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Exercise Prescription for the Elderly

Current Recommendations

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Contents

Abstract

The benefits for elderly individuals of regular participation in both cardiovascular and resistance-training programmes are great. Health benefits include a significant reduction in risk of coronary heart disease, diabetes mellitus and insulin resistance, hypertension and obesity as well as improvements in bone density, muscle mass, arterial compliance and energy metabolism. Additionally, increases in cardiovascular fitness (maximal oxygen consumption and endurance), muscle strength and overall functional capacity are forthcoming allowing elderly individuals to maintain their independence, increase levels of spontaneous physical activity and freely participate in activities associated with daily living. Taken together, these benefits associated with involvement in regular exercise can significantly improve the quality of life in elderly populations. It is noteworthy that the quality and quantity of exercise necessary to elicit important health benefits will differ from that needed to produce significant gains in fitness.

This review describes the current recommendations for exercise prescriptions for the elderly for both cardiovascular and strength/resistance-training programmes. However, it must be noted that the benefits described are of little value if elderly individuals do not become involved in regular exercise regimens. Consequently, the major challenges facing healthcare professionals today concern: (i) the implementation of educational programmes designed to inform elderly individuals of the health and functional benefits associated with regular physical activity as well as how safe and effective such programmes can be; and (ii) design interventions that will both increase involvement in regular exercise as well as improve adherence and compliance to such programmes.

The number of individuals aged 65 years and over is the fastest growing segment of our population. Thus, there is a need to determine the extent to which habitual exercise and physical activity can improve health, functional capacity, quality of life and independence in this population. Current research indicates that participation in a regular exercise programme is an effective intervention to reduce and/or prevent a number of functional and health-associated declines known to occur with advancing age. Furthermore, the trainability of older adults is evidenced by their ability to adapt and respond to both endurance and strength training. Aerobic/endurance training can help to maintain and improve various aspects of cardiovascular function and health, as measured by maximal oxygen consumption ($\dot{V}O_{2max}$) and cardiac output, as well as enhance submaximal endurance. Strength/resistance training will help offset the loss in muscle mass and strength typically associated with normal aging, thereby improving functional capacity. Importantly, reductions in risk factors associated with disease states (heart disease, diabetes mellitus, osteoporosis) will improve health status and contribute to an increase in life-span. Together, these training adaptations will greatly improve the functional capacity of older men and women, thereby improving quality of life and continued independent living in this population.

1. Cardiovascular Considerations with Exercise

1.1 Health Benefits

Since the 1980s, it has been repeatedly shown that regular exercise performed at low to moderate intensity is associated with improvements in traditional as well as emerging risk factors associated with cardiovascular disease.[1-6] More importantly, improvements in these cardiovascular risk factors do not depend on an increase in $\dot{V}O_{2max}$.[2,3,5,6] Specifically, recent evidence has suggested that individuals who have been very inactive for most of their life can benefit from the incorporation of light to moderate exercise programmes.[7] However, for individuals who are more fit, a greater exercise intensity may be required to elicit any further health benefits.[8]

Bodyweight and fatness increase with advancing age.[9] Accumulation of body fat, in particular in truncal regions, is closely associated with an increased risk of morbidity and premature mortality.[9] Individuals who habitually exercise appear to accumulate less adipose tissue particularly in upper, central body regions with age.[10] Consistent with these cross-sectional study findings, a period of aerobic exercise training can induce a preferential loss of fat from the central body regions[11] and favourably modify the abdominal fat distribution profile in older adults.[12] Thus, regular exercise appears to have the effect of reducing the risk for metabolic disorders associated with upper body obesity in older adults.

In sedentary humans, advancing age is associated with unfavourable changes in plasma lipid and lipoprotein levels.[13] These abnormalities have been identified as major risk factors for coronary heart disease.[13] In general, a physically active lifestyle is associated with a more favourable lipid and lipoprotein profile in middle-aged and older adults.[5,14] The most consistent effect of regular aerobic exercise on plasma lipoprotein levels is an increase in the cardioprotective high density lipoprotein-cholesterol levels.[5] Plasma low density lipoprotein-cholesterol levels are not obviously modulated by regular exercise unless accompanied by significant reduction in bodyweight.[1,15]

Elevated fasting plasma insulin levels, impaired glucose tolerance, and reduced insulin sensitivity have all been associated with an increased risk of coronary heart disease.[16,17] Physically active older men and women demonstrate favourable levels of fasting plasma insulin, glucose tolerance and insulin sensitivity compared with age-matched sedentary peers.[4] It is important to emphasise, however, that the improvement in carbohydrate metabolism induced by regular exercise reverses rapidly upon cessation of exercise routine.[4] As such, the continuation of a regular exercise regimen is critical for primary and secondary prevention of diabetes mellitus and other diseases associated with carbohydrate metabolism in older adults.

Arterial blood pressure increases with advancing age, contributing to age-related increases in the risk of a number of cardiovascular disorders.[18] Regular aerobic exercise is associated with the attenuation of age-related increases in arterial blood pressure.[19,20] Recent findings indicate that regular aerobic exercise produces clinically significant reductions in blood pressure at rest in middle-aged and older adults with elevated baseline levels, and these reductions occur within the necessary time period based on current therapeutic guidelines.[20-22] Thus, sufficient evidence is available at this time to recommend regular exercise as primary prevention and secondary treatment of age-related increases in arterial blood pressure.[19]

Recently, several investigators began to address the influences of regular aerobic exercise on emerging risk factors (e.g. arterial compliance, endothelial function) in older adults. In a recent study, we found that the progressive declines in carotid arterial compliance as well as endothelial functions with age observed in sedentary men were markedly attenuated or even absent in endurance-trained men.[2,3] Moreover, essentially daily aerobic exercise for 3 months significantly increased carotid artery compliance and endothelial function in a group of previously sedentary middle-aged and older men.[2,3] Thus, currently available evidence indicates that regular aerobic exercise exerts beneficial influences on both traditional and emerging risk factors in middle-aged and older adults.

1.2 Functional and Fitness Benefits

Physiological functional capacity, as assessed by $\dot{V}O_{2max}$ [23] and peak exercise performance,[24] declines with advancing age in both men and women. This would eventually contribute to a loss of independence, increased incidence of disability and reduced quality of life in older adults. Moreover, because maximal aerobic capacity has recently been shown to be an independent risk factor for all-cause and cardiovascular disease mortality,[25,26] the age-related decrease may contribute to premature death in middle-aged and older adults. Based largely on data in men, the concept has been established that the rate of decline in $\dot{V}O_{2max}$ with age is attenuated in adults who perform regular aerobic exercise.[4,27] Additionally, the absolute levels of $\dot{V}O_{2max}$ are substantially higher in trained individuals than those of sedentary peers throughout the age range. Thus, endurance-trained adults possess higher levels of physiological capacity and lower risks of premature mortality at any age.

Since an original study published in 1984,[28] a number of studies have confirmed an increase in $\dot{V}O_{2max}$ in response to endurance training in previously sedentary older men and women, as long as the exercise intensity is adequate and prolonged.[4,29] As such, the currently prevailing concept is that the relative (percentage) increase in $\dot{V}O_{2max}$ is similar in both young and older adults.[4,30] However, because of substantially lower baseline levels, the absolute increase in $\dot{V}O_{2max}$ is substantially smaller in older adults. Similarly, the relative increases in $\dot{V}O_{2max}$ observed following endurance training appear to be similar in older men and women.[30]

1.3 Basic Guidelines for Exercise Prescription

In general, the same principles of exercise prescription should be applied to adults of all ages, including older adults. One important distinction, however, is that older adults of the same age would be dramatically different in their baseline physiological state and response to the same exercise stimuli. Thus, the exercise programme should be individually constructed based on the fitness level and needs of each older adult.

There is a distinction between exercise prescription for aerobic fitness and for health as the optimum exercise stimuli to alter these respective variables are different. For the elderly, it has become more important to engage in physical activity to promote health and functional capacity rather than aerobic fitness. In fact, the consensus public health message from the Center for Disease Control (CDC) and the American College of Sports Medicine (ACSM)[31] recommended that 'every US adult should accumulate 30 minutes or more of moderate-intensity physical activity on most, preferably all, days of the week'. The following exercise prescriptions are generally consistent with this recommendation and emphasise the promotion of health and physical function rather than aerobic fitness.

The exercise prescription consists of 5 different but interacting elements: warm-up, intensity, duration, frequency and exercise type/mode.

1.3.1 Warm-up

It is recommended that all exercise bouts should start with a routine of gentle warm-up and stretching of the muscles. This is particularly important for older adults who are prone to exercise-induced musculoskeletal injuries and cardiac events. In addition to the general warm-up and stretching, light movement simulating the actual exercise activities (e.g. swinging of a racket before a tennis match) should also be performed.

1.3.2 Exercise Intensity

Moderate intensity of exercise should be emphasised for older adults. There is considerable experimental evidence to support such a recommendation. First, regular exercises performed at low to moderate intensity are associated with improvements in traditional as well as emerging risk factors associated with cardiovascular disease.[1-6] Second, compared with the higher intensities of exercise, moderate exercise is associated with a significantly lower rate of injury in older adults. Third, older adults appear to prefer exercise at moderate intensity,[32] which should result in better compliance and maintenance. At the beginning of an exercise programme, however, exercise intensity for previously sedentary older adults should be kept even lower and increased gradually to moderate intensity according to his/her tolerance and preference.

Exercise intensity can be classified in several different ways. The use of heart rate is a common and objective standard. A maximal heart rate of 55 to 70% and a heart rate reserve of 40 to 60% corresponds to a 'moderate' intensity of exercise. Because a maximal exercise stress test for older adults is not feasible in many settings, the age-predicted equation (i.e. 220 – age) has been extensively used for estimating maximal heart rate. However, a recent study[33] combining a meta-analysis approach and a laboratory-based approach has demonstrated that the currently used equation (220 – age) underestimates true maximal heart rate in older adults, and that this would have the effect of underestimating the appropriate intensity of prescribed exercise programmes. A more accurate regression equation is $208 - (0.7 \times \text{age})$ in apparently healthy adults.[33] However, because of a large scatter associated with this variable, the use of a measured maximal heart rate is preferable to an age-predicted maximal heart rate whenever possible. Additionally, the use of medication (e.g. β-blockers) and smoking can influence maximal heart rate. Moreover, when heart rate is used to prescribe exercise intensity during swimming, it should be reduced appropriately. Because swimming is performed in the supine position, maximal heart rate during swimming is ≈10 beats/min lower compared with upright exercise (e.g. running).[33]

The prescription of exercise intensity can also be performed with the rating of perceived exertion.

A rating of 12 to 13, perceived as 'somewhat hard', corresponds to moderate intensity exercise.

1.3.3 Exercise Duration

The duration and intensity of exercise are closely interrelated. For older adults, low to moderate intensity of longer duration is recommended.[31] On the basis of the currently recommended moderate intensity of exercise, a minimum of 30 minutes per day of exercise should be performed. In the initial phase of the exercise programme, older adults should gradually increase exercise duration rather than exercise intensity. When the exercise intensity has to be high, the duration of exercise needs to be reduced accordingly.

The duration of a single bout of activities appears to be far less important than the total volume or accumulation of activities. A series of short bouts of exercise (e.g. 10 minutes of exercise 3 times/day) can be spread throughout the day. It appears that as long as the accumulated amount of exercise exceeds 30 minutes, it will confer significant health benefit. This is particularly advantageous for older adults because it allows them to incorporate regular exercise into their daily lifestyle. This can be easily achieved by choosing to walk or cycle to work and climb stairs rather than taking elevators. Thus, available evidence indicates that the total amount of activity appears to be more important than the specific manner (e.g. frequency, mode) in which the physical activity is performed.[31]

1.3.4 Frequency

While moderate levels of physical activity can confer significant health benefits, physical activity must be performed frequently to prolong and maintain such beneficial effects. Consistent with the current recommendation by the CDC and ACSM,[31] older adults should perform moderate exercise on most and preferably all days of the week. If vigorous exercise is included in the exercise programme, the frequency of exercise should be reduced (e.g. 3 days/week) to minimise potential risks of musculoskeletal injuries and cardiac events.

1.3.5 Exercise Type/Mode

The selection of type/mode of activity should be based on the participant's fitness level as well as his/her interests and available resources. The choice of activity that is enjoyable and has minimal potential for injury would lead to better compliance and maintenance. Additionally, current recommendations repeatedly emphasise the incorporation of exercise into everyday life rather than structured supervised activities. For these reasons, walking has become a choice of physical activity for older adults.[34,35] Walking is the most preferred activity among older adults[36] and does not require specific skills, clothing or equipment. It can offer companionship if walking is performed with a spouse and/or friends, and can be easily incorporated into daily activities, such as walking to work and social events.

Cycling and/or swimming may be preferable to walking/jogging for those with poor balance and musculoskeletal problems. However, it should be noted that exercise in the water carries the extra hazard of drowning and arrhythmias. When choosing activities that require skills (e.g. tennis, swimming), it is important to make certain that participants have appropriate abilities to derive sufficient health benefits.

Over the last decade, exercise facilities/fitness clubs have become an important place for daily workouts. These facilities allow participants to perform a combination of various exercises (i.e. cross-training) in a supervised environment. From a public health standpoint, such forms of physical activity may be particularly advantageous because they would result in better compliance and fewer musculoskeletal injuries. In this regard, a recent study has demonstrated that such gym-based activities would confer similar health benefits to those obtained in aerobic exercise programmes.[22]

2. Strength/Resistance Training

2.1 Health Considerations

The loss of muscle mass (sarcopenia) with age in humans is well documented.[37-42] A primary factor in sarcopenia appears to be disuse of skeletal muscle resulting in atrophy. Directly associated with the loss of muscle mass is a reduction in muscle strength. Inactivity may also play a role, contributing to other factors affecting aging muscle mass including neuromuscular realignment, reduction in growth factors and changes in muscle protein turnover. The consequences of sarcopenia can be extensive as there is an increased susceptibility to falls and fractures, impairments in the ability to thermoregulate, a reduction in metabolic rate, deficiencies in glucose regulation, and overall loss in functional capacity and the ability to perform everyday tasks.

Muscle atrophy appears to result from a gradual loss of both muscle fibre size as well as number. A gradual loss in muscle cross-sectional area is consistently found with advancing age such that at age 50 years there is a reduction of ≈10% of total muscle area. After 50 years of age, the rate of muscle area loss is significantly accelerated. Muscle strength declines by ≈15% per decade in the 6th and 7th decade, and about 30% thereafter. While there is some indication that intrinsic muscle function is reduced with advancing age, the overwhelming majority of the loss in strength results from an age-related decrease in muscle mass. The number of functional motor units declines with advancing age requiring surviving motor units to innervate a greater number of muscle fibres. Participation in a strength training programme by elderly individuals has been shown to elicit a number of health benefits including improvements in insulin sensitivity, bone density, body fat and energy metabolism.[6,43-46]

2.2 Functional and Fitness Benefits

Given an adequate training stimulus, older individuals are capable of making significant gains in strength of the same relative magnitude as their younger counterparts. Increases of 2- to 3-fold in muscle strength can be accomplished in a relatively short period of time (3 to 4 months) in fibres recruited during training in older adults. The initial increase in strength is likely mediated by neural adaptations allowing for greater fibre recruitment, while with more prolonged resistance training, modest increases in muscle size are possible. As there is a greater cross-sectional area loss in type II muscle fibres with advancing age,[39,47-49] resistance training would be ideally suited to maintain or improve the size and mass of these fibres. Together, these adaptations to resistance training contribute to the significant improvements observed in functional capacity in this age group. This also plays an important role in allowing these individuals to increase levels of physical activity and to continue to participate in activities associated with daily living, both of which contribute to maintenance of and improvement in cardiovascular function. Because sarcopenia and muscle weakness may be an almost universal characteristic of advancing age, strategies for preserving or increasing muscle mass in the older adult should be implemented.

2.3 Basic Guidelines for Exercise Prescription

Elderly adults may be more susceptible to orthopaedic injuries and cardiovascular complications, thus medical screening is essential (see section 3). Additionally, when beginning a resistance training programme, proper instruction on correct and safe lifting techniques is necessary to reduce the risk of injury as well as other health-related complications. In the health club setting, this instruction can be received from properly trained and certified trainers. If one desires to train at home, proper instruction on lifting techniques should be acquired before initiating home-based training.

2.3.1 Warm-up

A proper warm-up should be conducted before resistance training, similar to that described in section 1.3.1. As a result of a loss in elasticity of muscle and connective tissue with advancing age and the subsequent increase in stiffness, a proper warm-up is essential in reducing the risk of injuries in older populations.

2.3.2 Exercise Intensity

Elderly individuals beginning a resistance training programme should start at a low intensity and gradually progress over time. Strength training exercises should begin with light weights that can be lifted comfortably through a full range of motion using good posture and mechanics. Individuals should avoid holding their breath during force production (Valsalva manoeuvre). The amount of weight that is lifted should be increased progressively as strength improves. The eventual goal is to achieve a relatively high intensity resistance training programme that has been shown to be the most effective in improving strength even in older populations.[6,43,50-52]

The intensity is generally prescribed as a percentage of the individual's 1-repetition maximum (1-RM: the maximum amount of weight that can be safely lifted 1 time). The goal is to determine the amount of weight necessary to complete 1 set of 8 to 15 repetitions that brings the muscle group to volitional fatigue (8- to 15-RM). This corresponds approximately to 60 to 80% of the 1-RM. This intensity has been demonstrated to result in significant gains in muscle strength and mass.[43,50-53] While higher training intensities (85 to 100% of 1-RM) can lead to greater gains in strength, for older populations this may increase the risk of musculoskeletal injuries. If an increase in muscle endurance is desired, it is generally recommended to use a lower intensity weight that can be lifted for more repetitions.

2.3.3 Exercise Duration

Currently, there is considerable debate regarding the volume of resistance training necessary to produce optimal benefits in muscle strength. Typically, multiple sets (2 to 3 sets) of 8- to 15-RM are prescribed. However, a number of studies suggest that a single set can result in similar strength gains when compared with the use of multiple sets.[54-58] A single set resistance training programme can be completed in a shorter period of time which has been suggested to increase compliance and reduce the rate of dropouts.[55-57] Regardless, it is clear that a single set is sufficient to produce significant strength gains. Multiple sets can be employed if the potential for greater strength gains is desired.

2.3.4 Frequency

As elderly individuals beginning a resistance training programme generally have reduced muscle strength and mass compared with their younger counterparts, significant improvements in muscle strength are consistently observed with a training frequency of 2 to 3 days/week.[59-61] While increasing the training frequency to 4 to 5 days/week may result in further gains in strength, it may result in a decrease in compliance. This is particularly true when resistance training is coupled with some form of cardiovascular training as described above in section 1.3.4. Thus, for elderly individuals beginning a resistance training programme a frequency of 2 to 3 days/week is generally recommended.

2.3.5 Exercise Type/Mode

Resistance training should be directed at the large muscle groups that are important in everyday activities incorporating arms/shoulders, chest, back, hips and legs. Each repetition should be performed slowly through the full range of motion, allowing adequate time to lift the weight (concentric contraction) as well as to lower the weight (eccentric contraction). From an equipment standpoint, variable resistance machines using weight stacks are desirable for this population, for a number of reasons: (i) they reduce the risk of injuries to hands and feet; (ii) they decrease the risk of injury to the lower back; (iii) they are associated with a reduced risk of exercised-induced hypertension; (iv) the weights can be adjusted in small increments; and (v) resistance can generally be applied through the full range of motion.

3. Contraindications

In general, apparently healthy older adults can safely engage in physical activity unless they are planning to undergo vigorous exercise. The American College of Cardiology and American Heart Association recommend exercise stress testing in asymptomatic men older than 40 years and women older than 50 years before they start vigorous exercise.[62]

According to the exercise standards proposed by the American Heart Association,[63] for a small number of older adults with existing disease, the risks of exercise may outweigh the potential benefits of regular exercise. For example, exercise may aggravate pre-existing diseases and conditions common to older adults, including angina, arthritis, osteoporosis and stage III hypertension. A more detailed list of contraindications for physical activity can be found in the *ACSM's Guidelines for Exercise Testing and Prescription*.[64] Fortunately, the potential risks of exercise can be greatly reduced by medical history, physical examination, risk stratification, close supervision and education.

4. Conclusion

It is clear that participation in a programme of regular exercise (cardiovascular and resistance) elicits many benefits for elderly individuals. These benefits range from important health-related issues such as cardiovascular disease, diabetes mellitus and osteoporosis, to more functional benefits that allow for continued independence and the ability to safely and effectively participate in activities associated with daily living. However, these benefits are of little value if elderly individuals do not become involved in regular exercise regimens. The major challenges facing healthcare professionals today concern: (i) the implementation of educational programmes designed to inform elderly individuals of the health and functional benefits associated with regular physical activity as well as how safe and effective such programmes can be; and (ii) design interventions that will both increase involvement in regular exercise as well as improve adherence and compliance to such programmes.

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References

1. Tran ZV, Weltman A. Differential effects of exercise on serum lipid and lipoprotein levels seen with changes in body weight. JAMA 1985; 254: 919-24
2. DeSouza CA, Shapiro LF, Clevenger CM, et al. Regular aerobic exercise prevents and restores age-related declines in endothelium-dependent vasodilation in healthy men. Circulation 2000; 102: 1351-7
3. Tanaka H, Dinenno FA, Monahan KD, et al. Aging, habitual exercise, and dynamic arterial compliance. Circulation 2000; 102: 1270-5
4. Holloszy JO, Kohrt WM. Exercise. In: Masoro EJ. Handbook of physiology: aging. New York (NY): Oxford University Press, 1995: 633-66
5. Despres JP, Lamarche B. Low-intensity endurance exercise training, plasma lipoproteins and the risk of coronary heart disease. J Int Med 1994; 236: 7-22
6. ACSM Position Stand. Exercise and physical activity for older adults. Med Sci Sports Exerc 1998; 30 (6): 992-1008
7. Lee IM, Rexrode KM, Cook NR, et al. Physical activity and coronary heart disease in women. JAMA 2001; 285: 1447-54
8. Lee IM, Hsieh CC, Paffenbarger RS. Exercise intensity and longevity inn men: the Harvard Alumni Health study. JAMA 1995; 273: 1179-84
9. Stevens J, Cai J, Pamuk ER, et al. The effect of age on the association between body-mass index and mortality. N Engl J Med 1998; 338: 1-7
10. Kohrt WM, Malley MT, Dalsky GP, et al. Body composition of healthy sedentary and trained, young and older men and women. Med Sci Sports Exerc 1992; 24 (7): 832-7
11. Schwartz RS, Shuman WP, Larson V, et al. The effect of intensive endurance exercise training on body fat distribution in young and old men. Metabolism 1991; 40 (5): 545-51
12. Kohrt WM, Obert KA, Holloszy JO. Exercise training improves fat distribution patterns in 60- and 70-year-old men and women. J Gerontol 1992; 47 (4): M99-M105
13. National Cholesterol Education Program. Detection, evaluation, and treatment of high blood cholesterol in adults (Adult treatment panel II). Circulation 1994; 89 (3): 1329-445
14. Stevenson ET, Davy KP, Seals DR. Hemostatic, metabolic, and androgenic risk factors for coronary heart disease in physically active and less active postmenopausal women. Arterioscler Thromb 1995; 15: 669-77
15. Haskell WL. The influence of exercise training on plasma lipids and lipoproteins in health and disease. Acta Med Scand Suppl 1986; 711: 25-37
16. Cefalu WT, Werbel S, Bell-Farrow AD, et al. Insulin resistance and fat patterning with aging: relationship to metabolic risk factors for cardiovascular disease. Metabolism 1998; 47 (4): 401-8
17. Mykkanen L, Laakso M, Pyorala K. High plasma insulin level associated with coronary heart disease in the elderly. Am J Epidemiol 1993; 137 (11): 1190-202
18. Joint National Committee on Prevention Detection, Evaluation, and Treatment of High Blood Pressure. The Sixth report of the Joint National Committee on Prevention, Detection, Evaluation, and Treatment of High Blood Pressure. Arch Intern Med 1997; 157 (24): 2413-46
19. Tanaka H, DeSouza CA, Seals DR. Exercise and hypertension in older adults. In: Tanaka H, Shindo M, editors. Exercise for preventing common diseases. Tokyo: Springer-Verlag, 1999: 45-50
20. Seals DR, Silverman HG, Reiling MJ, et al. Effect of regular aerobic exercise on elevated blood pressure in postmenopausal women. Am J Cardiol 1997; 80 (1): 49-55
21. Hagberg JM, Montain SJ, Martin WH, et al. Effect of exercise training in 60- to 69-year-old persons with essential hypertension. Am J Cardiol 1989; 64: 348-53
22. Ishikawa K, Ohta T, Zhang J, et al. Influence of age and gender on exercise training-induced blood pressure reduction in systemic hypertension. Am J Cardiol 1999; 84 (2): 192-6

23. Buskirk ER, Hodgson JL. Age and aerobic power: the rate of change in men and women. Fed Proc 1987; 46: 1824-9
24. Tanaka H, Seals DR. Age and gender interactions in physiological functional capacity: insight from swimming performance. J Appl Physiol 1997; 82 (3): 846-51
25. Blair SN, Kohl HW, Paffenbarger RS, et al. Physical fitness and all-cause mortality: a prospective study of men and women. JAMA 1989; 262: 2395-401
26. Blair SN, Kohl HW, Barlow CE, et al. Changes in physical fitness and all-cause mortality. JAMA 1995; 273: 1093-8
27. Hagberg JM. Effect of training on the decline of $\dot{V}O_{2max}$ with aging. Fed Proc 1987; 46: 1830-3
28. Seals DR, Hagberg JM, Hurley BF, et al. Endurance training in older men and women I. cardiovascular responses to exercise. J Appl Physiol 1984; 57 (4): 1024-9
29. Dempsey JA, Seals DR. Aging, exercise, and cardiopulmonary function. In: Lamb DR, Gisolfi CV, Nadel E, editors. Perspectives in exercise science and sports medicine. Vol. 8. Exercise in older adults. Carmel (IN): Cooper Publishing Group, 1995: 237-304
30. Kohrt WM, Malley MT, Coggan AR, et al. Effects of gender, age, and fitness level on response of $\dot{V}O_{2max}$ to training in 60-71 yr olds. J Appl Physiol 1991; 71 (5): 2004-11
31. Pate RR, Pratt M, Blair SN, et al. Physical activity and public health: a recommendation from the Centers for Disease Control and Prevention and the American College of Sports Medicine. JAMA 1995; 273 (5): 402-7
32. King AC, Haskell WL, Taylor CB, et al. Group- *vs* home-based exercise training in healthy older men and women: a community-based clinical trial. JAMA 1991; 266: 1535-42
33. Tanaka H, Monahan KD, Seals DR. Age-predicted maximal heart rate revisited. J Am Coll Cardiol 2001; 37 (1): 153-6
34. Hakim AA, Curb JD, Petrovitch H, et al. Effects of walking on coronary heart disease in elderly men: the Honolulu Heart Program. Circulation 1999; 100 (1): 9-13
35. Manson JE, Hu FB, Rich-Edwards JW, et al. A prospective study of walking as compared with vigorous exercise in the prevention of coronary heart disease in women. N Engl J Med 1999; 341 (9): 650-8
36. Booth ML, Bauman A, Owen N, et al. Physical activity preferences, preferred sources of assistance, and perceived barriers to increased activity among physically inactive Australians. Prev Med 1997; 26: 131-7
37. Dutta C, Hadley EC. The significance of sarcopenia in old age. J Gerontol 1995; 50A: 1-4
38. Larsson L. Morphological and functional characteristics of the ageing skeletal muscle in man: a cross sectional study. Acta Physiol Scand Suppl. 1978; 457: 1-36
39. Lexell J. Human aging, muscle mass, and fiber type composition. J Gerontol 1995; 50A Spec.: 11-6
40. Overend TJ, Cunningham DA, Paterson DH, et al. Thigh composition in young and elderly men determined by computed tomography. Clin Physiol 1992; 12: 629-40
41. Young A, Stokes M, Crowe M. Size and strength of the quadriceps muscles of old and young women. Eur J Clin Invest 1984; 14: 282-7
42. Young A, Stokes M, Crowe M. Size and strength of the quadriceps muscles of old and young men. Clin Physiol 1985; 5: 145-54
43. Evans WJ. Exercise training guidelines for the elderly. Med Sci Sports Exerc 1999; 31 (1): 12-7
44. Miller JP, Pratley RE, Goldberg AP, et al. Strength training increases insulin action in healthy 50- to 65-yr-old men. J Appl Physiol 1994; 77: 1122-7
45. Pratley R, Nicklas B, Rubin M, et al. Strength training increases resting metabolic rate and norepinephrine levels in healthy 50- to 65-yr-old men. J Appl Physiol 1994; 76 (1): 133-7
46. Treuth MS, Hunter GR, Kekes-Szabo T. Reduction in intra-abdominal adipose tissue after strength training in older women. J Appl Physiol 1995; 78 (4): 1425-31
47. Lexell J, Taylor T. Variability in muscle fiber areas in whole human quadriceps muscle: effect of increasing age. J Anat 1991; 174: 239-49
48. Aniansson A, Hedberg M, Henning G, et al. Muscle morphology, enzymatic activity, and muscle strength in elderly men: a follow up study. Muscle Nerve 1986; 9: 585-91
49. Essen-Gustavsson B, Borges O. Histochemical and metabolic characteristics of human skeletal muscle in relation to age. Acta Physiol Scand 1986; 126: 107-14
50. Feigenbaum MS, Pollock ML. Prescription of resistance training for health and disease. Med Sci Sports Exerc 1999; 31 (1): 38-45
51. Fleck SJ, Kraemer WJ. Designing resistance training programs. 2nd ed. Champaign (IL): Human Kinetics Books, 1997: 1-115
52. McDonagh MN, Davies CM. Adaptive response of mammalian skeletal muscle to exercise with high loads. Eur J Appl Physiol 1984; 52: 139-55
53. ACSM Position Stand. The Recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. Med Sci Sports Exerc 1998; 30 (6): 975-91
54. Graves JE, Holmes BL, Leggett SH, et al. Single versus multiple set dynamic and isometric lumbar extension strength training. In: Proceedings of the World Confederation for Physical Therapy, 11th International Congress. III. London: Charted Society of Physiotherapy, 1991: 1340-2
55. Messier SP, Dill ME. Alterations in strength and maximal oxygen uptake consequent to Nautilus circuit weight training. Res Q Exerc Sport 1985; 56: 345-51
56. Feigenbaum MS, Pollock ML. Strength training: rationale for current guidelines for adult fitness programs. Physician Sportsmed 1997; 25 (2): 44-64
57. Westcott WL, Greenberger K, Milinus D. Strength-training research: sets and repetitions. Scholastic Coach 1989; 58: 98-100
58. Berger RA. Application of research findings in progressive resistance exercise to physical therapy. J Assoc Phys Mental Rehabil 1965: 19: 200-3
59. Hunter GR. Changes in body composition, body build, and performance associated with different weight training frequencies in males and females. Natl Strength Cond Assoc J 1985; 7: 26-8
60. Graves JE, Pollock ML, Foster DN, et al. Effect of training frequency and specificity on isometric lumbar extension strength. Spine 1990; 15: 504-9

61. Demichele PD, Pollock ML, Graves JE, et al. Effect of training frequency on the development of isometric torso rotation strength. Arch Phys Med Rehabil 1997; 27: 64-9
62. Gibbons RJ, Balady GJ, Beasley JW, et al. ACC/AHA guidelines for exercise testing: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Exercise Testing). J Am Coll Cardiol 1997; 30 (1): 260-315
63. Fletcher GF, Froelicher VF, Hartley LH, et al. Exercise standards: a statement for health professionals from the American Heart Association. Circulation 1990; 82 (6): 2286-322
64. American College of Sports Medicine. ACSM's guidelines for exercise testing and prescription. 6th ed. Baltimore (MD): Lippincott Williams & Wilkins, 2000

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