Exercise and the Elderly: A Scientific Rationale for Exercise Prescription

Heather Mernitz, MS, and Ann Yelmokas McDermott, PhD, LN

Abstract

- *Objective:* To review the benefits of exercise intervention in older persons and the role of exercise in the prevention and treatment of chronic disease.
- *Methods:* Qualitative assessment of the literature focusing on randomized controlled trials.
- *Results:* Participation in regular physical activity, including aerobic exercise and strength training, can improve health, functional ability, and quality of life in older persons. Higher levels of aerobic activity are associated with increased physical fitness, decreased total mortality, and improvements in cardiovascular risk profile. Resistance training combats myopathy and osteopenia and increases muscle endurance and function. Additional benefits from exercise include improved bone health and improved postural stability. Starting an exercise program in later life can significantly modify risk factors for morbidity and mortality even if a person has been sedentary in prior years.
- *Conclusion:* Physical activity should be encouraged in healthy seniors and should be considered a primary or adjunctive therapy in the treatment of chronic diseases associated with aging. Physicians can play a major role in communicating the benefits of exercise and encouraging physical activity in their patients.

By the year 2030, the number of individuals aged 65 years and older will reach 70 million in the United States, with persons aged 85 and older constituting the fastest growing segment of the population [1]. This group also represents the population with the highest rate of physical inactivity. Only 30% of those aged 65 and older report any regular exercise. By age 75, about 1 in 3 men and 1 in 2 women do not engage in any physical activity [2]. This inactivity is associated with a greater disease burden and decreased functional status.

Exercise, including aerobic activities and strength training, can improve health, functional ability, and quality of life in older persons, even in the presence of frailty and chronic illness [3]. Higher levels of aerobic activity are associated with increased physical fitness, decreased total mortality, and improvements in cardiovascular risk profile [4–8]. Resistance training combats myopathy and osteopenia and increases muscle endurance and function [9–12]. Tai chi, yoga, stretching, and balance training may improve physical functioning and may be of benefit in patients with hypertension, heart disease, and arthritis [13–22]. Further, starting an exercise program later in life can significantly modify risk factors for morbidity and mortality even if a person has been sedentary in prior years [23]. As shown in the **Figure**, older women who remained or became active had dramatically lower cardiovascular and all-cause mortality as compared with inactive women over the course of a 5.7-year prospective cohort study (n = 7553) [23].

In addition to improving health, exercise also has the potential to reduce health care costs. An analysis of the economic burden of inactivity concluded that physical activity confers a mean net annual benefit of $330 per person in direct medical expenses [24]. Increasing participation in regular moderate physical activity among the more than 88 million inactive Americans over age 15 could reduce annual national medical costs by as much as $76.6 billion. Importantly, researchers conclude that the benefits of long-term exercise are not age-specific and are evident even when complicated by multiple chronic diseases.

This article reviews the health benefits of physical activity and exercise, focusing on randomized controlled trials (RCTs) that address exercise in the elderly. Evidence from large prospective cohort studies, meta-analyses, and substantive review articles by experts in the field also is presented. In this article, we review the relevant literature pertaining to the role of exercise in cardiovascular health, strength, postural stability, cognitive function, psychological health, and immune function as well as the prevention and treatment of chronic disease. In a companion article, "Exercise and the elderly: guidelines and practical prescription applications for the clinician" (pp. 117–127), we provide resources and recommendations for prescribing exercise through the use of case studies. It is important for physicians and other health care providers

From the Jean Mayer USDA Human Nutrition Research Center on Aging at Tufts University, Boston, MA.

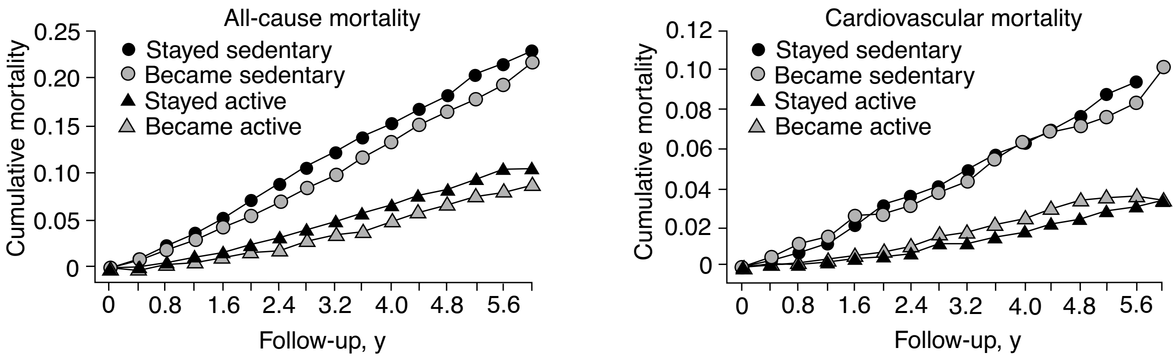

Figure. Relationship of changes in physical activity and mortality among older women. (Reprinted with permission from Gregg EW, Cauley JA, Stone K, et al. Relationship of changes in physical activity and mortality among older women. JAMA 2003;289:2379–86.)

to play a major role in disseminating research results, encouraging physical activity, and dispelling myths that persist as barriers to exercise in the elderly.

Benefit of Exercise in Various Health Domains

Cardiovascular Health

Many large cohort studies and several RCTs suggest that regular physical activity and cardiovascular fitness are associated with a reduced risk of coronary heart disease (CHD) [5,25–27]. In a Finnish cohort of 1166 men (aged 42–60), subjects in the highest physical activity tertile had one third the risk of myocardial infarction (MI) as compared with subjects in the lowest tertile [28]. Cardiorespiratory fitness as measured by maximal oxygen uptake (VO_2max) had a strong inverse association with the risk of acute MI. In another study (RCT, n = 19), 4 weeks of short bouts of high-intensity endurance exercise (bicycle ergometer, 80% VO_2max, 10 min/session, 6×/day) improved endothelium-dependent vasodilation in both epicardial coronary and resistance vessels in patients with coronary artery disease, indicating a rapid beneficial effect [6]. In addition to total physical activity, running, walking, and weight training were associated with reduced CHD risk in a cohort of 44,452 American men [8].

Lipid and lipoprotein profiles are positively impacted by exercise, even with minimal weight change [7]. Lipoprotein profile improvements appear to be related to the amount of activity, not necessarily exercise intensity or improvement in fitness level. Aerobic exercise has been found to lower serum low-density lipoprotein (LDL) cholesterol in men and postmenopausal women, especially in combination with a diet moderately low in fat and cholesterol [29]. While low amounts of exercise are associated with beneficial changes in plasma lipoprotein profiles, higher levels result in more pronounced changes, with improved high-density lipoprotein (HDL) cholesterol levels [30]. The mechanism behind this effect may include increased lipoprotein lipase activity in adipose tissue and muscle and/or decreased hepatic lipase and cholesteryl ester transfer protein activity. Enhanced clearance of very low density lipoproteins and chylomicron remnants results in decreased triglyceride exchange availability, increased LDL particle size, and increased HDL cholesterol levels.

Strength

Sarcopenia is the loss of muscle mass and strength that occurs with aging, even in the absence of illness or chronic disease [31]. Often, sarcopenia is accompanied by increased total and central adiposity [32], increasing the risk of cardiovascular complications and other chronic diseases. Longitudinal studies indicate a decline in lean mass of 0.25–0.30 kg/year after age 20, with losses accelerated by advancing age, disease, and menopause [33–35]. Type II muscle fibers, the fast twitch fibers responsible for short, quick movements [36], appear to be primarily affected by this loss, leading to disability, frailty, loss of independence, reduced protein stores to overcome the stress of illness, and increased mortality [37]. Peak skeletal muscle power (force × velocity of muscle shortening), a strong predictor of functional status and mobility in older people, also has been shown to decline with advancing age, often earlier and more dramatically than loss of strength [38–40]. This loss of power impairs the ability to perform rapid, intense movements, such as the movements needed to reverse a forward fall.

Through high-velocity (rapid, high-power) strength training programs, older men and women have been able to improve muscle power [41,42]. Progressive resistance training (PRT) has been shown to increase both strength and muscle mass at any age and is of benefit even in the presence of underlying disease [37]. Home-, hospital- and/or community-based PRT exercise, when performed properly offers numerous beneficial side effects, including potential improvements in balance, gait stability, sleep quality, mental health, immune function, and overall physical functioning

[43–47]. In contrast to resistance exercise, aerobic training is less effective in the treatment of age-related sarcopenia [48].

Research indicates that the aging musculoskeletal system retains its responsiveness to PRT [37]. An RCT in 100 frail, very elderly people (aged 72–98) demonstrated that a high-intensity, progressive program (80% of 1-repetition maximum [1-RM], 45 min/session, 3×/week for 10 weeks) can improve muscle strength and size, increase mobility, and lead to higher levels of spontaneous physical activity [48]. While only modest muscle area changes were observed in this population, significant improvements in muscle strength indicate that 10 weeks of PRT can improve neuronal recruitment of existing underused skeletal muscle. Notably, these subjects were older than the average U.S. nursing home resident (mean age, 87), and the protocol did not exclude subjects with chronic disease, unless acutely decompensated or terminal. PRT programs of low intensity/more repetitions (50% 1-RM, 13 repetitions) have proven to be as effective as high-intensity programs (80% 1-RM, 8 repetitions) in improving muscle strength and endurance in adults aged 60 to 83 [49].

Postural Stability

In the population aged 65 and older, falls are the most common cause of nonfatal injuries and trauma-related hospital admissions [50]. Falls are associated with considerable morbidity, mortality, reduced functioning, and premature nursing home admissions in both men and women [51]. Home- and community-based exercise programs have been shown to be feasible and effective in maintaining functional status, improving balance, reducing falls, and lowering the incidence of vertebral fractures [52–59]. In an RCT (n = 233), Campbell et al demonstrated that moderate-intensity strengthening and balance exercises coupled with a walking plan, when administered by a physical therapist, decreased falls by 42% and decreased fall-related injuries by 13% in a group of women aged 80 and over [60]. The same home-based exercise program, when administered by a trained nurse, was able to reduce falls by 46% in men and women aged 75 and older (n = 450) [61]. Serious injuries and hospital admissions due to falls were reduced, and the program was shown to be cost-effective, especially for those aged 80 years and older. A group-based exercise intervention alone or in combination with home hazard management and vision improvement was found to reduce falls in healthy seniors aged 70 to 84 (RCT, n = 1090) [62]. The combination of all 3 interventions resulted in further benefit, decreasing fall rate an estimated 14%, an effect mainly attributed to improvements in balance. Van Haastregt and colleagues provide practical guidelines for health professionals concerned with fall prevention in the elderly [63].

Cognition and Mental Health

Cross-sectional studies suggest that aerobic exercise may preserve and improve cognitive functioning [64]. In a cohort of 349 healthy adults aged 55 and older, high cardiorespiratory fitness was associated with increased preservation of cognitive function over a 6-year period [65]. In an RCT (n = 36) in which older exercisers (aged 65–74) followed a 10-week program of aquatic exercise (45 min/session, 3×/week), the exercisers demonstrated substantial improvement on 2 measures of dual-task attention compared with age-matched controls [66]. Walking has been found to improve executive control functions including planning, scheduling, working memory, and inhibition in adults aged 60 to 75 [67]. Most studies indicate that multiple aspects of attention and mental function can be positively affected by aerobic exercise. While leisure time physical activity was not shown to be any more effective than cognitive leisure activities (reading, playing board games) in preventing Alzheimer's disease or dementia in a cohort of 469 adults aged over 75 [68], longitudinal studies suggest that continued physical activity remains an important protective factor against cognitive decline in the elderly [69].

Observational and intervention studies suggest that regular physical exercise reduces symptoms of depression [70]. In an RCT of 156 men and women (aged ≥ 50) with major depressive disorder, a program of aerobic exercise (continuous walking or jogging, 70% to 85% maximal heart reserve, 30 min/session, 3×/week) was found to be as effective as antidepressant medication (sertraline) as measured by both a clinical rating scale and self-reported questionnaire [71]. Observational cohort studies suggest that exercise-based cardiac rehabilitation may improve behavioral and quality-of-life parameters in depressed patients after major cardiac events [72,73]. Although antidepressants may facilitate a more rapid initial therapeutic response, exercise appears equally effective in reducing depression in certain elderly populations.

Strength training also has been shown to modify symptoms of depression. Twenty weeks of unsupervised weight lifting was found to exert an antidepressive effect in depressed elderly patients (mean age, 71; n = 32) [46]. One third of these exercisers reported weight lifting regularly at a 26-week follow-up, suggesting that long-term changes in exercise behavior are possible in some subjects, even without supervision. Ten weeks of supervised weight training was shown in an RCT (n = 32) to improve subjective sleep quantity and quality in subjects aged 60 to 84 with major or minor depression or dysthymia [74].

Immune Function

While aging is associated with declines in immune function, especially T cell–dependent functions [75], exercise may slow or prevent the age-related decline in immune response. Cross-sectional comparisons have found that highly conditioned elderly women have superior natural killer cell activity and

T cell function when compared with age-matched sedentary controls [76]. Intervention studies have returned contradictory findings, suggesting that other factors, such as the duration of physical activity and baseline health status, may play a more central role in immune outcomes. While moderate exercise in healthy or arthritic elderly has never been shown to harm immune parameters, many researchers show no effect of aerobic or resistance training on immune markers such as cytokine production, prostaglandin E_2 production, serum cortisol, lymphocyte subsets, lymphocyte proliferation, natural killer cell–mediated cytotoxicity, or delayed type hypersensitivity response [47,77–79].

There is evidence that exercise may be particularly beneficial in frail elderly and those with impaired immune functioning [80]. A 17-week progressive exercise intervention (RCT; aerobic exercise, skill training, and games, 45 min/session, 2×/week) in 112 frail elderly men and women (mean age, 79), along with a nutrition intervention (enriched foods) had a small beneficial effect on delayed type hypersensitivity responsiveness, an in vivo measure of cellular immune response [80]. In 29 previously sedentary elderly, Woods et al found 6 months of aerobic training (60% VO_2max, 40 min/session, 3×/week) induced slight increases in T cell proliferation in response to mitogenic stimulation and in basal natural killer cell cytotoxic activity [81]. Overall, the small changes seen in some prospective studies generally fail to support immune benefits suggested by cross-sectional studies. However, critics caution that prospective studies have been limited in duration and statistical power and often fail to examine clinically relevant in vivo measurements of immune response [82]. More research is needed to define and describe potential immune benefits of long-term training in both healthy and impaired seniors.

Role of Exercise in Prevention and Treatment of Chronic Disease

CHD

Cardiac rehabilitation and exercise training are associated with improved outcomes in the elderly. The beneficial effects of endurance (aerobic) exercise on lipoprotein profiles and cardiovascular health were discussed previously. In CHD rehabilitation, strength training complements an aerobic exercise prescription [83–86]. While aerobic training more effectively modifies cardiovascular risk factors associated with the development of coronary artery disease, resistance training offers greater development of muscle strength, endurance, and mass [87]. PRT can decrease myocardial demands during daily activities, such as carrying groceries or lifting objects. A series of cross-sectional and cohort studies have shown that exercise training, when initiated early after hospitalization, can result in a 10% to 60% increase in functional capacity and a 10% to 25% reduction in myocardial work at standardized exercise workloads [88–91]. The extent of cardiovascular disease in a patient will determine the level of supervision and monitoring necessary for safe and effective training.

Hypertension

Chronic hypertension is a major risk factor for CHD and is estimated to be involved in nearly 70% of all stroke cases [92,93]. Current National Heart, Lung, and Blood Institute recommendations address the importance of strict hypertension control as early as the prehypertension stage and promote lifestyle modification and as an integral treatment step enhancing pharmacologic options [93]. Dietary changes, including the DASH diet (Dietary Approaches to Stop Hypertension), are recommended, along with regular aerobic activity at least 30 minutes per day most days of the week [93]. Moderate-intensity aerobic exercise (55%–70% maximal heart rate or 40%–60% VO_2max) has repeatedly been shown to reduce blood pressure (BP) in patients with mild to moderate hypertension [94–97]. Studies indicate that endurance exercise training will elicit an average reduction of 10 mm Hg in both systolic and diastolic BPs in individuals with mild hypertension (systolic BP 90–140 mm Hg, diastolic BP 105–180 mm Hg) [94]. A meta-analysis of recent trials in hypertensive patients suggests that reductions in systolic BP as small as 1 to 3 mm Hg decrease the relative risk of stroke by as much as 20% to 30% [98].

Of specific relevance to the aging population, 9 months of low- or moderate-intensity aerobic training (53% and 73% VO_2max, respectively) was shown to decrease BP in hypertensive men and women aged 60 to 69 in a longitudinal study [99]. Interestingly, low-intensity training may lower BP as much or more than moderate-intensity training in older persons with hypertension. Strength training also was shown to reduce resting BP in 21 men and women aged 65–73 in a 6-month prospective intervention [100]. According to the latest guidelines from the Joint National Committee for the Detection, Evaluation, and Treatment of Hypertension, the changes in resting BP noted in older adults after 6 months of heavy strength training represent a shift from the high normal to the normal category. Endurance exercise coupled with PRT offers a nonpharmacologic alternative to reduce hypertension incidence and severity in susceptible individuals.

Congestive Heart Failure

The ability of congestive heart failure (CHF) patients to comfortably perform activities of daily living can be enhanced through exercise. Improvements in exercise duration and VO_2max have been demonstrated in many RCTs (for more complete reviews, see Piña et al [101] and Witham et al [102]). Changes in peak VO_2 from 12% to 31% generally occur quickly (by the third week of training) and persist with continued exercise compliance. In older women (aged ≥ 65) with CHF, 10 weeks of PRT (80% 1-RM, 3×/week) was shown to counteract the skeletal muscle myopathy of heart failure and improve muscle strength, endurance, and type I muscle fiber area [103]. While a few studies have reported exercise-related complications that highlight the need for medical supervision and/or educated self-monitoring, the majority of researchers have found no exercise-related complications with low- to moderate-intensity exercise training (35% to 70% maximal heart rate, 20%–60% VO_2max) in CHF patients.

Many potential mechanisms exist for this improvement in oxidative metabolism and exercise tolerance in CHF patients, including decreased catecholamine levels, increased ventilatory capacity through respiratory muscle conditioning, delayed blood lactate accumulation, improved endothelial function, myocardial adaptations, and modification of skeletal muscle morphology. Santoro et al reported the average size of the mitochondria in 6 heart failure patients increased by 23.4% after 16 weeks of supervised upper and lower extremity exercise training [104]. While large-scale, randomized trials indicating direct improvements in survival and quality of life are limited, preliminary results are promising and indicate that exercise may offer a benefit for individuals with stable CHF.

Diabetes

Results from the Diabetes Prevention Program, a 27-center RCT (*n* = 3234), suggest that diet and exercise can be more effective than pharmacologic therapy (metformin) in preventing or delaying the onset of type 2 diabetes in people with impared glucose tolerance [105–107]. A lifestyle intervention designed to achieve and maintain a weight reduction of at least 7% of initial body weight through a low-calorie, low-fat diet and moderate physical activity (such as brisk walking) for 150 min/week or more decreased diabetes incidence by 58%, while metformin reduced the incidence by only 31%. Effects were similar in men and women and in all racial and ethnic groups, with the most profound impact in the oldest subgroup (aged ≥ 60). These results complement earlier findings and demonstrate the efficacy of diabetes prevention in high-risk subjects through diet and exercise interventions [108]. Exercise can decrease the risk of CHD in diabetics through improved cardiovascular fitness and lipoprotein risk profile and reduced blood pressure and central obesity.

In type 2 diabetic patients, exercise may improve glucose uptake and insulin sensitivity and return elevated blood glucose to normal levels. Animal studies indicate this effect may be mediated by increases in the GLUT-4 glucose transporter protein in muscle [109]. Clinical studies confirm these results and suggest that older human skeletal muscle retains the ability to increase muscle GLUT-4 and improve insulin action in response to endurance training [110]. Further, exercise can improve modifiable risk factors for the premature coronary disease associated with diabetes. Evidence for an exercise training benefit is strongest for improvements in endothelial vasodilator function and left ventricular diastolic function, with fewer studies examining improvements in arterial stiffness and systemic inflammation [111]. While most studies demonstrating the beneficial effects of exercise in diabetics have used an aerobic exercise intervention, Castaneda and colleagues demonstrated 16 weeks of supervised PRT (60% to 80% 1-RM, 45 min/session, 3×/week) can improve glycemic control and reverse some abnormalities associated with the metabolic syndrome in older Latino adults with type 2 diabetes (RCT; *n* = 62; mean age, 66) [112]. Program compliance was high. Decreased plasma glycosylated hemoglobin, systolic BP, and trunk fat mass, increased lean mass, and a reduction in prescribed diabetes medication doses were evident. Since muscle tissue represents the primary site for glucose storage and oxidation, increased lean mass results in greater capacity for glucose disposal, and thereby improved glycemic control in type 2 diabetics. Exercise of any intensity level can be used to modify morbidity and mortality risk factors in patients with type 1 diabetes provided they have good blood glucose control prior to initiating the exercise program and adequate knowledge of the use of carbohydrate supplementation and insulin therapy to maintain blood glucose levels throughout each exercise session [113].

Arthritis

Osteoarthritis (OA), a painful and disabling disease, is strongly associated with aging. Evidence from large RCTs indicates that both aerobic training and PRT can reduce pain and improve function in patients with knee OA [114–116]. A daily walking program was shown in an RCT to be effective in addressing symptoms of OA [117]. Exercises especially directed toward increasing the strength of the quadriceps and preserving the normal mobility of the knee are strongly recommended [114]. PRT benefits include improvements in pain and functional index, prevention of disability in activities of daily living, and prolonged functional independence in older patients with OA [118]. For an extensive review of exercise in the management of osteoarthritis and practical recommendations for the clinician, see the 2001 report from the American Geriatrics Society Panel on Exercise and Osteoarthritis [119].

Exercise also may benefit patients with rheumatoid arthritis. In a recent meta-analysis of RCTs , the authors concluded that dynamic exercise therapy is effective in increasing aerobic capacity and muscle strength with no detrimental effects on disease activity or pain [120]. In 30 elderly patients with well-controlled rheumatoid arthritis, PRT (12 weeks, 80% 1-RM, 2×/week) was shown to increase strength, balance, and gait speed while reducing protein catabolism and self-reported pain and fatigue [121,122]. Further, high-intensity training was shown to have no adverse affect on immune function in this population, alleviating the concern that exercise could further aggravate autoimmune responses [47].

Osteoporosis

Long-term, high-intensity strength training (5 exercises at 80% 1-RM, 2×/week for 1 year) has been shown to maintain and increase bone density in postmenopausal women (RCT, n = 39) [123]. On the other hand, short-term moderate-intensity physical activity (combined, varied exercise program with increasing intensity, 45 min/session, 2×/week for 17 weeks) was not shown to have an effect on bone parameters beyond the effect of increased consumption of nutrient-dense foods (RCT, n = 143) [124]. This suggests longer intervention time is required for measurable bone density improvements. Several recent meta-analyses including men and postmenopausal women demonstrate that aerobic exercise and PRT can be equally efficacious in preserving and improving bone mineral density compared with sedentary controls [125–128].

In addition to preserving lean body mass in frail elderly subjects, 17 weeks of exercise (a varied exercise program with increasing intensity, 45 min/session, 2×/week) served to significantly increase energy intake (RCT, n = 159) [129]. This effect is not consistent across all studies but does suggest that exercise may have the potential to affect dietary intake and thus improve micronutrient intake in elderly populations. While the effects of exercise on appetite and bone density are still under investigation, it is clear that high-intensity PRT can help prevent falls independent of bone parameters [130].

Obesity

More than 60% of the U.S. adult population is overweight or obese, a condition that increases the risk of several chronic diseases, including CHD, stroke, type 2 diabetes, hypertension, and cancers at multiple sites [131,132]. Investigators conducting a large prospective cohort study recently estimated that current patterns of overweight and obesity in the United States could account for 14% of all deaths due to cancer in men and 20% of those in women [133]. An RCT on the impact of exercise on total and intra-abdominal body fat in 173 overweight and obese postmenopausal women found that regular moderate-intensity exercise (3.5 ± 1.2 days/week, 176 ± 91 min/week), such as brisk walking or bicycling, resulted in reduced body weight and fat [134]. The changes seen in this study were dose-dependent, with more active exercisers losing more intra-abdominal fat. A total body strength training program also was shown to decrease intra-abdominal fat and increase strength in 14 healthy older women (mean age, 67 ± 1), although this study lacked a control group for comparison [135]. PRT has the additional advantage of preventing the concomitant loss of bone and muscle seen with dieting alone or dieting plus aerobic exercise [136]. While both aerobic and PRT programs have been used successfully to address overweight and obesity [137], a mixed program incorporating endurance and strength training combined with diet and lifestyle changes may offer the best means for weight loss and weight maintenance at a lower weight.

Conclusion

In both aging and disease, inactivity is associated with physical and functional decline. A substantial body of literature clearly demonstrates the health benefits of physical activity and exercise training at all life stages. Exercise also can contribute to better nutritional status by increasing energy requirements (which may prevent protein and micronutrient deficiencies), improving dietary protein retention, and attenuating the age-related drop in resting energy expenditure. Physicians can help patients by explaining the benefits of exercise and encouraging sound and effective changes in physical activity levels. While care needs to be taken when starting a previously sedentary individual on an exercise regimen, inactivity presents a far greater danger than the possibility of injury from exercise. While some patients will have musculoskeletal complaints when starting a new program [138], the frequency of injury from moderate-intensity exercise has been shown repeatedly to be very low, even in elderly populations with chronic disease [139–144]. Often, minor modifications to an existing exercise program, such as increasing warm-up and cool-down periods or decreasing exercise intensity, can decrease muscle soreness and risk of injury and increase long-term adherence. Exercise is an invaluable prescription in efforts to prevent disease, treat chronic diseases, and maintain functional capacity and independence in our aging population.

Acknowledgment: We thank Maria Fiatarone Singh, MD, FRACP, Professor of Medicine, University of Sydney, Australia, and Robert L. Dobrow, MD, Assistant Clinical Professor, University of California San Francisco Medical School, for their time and insight in reviewing this article.

Corresponding author: Ann Yelmokas McDermott, PhD, LN, Lipid Metabolism Laboratory, Rm 527, Jean Mayer USDA Human Nutrition Research Center on Aging at Tufts University, 711 Washington St., Boston, MA 02111, ann.mcdermott@tufts.edu.

Funding/support: Dr. McDermott is supported by an NIH Postdoctoral Fellowship Award (F32 DK064512-01). This material is based on work supported by the U.S. Department of Agriculture, under agreement No. 58-1950-4-401. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the U.S. Department of Agriculture.

Financial disclosures: None.

Author contributions: conception and design, HM, AYM; drafting of the article, HM, AYM; critical revision of the article, HM, AYM.

References

1. American College of Sports Medicine Position Stand. Exercise and physical activity for older adults. Med Sci Sports Exerc 1998;30:992–1008.
2. U.S. Department of Health and Human Services. Physical activity and health: a report of the surgeon general. Atlanta: U.S. Department of Health and Human Services; 1996.
3. Morey MC, Pieper CF, Crowley GM, et al. Exercise adherence and 10-year mortality in chronically ill older adults. J Am Geriatr Soc 2002;50:1929–33.
4. Paffenbarger RS Jr, Hyde RT, Wing AL, Hsieh CC. Physical activity, all-cause mortality, and longevity of college alumni. N Engl J Med 1986;314:605–13.
5. Paffenbarger RS Jr, Hyde RT, Wing AL, et al. The association of changes in physical-activity level and other lifestyle characteristics with mortality among men. N Engl J Med 1993;328:538–45.
6. Hambrecht R, Wolf A, Gielen S, et al. Effect of exercise on coronary endothelial function in patients with coronary artery disease. N Engl J Med 2000;342:454–60.
7. Kraus WE, Houmard JA, Duscha BD, et al. Effects of the amount and intensity of exercise on plasma lipoproteins. N Engl J Med 2002;347:1483–92.
8. Tanasescu M, Leitzmann MF, Rimm EB, et al. Exercise type and intensity in relation to coronary heart disease in men. JAMA 2002;288:1994–2000.
9. Adams KJ, Swank AM, Berning JM, et al. Progressive strength training in sedentary, older African American women. Med Sci Sports Exerc 2001;33:1567–76.
10. Ades PA, Ballor DL, Ashikaga T, et al. Weight training improves walking endurance in healthy elderly persons. Ann Intern Med 1996;124:568–72.
11. Alexander NB, Galecki AT, Grenier ML, et al. Task-specific resistance training to improve the ability of activities of daily living-impaired older adults to rise from a bed and from a chair. J Am Geriatr Soc 2001;49:1418–27.
12. Kerr D, Ackland T, Maslen B, et al. Resistance training over 2 years increases bone mass in calcium-replete postmenopausal women. J Bone Miner Res 2001;16:175–81.
13. Li F, Fisher KJ, Harmer P, McAuley E. Delineating the impact of Tai Chi training on physical function among the elderly. Am J Prev Med 2002;23(2 Suppl):92–7.
14. Li F, Harmer P, McAuley E, et al. An evaluation of the effects of Tai Chi exercise on physical function among older persons: a randomized controlled trial. Ann Behav Med 2001;23:139–46.
15. Wolf SL, Barnhart HX, Ellison GL, Coogler CE. The effect of Tai Chi Quan and computerized balance training on postural stability in older subjects. Atlanta FICSIT Group. Frailty and Injuries: Cooperative Studies on Intervention Techniques. Phys Ther 1997;77:371–81.
16. Hartman CA, Manos TM, Winter C, et al. Effects of T'ai Chi training on function and quality of life indicators in older adults with osteoarthritis. J Am Geriatr Soc 2000;48:1553–9.
17. Young DR, Appel LJ, Jee S, Miller ER 3rd. The effects of aerobic exercise and T'ai Chi on blood pressure in older people: results of a randomized trial. J Am Geriatr Soc 1999;47:277–84.
18. Patel C, North WR. Randomised controlled trial of yoga and bio-feedback in management of hypertension. Lancet 1975;2:93–5.
19. Manchanda SC, Narang R, Reddy KS, et al. Retardation of coronary atherosclerosis with yoga lifestyle intervention. J Assoc Physicians India 2000;48:687–94.
20. Nowalk MP, Prendergast JM, Bayles CM, et al. A randomized trial of exercise programs among older individuals living in two long-term care facilities: the FallsFREE program. J Am Geriatr Soc 2001;49:859–65.
21. Rogind H, Bibow-Nielsen B, Jensen B, et al. The effects of a physical training program on patients with osteoarthritis of the knees. Arch Phys Med Rehabil 1998;79:1421–7.
22. Wolf SL, Sattin RW, Kutner M, et al. Intense tai chi exercise training and fall occurrences in older, transitionally frail adults: a randomized, controlled trial. J Am Geriatr Soc 2003;51:1693–701.
23. Gregg EW, Cauley JA, Stone K, et al. Relationship of changes in physical activity and mortality among older women. JAMA 2003;289:2379–86.
24. Pratt M, Macera C, Wang G. Higher direct medical costs associated with physical inactivity. Phys Sports Med 2000;28:10.
25. Paffenbarger RS Jr, Hyde RT, Hsieh CC, Wing AL. Physical activity, other life-style patterns, cardiovascular disease and longevity. Acta Med Scand Suppl 1986;711:85–91.
26. Blair SN, Kohl HW 3rd, Barlow CE, et al. Changes in physical fitness and all-cause mortality. A prospective study of healthy and unhealthy men. JAMA 1995;273:1093–8.
27. Blair SN, Kohl HW 3rd, Paffenbarger RS Jr, et al. Physical fitness and all-cause mortality. A prospective study of healthy men and women. JAMA 1989;262:2395–401.
28. Lakka TA, Venalainen JM, Rauramaa R, et al. Relation of leisure-time physical activity and cardiorespiratory fitness to the risk of acute myocardial infarction. N Engl J Med 1994;330:1549–54.
29. Stefanick ML, Mackey S, Sheehan M, et al. Effects of diet and exercise in men and postmenopausal women with low levels of HDL cholesterol and high levels of LDL cholesterol. N Engl J Med 1998;339:12–20.
30. Tall AR. Exercise to reduce cardiovascular risk–how much is enough? N Engl J Med 2002;347:1522–4.
31. Roubenoff R, Heymsfield SB, Kehayias JJ, et al. Standardization of nomenclature of body composition in weight loss. Am J Clin Nutr 1997;66:192–6.
32. Poehlman ET, Toth MJ, Bunyard LB, et al. Physiological predictors of increasing total and central adiposity in aging men and women. Arch Intern Med 1995;155:2443–8.
33. Flynn MA, Nolph GB, Baker AS, et al. Total body potassium in aging humans: a longitudinal study. Am J Clin Nutr 1989;50:713–7.
34. Forbes GB, Reina JC. Adult lean body mass declines with age: some longitudinal observations. Metabolism 1970;19:653–63.
35. Poehlman ET, Toth MJ, Fishman PS, et al. Sarcopenia in aging

humans: the impact of menopause and disease. J Gerontol A Biol Sci Med Sci 1995;50 Spec No:73–7.
36. Lexell J. Human aging, muscle mass, and fiber type composition. J Gerontol A Biol Sci Med Sci 1995;50 Spec No:11–6.
37. Roubenoff R. Sarcopenia and its implications for the elderly. Eur J Clin Nutr 2000;54(Suppl 3):S40–7.
38. Foldvari M, Clark M, Laviolette LC, et al. Association of muscle power with functional status in community-dwelling elderly women. J Gerontol A Biol Sci Med Sci 2000;55: M192–9.
39. Metter EJ, Conwit R, Tobin J, Fozard JL. Age-associated loss of power and strength in the upper extremities in women and men. J Gerontol A Biol Sci Med Sci 1997;52:B267–76.
40. Suzuki T, Bean JF, Fielding RA. Muscle power of the ankle flexors predicts functional performance in community-dwelling older women. J Am Geriatr Soc 2001;49:1161–7.
41. Fielding RA, LeBrasseur NK, Cuoco A, et al. High-velocity resistance training increases skeletal muscle peak power in older women. J Am Geriatr Soc 2002;50:655–62.
42. Newton RU, Hakkinen K, Hakkinen A, et al. Mixed-methods resistance training increases power and strength of young and older men. Med Sci Sports Exerc 2002;34:1367–75.
43. Topp R, Mikesky A, Wigglesworth J, et al. The effect of a 12–week dynamic resistance strength training program on gait velocity and balance of older adults. Gerontologist 1993; 33:501–6.
44. Hausdorff JM, Nelson ME, Kaliton D, et al. Etiology and modification of gait instability in older adults: a randomized controlled trial of exercise. J Appl Physiol 2001;90:2117–29.
45. Montgomery P, Dennis J. Physical exercise for sleep problems in adults aged 60+. Cochrane Database Syst Rev 2002;(4): CD003404.
46. Singh NA, Clements KM, Singh MA. The efficacy of exercise as a long-term antidepressant in elderly subjects: a randomized, controlled trial. J Gerontol A Biol Sci Med Sci 2001;56: M497–504.
47. Rall LC, Roubenoff R, Cannon JG, et al. Effects of progressive resistance training on immune response in aging and chronic inflammation. Med Sci Sports Exerc 1996;28:1356–65.
48. Fiatarone MA, O'Neill EF, Ryan ND, et al. Exercise training and nutritional supplementation for physical frailty in very elderly people. N Engl J Med 1994;330:1769–75.
49. Vincent KR, Braith RW, Feldman RA, et al. Resistance exercise and physical performance in adults aged 60 to 83. J Am Geriatr Soc 2002;50:1100–7.
50. Centers for Disease Control and Prevention. Falls and hip fractures among older adults. Available at from http://www.cdc.gov/ncipc/factsheets/falls.htm. Accessed 19 Jan 2004.
51. Kiebzak GM, Beinart GA, Perser K, et al. Undertreatment of osteoporosis in men with hip fracture. Arch Intern Med 2002; 162:2217–22.
52. Robertson MC, Campbell AJ, Gardner MM, Devlin N. Preventing injuries in older people by preventing falls: a meta-analysis of individual-level data. J Am Geriatr Soc 2002;50: 905–11.
53. Carter ND, Khan KM, McKay HA, et al. Community-based exercise program reduces risk factors for falls in 65- to 75-year-old women with osteoporosis: randomized controlled trial [published erratum in CMAJ 2003;168:152]. CMAJ 2002;167:997–1004.
54. Lord SR, Castell S, Corcoran J, et al. The effect of group exercise on physical functioning and falls in frail older people living in retirement villages: a randomized, controlled trial. J Am Geriatr Soc 2003;51:1685–92.
55. Province MA, Hadley EC, Hornbrook MC, et al. The effects of exercise on falls in elderly patients. A preplanned meta-analysis of the FICSIT Trials. Frailty and Injuries: Cooperative Studies of Intervention Techniques. JAMA 1995;273:1341–7.
56. Binder EF, Schechtman KB, Ehsani AA, et al. Effects of exercise training on frailty in community-dwelling older adults: results of a randomized, controlled trial J Am Geriatr Soc 2002;50:1921–8.
57. Gillespie LD, Gillespie WJ, Robertson MC, et al. Interventions for prevention falls in elderly people. Cochrane Database Syst Rev 2001;(3):CD000340.
58. Guideline for the prevention of falls in older persons. American Geriatrics Society, British Geriatrics Society, and American Academy of Orthopaedic Surgeons Panel on Falls Prevention. J Am Geriatr Soc 2001;49:664–72.
59. Sinaki M, Itoi E, Wahner HW, et al. Stronger back muscles reduce the incidence of vertebral fractures: a prospective 10 year follow-up of postmenopausal women. Bone 2002; 30:836–41.
60. Campbell AJ, Robertson MC, Gardner MM, et al. Randomised controlled trial of a general practice programme of home based exercise to prevent falls in elderly women. BMJ 1997;315:1065–9.
61. Robertson MC, Gardner MM, Devlin N, et al. Effectiveness and economic evaluation of a nurse delivered home exercise programme to prevent falls. 2: Controlled trial in multiple centres. BMJ 2001;322:701–4.
62. Day L, Fildes B, Gordon I, et al. Randomised factorial trial of falls prevention among older people living in their own homes. BMJ 2002;325:128.
63. van Haastregt JC, van Rossum E, Diederiks JP, et al. Preventing falls and mobility problems in community-dwelling elders: the process of creating a new intervention. Geriatr Nurs 2000;21:309–14.
64. van Boxtel MP, Paas FG, Houx PJ, et al. Aerobic capacity and cognitive performance in a cross-sectional aging study. Med Sci Sports Exerc 1997;29:1357–65.
65. Barnes DE, Yaffe K, Satariano WA, Tager IB. A longitudinal study of cardiorespiratory fitness and cognitive function in healthy older adults. J Am Geriatr Soc 2003;51:459–65.
66. Hawkins HL, Kramer AF, Capaldi D. Aging, exercise, and attention. Psychol Aging 1992;7:643–53.
67. Kramer AF, Hahn S, Cohen NJ, et al. Ageing, fitness and neurocognitive function. Nature 1999;400:418–9.
68. Verghese J, Lipton RB, Katz MJ, et al. Leisure activities and the risk of dementia in the elderly. N Engl J Med 2003;348: 2508–16.
69. Laurin D, Verreault R, Lindsay J, et al. Physical activity and risk of cognitive impairment and dementia in elderly persons. Arch Neurol 2001;58:498–504.

70. McNeil JK, LeBlanc EM, Joyner M. The effect of exercise on depressive symptoms in the moderately depressed elderly. Psychol Aging 1991;6:487–8.
71. Blumenthal JA, Babyak MA, Moore KA, et al. Effects of exercise training on older patients with major depression. Arch Intern Med 1999;159:2349–56.
72. Milani RV, Lavie CJ, Cassidy MM. Effects of cardiac rehabilitation and exercise training programs on depression in patients after major coronary events. Am Heart J 1996;132:726–32.
73. Milani RV, Lavie CJ. Prevalence and effects of cardiac rehabilitation on depression in the elderly with coronary heart disease. Am J Cardiol 1998;81:1233–6.
74. Singh NA, Clements KM, Fiatarone MA. A randomized controlled trial of the effect of exercise on sleep. Sleep 1997;20: 95–101.
75. Chakravarti B, Abraham GN. Aging and T-cell-mediated immunity. Mech Ageing Dev 1999;108:183–206.
76. Nieman DC, Henson DA, Gusewitch G, et al. Physical activity and immune function in elderly women. Med Sci Sports Exerc 1993;25:823–31.
77. Fahlman M, Boardley D, Flynn MG, et al. Effects of endurance training on selected parameters of immune function in elderly women. Gerontology 2000;46:97–104.
78. Flynn MG, Fahlman M, Braun WA, et al. Effects of resistance training on selected indexes of immune function in elderly women. J Appl Physiol 1999;86:1905–13.
79. Bermon S, Philip P, Ferrari P, et al. Effects of a short–term strength training programme on lymphocyte subsets at rest in elderly humans. Eur J Appl Physiol Occup Physiol 1999;79: 336–40.
80. Chin A Paw MJ, de Jong N, Pallast EG, et al. Immunity in frail elderly: a randomized controlled trial of exercise and enriched foods. Med Sci Sports Exerc 2000;32:2005–11.
81. Woods JA, Ceddia MA, Wolters BW, et al. Effects of 6 months of moderate aerobic exercise training on immune function in the elderly. Mech Ageing Dev 1999;109:1–19.
82. Woods JA, Lowder TW, Keylock KT. Can exercise training improve immune function in the aged? Ann N Y Acad Sci 2002;959:117–27.
83. Beniamini Y, Rubenstein JJ, Zaichkowsky LD, Crim MC. Effects of high-intensity strength training on quality-of-life parameters in cardiac rehabilitation patients. Am J Cardiol 1997;80:841–6.
84. Jolliffe JA, Rees K, Taylor RS, et al. Exercise-based rehabilitation for coronary heart disease. Cochrane Database Syst Rev 2001;(1):CD001800.
85. Pasquali SK, Alexander KP, Peterson ED. Cardiac rehabilitation in the elderly. Am Heart J 2001;142:748–55.
86. Lavie CJ, Milani RV. Benefits of cardiac rehabilitation and exercise training programs in elderly coronary patients. Am J Geriat Cardiol 2001;10:323–7.
87. Pollock ML, Franklin BA, Balady GJ, et al. AHA Science Advisory. Resistance exercise in individuals with and without cardiovascular disease: benefits, rationale, safety, and prescription: an advisory from the Committee on Exercise, Rehabilitation, and Prevention, Council on Clinical Cardiology, American Heart Association; Position paper endorsed by the American College of Sports Medicine. Circulation 2000;101:828–33.
88. Lavie CJ, Milani RV. Effects of cardiac rehabilitation programs on exercise capacity, coronary risk factors, behavioral characteristics, and quality of life in a large elderly cohort. Am J Cardiol 1995;76:177–9.
89. Williams MA, Maresh CM, Esterbrooks DJ, et al. Early exercise training in patients older than age 65 years compared with that in younger patients after acute myocardial infarction or coronary artery bypass grafting. Am J Cardiol 1985; 55:263–6.
90. Ades PA, Hanson JS, Gunther PG, Tonino RP. Exercise conditioning in the elderly coronary patient. J Am Geriatr Soc 1987;35:121–4.
91. Lavie CJ, Milani RV, Littman AB. Benefits of cardiac rehabilitation and exercise training in secondary coronary prevention in the elderly. J Am Coll Cardiol 1993;22:678–83.
92. Bronner LL, Kanter DS, Manson JE. Primary prevention of stroke. N Engl J Med 1995;333:1392–400.
93. Chobanian AV, Bakris GL, Black HR, et al. The Seventh Report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure: the JNC 7 Report [published erratum in JAMA 2003;290:197]. JAMA 2003;289:2560–71.
94. American College of Sports Medicine. Position Stand. Physical activity, physical fitness, and hypertension. Med Sci Sports Exerc 1993;25:i–x.
95. Kokkinos PF, Holland JC, Pittaras AE, et al. Cardiorespiratory fitness and coronary heart disease risk factor association in women. J Am Coll Cardiol 1995;26:358–64.
96. Kokkinos PF, Narayan P, Colleran JA, et al. Effects of regular exercise on blood pressure and left ventricular hypertrophy in African-American men with severe hypertension. N Engl J Med 1995;333:1462–7.
97. Duncan JJ, Farr JE, Upton SJ, et al. The effects of aerobic exercise on plasma catecholamines and blood pressure in patients with mild essential hypertension. JAMA 1985;254:2609–13.
98. Staessen JA, Wang JG, Thijs L. Cardiovascular protection and blood pressure reduction: a meta-analysis [published erratum in Lancet 2002;359:360]. Lancet 2001;358:1305–15.
99. Hagberg JM, Montain SJ, Martin WH, Ehsani AA. Effect of exercise training in 60- to 69-year-old persons with essential hypertension. Am J Cardiol 1989;64:348–53.
100. Martel GF, Hurlbut DE, Lott ME, et al. Strength training normalizes resting blood pressure in 65- to 73-year-old men and women with high normal blood pressure. J Am Geriatr Soc 1999;47:1215–21.
101. Pina IL, Apstein CS, Balady GJ, et al. Exercise and heart failure: A statement from the American Heart Association Committee on exercise, rehabilitation, and prevention. Circulation 2003;107:1210–25.
102. Witham MD, Struthers AD, McMurdo ME. Exercise training as a therapy for chronic heart failure: can older people benefit? J Am Geriatr Soc 2003;51:699–709.
103. Pu CT, Johnson MT, Forman DE, et al. Randomized trial of progressive resistance training to counteract the myopathy of chronic heart failure. J Appl Physiol 2001;90:2341–50.

104. Santoro C, Cosmas A, Forman D, et al. Exercise training alters skeletal muscle mitochondrial morphometry in heart failure patients. J Cardiovasc Risk 2002;9:377–81.
105. The Diabetes Prevention Program (DPP) Research Group. The Diabetes Prevention Program (DPP): description of lifestyle intervention. Diabetes Care 2002;25:2165–71.
106. The Diabetes Prevention Program Research Group. Effects of withdrawal from metformin on the development of diabetes in the diabetes prevention program. Diabetes Care 2003;26: 977–980.
107. Knowler WC, Barrett-Connor E, Fowler SE, et al. Reduction in the incidence of type 2 diabetes with lifestyle intervention or metformin. N Engl J Med 2002;346:393–403.
108. Tuomilehto J, Lindstrom J, Eriksson JG, et al. Prevention of type 2 diabetes mellitus by changes in lifestyle among subjects with impaired glucose tolerance. N Engl J Med 2001; 344:1343–50.
109. Kern M, Dolan PL, Mazzeo RS, et al. Effect of aging and exercise on GLUT-4 glucose transporters in muscle. Am J Physiol 1992;263(2 Pt 1):E362–7.
110. Cox JH, Cortright RN, Dohm GL, Houmard JA. Effect of aging on response to exercise training in humans: skeletal muscle GLUT-4 and insulin sensitivity. J Appl Physiol 1999; 86:2019–25.
111. Stewart KJ. Exercise training and the cardiovascular consequences of type 2 diabetes and hypertension: plausible mechanisms for improving cardiovascular health. JAMA 2002;288:1622–31.
112. Castaneda C, Layne JE, Munoz-Orians L, et al. A randomized controlled trial of resistance exercise training to improve glycemic control in older adults with type 2 diabetes. Diabetes Care 2002;25:2335–41.
113. Zinman B, Ruderman N, Campaigne BN, et al. American Diabetes Association. Physical activity/exercise and diabetes. Diabetes Care 2004;27 Suppl 1:S58–62.
114. Pendleton A, Arden N, Dougados M, et al. EULAR recommendations for the management of knee osteoarthritis: report of a task force of the Standing Committee for International Clinical Studies Including Therapeutic Trials (ESCISIT). Ann Rheum Dis 2000;59:936–44.
115. Ettinger WH Jr, Burns R, Messier SP, et al. A randomized trial comparing aerobic exercise and resistance exercise with a health education program in older adults with knee osteoarthritis. The Fitness Arthritis and Seniors Trial (FAST). JAMA 1997;277:25–31.
116. Fransen M, McConnell S, Bell M. Exercise for osteoarthritis of the hip or knee. Cochrane Database Syst Rev 2003;(3): CD004286.
117. Evcik D, Sonel B. Effectiveness of a home-based exercise therapy and walking program on osteoarthritis of the knee. Rheumatol Int 2002;22:103–6.
118. Penninx BW, Messier SP, Rejeski WJ, et al. Physical exercise and the prevention of disability in activities of daily living in older persons with osteoarthritis. Arch Intern Med 2001;161: 2309–16.
119. American Geriatrics Society Panel on Exercise and Osteoarthritis. Exercise prescription for older adults with osteoarthritis pain: consensus practice recommendations [published erratum in J Am Geriatr Soc 2001;49:1400]. J Am Geriatr Soc 2001;49:808–23.
120. Van den Ende CH, Vliet Vlieland TP, Munneke M, Hazes JM. Dynamic exercise therapy for treating rheumatoid arthritis. Cochrane Database Syst Rev 2000;(2):CD000322.
121. Rall LC, Meydani SN, Kehayias JJ, et al. The effect of progressive resistance training in rheumatoid arthritis. Increased strength without changes in energy balance or body composition. Arthritis Rheum 1996;39:415–26.
122. Rall LC, Rosen CJ, Dolnikowski G, et al. Protein metabolism in rheumatoid arthritis and aging. Effects of muscle strength training and tumor necrosis factor alpha. Arthritis Rheum 1996;39:1115–24.
123. Nelson ME, Fiatarone MA, Morganti CM, et al. Effects of high-intensity strength training on multiple risk factors for osteoporotic fractures. A randomized controlled trial. JAMA 1994;272:1909–14.
124. de Jong N, Chin A Paw MJ, de Groot LC, van Staveren WA. Dietary supplements and physical exercise affecting bone and body composition in frail elderly persons. Am J Public Health 2000;90:947–54.
125. Kelley GA, Kelley KS, Tran ZV. Exercise and lumbar spine bone mineral density in postmenopausal women: a meta-analysis of individual patient data. J Gerontol A Biol Sci Med Sci 2002;57:M599–604.
126. Wolff I, van Croonenborg JJ, Kemper HC, et al. The effect of exercise training programs on bone mass: a meta-analysis of published controlled trials in pre- and postmenopausal women. Osteoporos Int 1999;9:1–12.
127. Kelley GA, Kelley KS, Tran ZV. Exercise and bone mineral density in men: a meta-analysis. J Appl Physiol 2000;88:1730–6.
128. Bonaiuti D, Shea B, Iovine R, et al. Exercise for preventing and treating osteoporosis in postmenopausal women. Cochrane Database Syst Rev 2002;(3):CD000333. 1996;312:278–86.
129. de Jong N, Chin A Paw MJ, de Graaf C, van Staveren WA. Effect of dietary supplements and physical exercise on sensory perception, appetite, dietary intake and body weight in frail elderly subjects. Br J Nutr 2000;83:605–13.
130. Reid IR. Therapy of osteoporosis: calcium, vitamin D, and exercise. Am J Med Sci 1996;312:278–86.
131. Pi-Sunyer FX. Comorbidities of overweight and obesity: current evidence and research issues. Med Sci Sports Exerc 1999;31(11 Suppl):S602–8.
132. Flegal KM, Carroll MD, Ogden CL, Johnson CL. Prevalence and trends in obesity among US adults, 1999-2000. JAMA 2002;288:1723–7.
133. Calle EE, Rodriguez C, Walker-Thurmond K, Thun MJ. Overweight, obesity, and mortality from cancer in a prospectively studied cohort of US adults. N Engl J Med 2003;348:1625–38.
134. Irwin ML, Yasui Y, Ulrich CM, et al. Effect of exercise on total and intra-abdominal body fat in postmenopausal women: a randomized controlled trial. JAMA 2003;289:323–30.
135. Treuth MS, Hunter GR, Kekes-Szabo T, et al. Reduction in intra–abdominal adipose tissue after strength training in older women. J Appl Physiol 1995;78:1425–31.
136. Ballor DL, Katch VL, Becque MD, Marks CR. Resistance

weight training during caloric restriction enhances lean body weight maintenance. Am J Clin Nutr 1988;47:19–25.
137. Fogelholm M, Kukkonen-Harjula K. Does physical activity prevent weight gain–a systematic review. Obes Rev 2000;1:95–111.
138. Judge JO, Whipple RH, Wolfson LI. Effects of resistive and balance exercises on isokinetic strength in older persons. J Am Geriatr Soc 1994;42:937–46.
139. Powell KE, Heath GW, Kresnow MJ, et al. Injury rates from walking, gardening, weightlifting, outdoor bicycling, and aerobics. Med Sci Sports Exerc 1998;30:1246–9.
140. Lemaster JW, Reiber GE, Smith DG, et al. Daily weight-bearing activity does not increase the risk of diabetic foot ulcers. Med Sci Sports Exerc 2003;35:1093–9.
141. Colbert LH, Hootman JM, Macera CA. Physical activity-related injuries in walkers and runners in the aerobics center longitudinal study. Clin J Sport Med 2000;10:259–63.
142. Pollock ML, Carroll JF, Graves JE, et al. Injuries and adherence to walk/jog and resistance training programs in the elderly. Med Sci Sports Exerc 1991;23:1194–200.
143. Sullivan DH, Wall PT, Bariola JR, et al. Progressive resistance muscle strength training of hospitalized frail elderly. Am J Phys Med Rehab 2001;80:503–9.
144. Brill PA, Probst JC, Greenhouse DL, et al. Clinical feasibility of a free-weight strength-training program for older adults. J Am Board Fam Pract 1998;11:445–51.