with Obesity: Secondary Analysis of a Randomized Controlled Trial. *J Nutr Health Aging*. 2022;26(6):552-557. Doi;10.1007/s12603-022-1812-x
65. Johnston BC, Kanters S, Bandayrel K, et al. Comparison of Weight Loss Among Named Diet Programs in Overweight and Obese Adults. *JAMA*. 2014;312(9):923-923. Doi;10.1001/jama.2014.10397
66. 66. Bazzano LA, He J, Ogden LG, et al. Fruit and vegetable intake and risk of cardiovascular disease in US adults: the first National Health and Nutrition Examination Survey Epidemiologic Follow-up Study. *Am J Clin Nutr*. 2002;76(1):93-99. Doi;10.1093/ajcn/76.1.93
67. Al-Reshed F, Sindhu S, Al Madhoun A, et al. Low carbohydrate intake correlates with trends of insulin resistance and metabolic acidosis in healthy lean individuals. *Front Public Health*. 2023;11. Doi;10.3389/fpubh.2023.1115333
68. Kahleova H, Petersen KF, Shulman GI, et al. Effect of a Low-Fat Vegan Diet on Body Weight, Insulin Sensitivity, Postprandial Metabolism, and Intramyocellular and Hepatocellular Lipid Levels in Overweight Adults: A Randomized Clinical Trial. *JAMA Netw Open*. 2020;3(11):e2025454. Doi;10.1001/jamanetworkopen.2020.25454
69. Verreijen AM, Engberink MF, Memelink RG, van der Plas SE, Visser M, Weijs PJM. Effect of a high protein diet and/or resistance exercise on the preservation of fat free mass during weight loss in overweight and obese older adults: a randomized controlled trial. *Nutr J*. 2017;16(1):10. Doi;10.1186/s12937-017-0229-6
70. Campos-Nonato I, Hernandez L, Barquera S. Effect of a High-Protein Diet versus Standard-Protein Diet on Weight Loss and Biomarkers of Metabolic Syndrome: A Randomized Clinical Trial. *Obes Facts*. 2017;10(3):238-251. Doi;10.1159/000471485
71. Kostogrys RB, Franczyk-Żarów M, Maślak E, Topolska K. Effect of low carbohydrate high protein (LCHP) diet on lipid metabolism, liver and kidney function in rats. *Environ Toxicol Pharmacol*. 2015;39(2):713-719. Doi;10.1016/j.etap.2015.01.008
72. Traylor DA, Gorissen SHM, Phillips SM. Perspective: Protein Requirements and Optimal Intakes in Aging: Are We Ready to Recommend More Than the Recommended Daily Allowance? *Adv Nutr*. 2018;9(3):171-182. Doi;10.1093/advances/nmy003
73. Kim IY, Park S, Jang J, Wolfe RR. Understanding Muscle Protein Dynamics: Technical Considerations for Advancing Sarcopenia Research. *Ann Geriatr Med Res*. 2020;24(3):157-165. Doi;10.4235/agmr.20.0041
74. Bhasin S, Apovian CM, Travison TG, et al. Effect of Protein Intake on Lean Body Mass in Functionally Limited Older Men: A Randomized Clinical Trial. *JAMA Intern Med*. 2018;178(4):530. Doi;10.1001/jamainternmed.2018.0008
75. Olaniyan ET, O'Halloran F, McCarthy AL. Dietary protein considerations for muscle protein synthesis and muscle mass preservation in older adults. *Nutr Res Rev*. 2021;34(1):147-157. Doi;10.1017/S0954422420000219
76. Kim IY, Schutzler S, Schrader A, et al. Quantity of dietary protein intake, but not pattern of intake, affects net protein balance primarily through differences in protein synthesis in older adults. *Am J Physiol Endocrinol Metab*. 2015;308(1):E21-28. Doi;10.1152/ajpendo.00382.2014
77. Offringa LC, Hartle JC, Rigdon J, Gardner CD. Changes in Quantity and Sources of Dietary Fiber from Adopting Healthy Low-Fat vs. Healthy Low-Carb Weight Loss Diets: Secondary Analysis of DIETFITS Weight Loss Diet Study. *Nutrients*. 2021;13(10):3625. Doi;10.3390/nu13103625
78. Heiman ML, Greenway FL. A healthy gastrointestinal microbiome is dependent on dietary diversity. *Mol Metab*. 2016;5(5):317-320. Doi;10.1016/j.molmet.2016.02.005
79. Grembi JA, Nguyen LH, Haggerty TD, Gardner CD, Holmes SP, Parsonnet J. Gut microbiota plasticity is correlated with sustained weight loss on a low-carb or low-fat dietary intervention. *Sci Rep*.

2020;10(1):1405. Doi;10.1038/s41598-020-58000-y
80. Home | Dietary Guidelines for Americans. Accessed June 1, 2024. https://www.dietaryguidelines.gov/
81. Murff HJ. In patients with CHD, a Mediterranean vs. low-fat diet reduced major CV events at 7 y. *Ann Intern Med*. 2022;175(9):JC100. Doi;10.7326/J22-0061
82. Salas-Salvadó J. Effect of a Mediterranean Diet Supplemented With Nuts on Metabolic Syndrome StatusOne-Year Results of the PREDIMED Randomized Trial. *Arch Intern Med*. 2008;168(22):2449-2449. Doi;10.1001/archinte.168.22.2449
83. Medicine GFIG. Paleo diet: What it is and why it's not for everyone. good-food. Accessed June 1, 2024. https://health.ucdavis.edu/blog/good-food/paleo-diet-what-it-is-and-why-its-not-for-everyone/2022/04
84. Masharani U, Sherchan P, Schloetter M, et al. Metabolic and physiologic effects from consuming a hunter-gatherer (Paleolithic)-type diet in type 2 diabetes. *Eur J Clin Nutr*. 2015;69(8):944-948. Doi;10.1038/ejcn.2015.39
85. Stomby A, Simonyte K, Mellberg C, et al. Diet-induced weight loss has chronic tissue-specific effects on glucocorticoid metabolism in overweight postmenopausal women. *Int J Obes*. 2015;39(5):814-819. Doi;10.1038/ijo.2014.188
86. Intermittent Fasting: What is it, and how does it work? Published September 29, 2023. Accessed June 1, 2024. https://www.hopkinsmedicine.org/health/wellness-and-prevention/intermittent-fasting-what-is-it-and-how-does-it-work
87. de Cabo Rafael, Mattson Mark P. Effects of Intermittent Fasting on Health, Aging, and Disease. *N Engl J Med*. 2019;381(26):2541-2551. Doi;10.1056/NEJMra1905136
88. Guo Y, Luo S, Ye Y, Yin S, Fan J, Xia M. Intermittent Fasting Improves Cardiometabolic Risk Factors and Alters Gut Microbiota in Metabolic Syndrome Patients. *J Clin Endocrinol Metab*. 2021;106(1):64-79. Doi;10.1210/clinem/dgaa644
89. Chair SY, Cai H, Cao X, Qin Y, Cheng HY, Ng MT. Intermittent Fasting in Weight Loss and Cardiometabolic Risk Reduction: A Randomized Controlled Trial. *J Nurs Res*. 2022;30(1):e185. Doi;10.1097/jnr.0000000000000469
90. Domaszewski P, Konieczny M, Dybek T, et al. Comparison of the effects of six-week time-restricted eating on weight loss, body composition, and visceral fat in overweight older men and women. *Exp Gerontol*. 2023;174:112116. Doi;10.1016/j.exger.2023.112116
91. Schroder JD, Falqueto H, Mânica A, et al. Effects of time-restricted feeding in weight loss, metabolic syndrome and cardiovascular risk in obese women. *J Transl Med*. 2021;19(1):3. Doi;10.1186/s12967-020-02687-0
92. Panda S, Maier G, Villareal DT. Targeting Energy Intake and Circadian Biology to Engage Mechanisms of Aging in Older Adults With Obesity: Calorie Restriction and Time-Restricted Eating. Lipsitz LA, ed. *J Gerontol Ser A*. 2023;78(Supplement_1): 79-85. Doi;10.1093/gerona/glad069
93. Aoyama S, Shibata S. The Role of Circadian Rhythms in Muscular and Osseous Physiology and Their Regulation by Nutrition and Exercise. *Front Neurosci*. 2017;11. Doi;10.3389/fnins.2017.00063
94. Hood S, Amir S. The aging clock: circadian rhythms and later life. *J Clin Invest*. 2017;127(2):437-446. Doi;10.1172/JCI90328
95. Choi YI, Park DK, Chung JW, Kim KO, Kwon KA, Kim YJ. Circadian rhythm disruption is associated with an increased risk of sarcopenia: a nationwide population-based study in Korea. *Sci Rep*. 2019;9(1):12015. Doi;10.1038/s41598-019-48161-w
96. Moro T, Tinsley G, Pacelli FQ, Marcolin G, Bianco A, Paoli A. Twelve Months of Time-restricted Eating and Resistance Training Improves Inflammatory Markers and Cardiometabolic Risk Factors. *Med Sci Sports Exerc*. 2021;53(12):2577. Doi;10.1249/MSS.0000000000002738
97. Villanueva JE, Livelo C, Trujillo AS, et al. Time-restricted feeding restores muscle function in Drosophila models of obesity and circadian-rhythm disruption. *Nat Commun*. 2019;10(1):2700. Doi;10.1038/s41467-019-10563-9
98. Villareal DT, Aguirre L, Gurney AB, et al. Aerobic or Resistance Exercise, or Both, in Dieting Obese Older Adults. *N Engl J Med*. 2017;376(20):1943-1955. Doi;10.1056/NEJMoa1616338
99. Beavers KM, Ambrosius WT, Rejeski WJ, et al. Effect of Exercise Type During Intentional Weight Loss on Body Composition in Older Adults with Obesity. *Obes Silver Spring Md*. 2017;25(11):1823-1829. Doi;10.1002/oby.21977
100. Waters DL, Aguirre L, Gurney B, et al. Effect of Aerobic or Resistance Exercise, or Both, on Intermuscular and Visceral Fat and Physical and Metabolic Function in Older Adults With Obesity While Dieting. Lipsitz L, ed. *J Gerontol Ser A*. 2022;77(1):131-139. Doi;10.1093/gerona/glab111
101. Ard JD, Miller GD. Lifestyle Therapy as Medicine for the Treatment of Obesity. In: Mechanick JI, Kushner RF, eds. *Lifestyle Medicine: A Manual for Clinical Practice*. Springer International Publishing; 2016:199-220. Doi;10.1007/978-3-319-24687-1_21
102. Berge J, Hjelmesaeth J, Hertel JK, et al. Effect of Aerobic Exercise Intensity on Energy Expenditure and Weight Loss in Severe Obesity-A Randomized Controlled Trial. *Obes Silver Spring Md*. 2021;29(2):359-369. Doi;10.1002/oby.23078
103. Kerksick C, Thomas A, Campbell B, 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*. 2009;6:23. Doi;10.1186/1743-7075-6-23

