Medicina Sportiva, Vol. 7 (EE4): E123–E133, 2003

STRENGTH TRAINING IN THE ELDERLY: BENEFITS, DANGERS, DOUBTS

Wiktor Niewiadomski, Anna Gąsiorowska, Gerard Cybulski

Department of Applied Physiology, M. Mossakowski Medical Research Center, Polish Academy of Sciences, Poland

ABSTRACT

The loss of strength and muscle mass progressing after the age of about 50 years can lead to considerable worsening of normal functioning of the elderly, and finally to the loss of independence. Strength training performed by the elderly can reverse strength and muscle mass loss to the considerable degree. However, this kind of training had been considered hazardous for cardiovascular system, especially because of substantial increase of arterial pressure, which could accompany strength exercises. Currently, the cardiovascular load imposed by properly conducted strength training is considered to be comparable to the load imposed by endurance training. It was believed that strength training decreases resting blood pressure, leads to beneficial changes in metabolism, protects against osteoporosis. However these beneficial effects have not been convincingly confirmed and adverse effects have been documented.

Key words: strength training, aging, sarcopenia, hemodynamic response, health-related benefits

Introduction

Roger and Evans (85) consider strength training as one of the most effective and cheapest ways to preserve independent living by elderly.

Resistance training – basic definitions

The aim of strength training is to increase muscle strength. Strength training requires the body's musculature to move against an opposing force, therefore it is also termed resistance training. Isometric exercise is a specific type of strength exercise, in which muscles are developing force but no movement at a joint occurs.

The basic unit of strength training is a repetition. The repetition is sequence of movements ending back in starting position. It normally consists of the concentric muscle action, when the muscles involved are shortening, and the eccentric muscle action, when they are lengthening.

Set is usually a predefined number of repetitions of chosen exercise performed continuously without stopping. The number of repetitions per set typically range from 1 to 15.

The maximum number of repetitions per set (RM) is the maximal number of repetitions, which can be performed without stopping at given resistance. Thus, 1-RM is the resistance at which only one repetition can be performed. Analogously, 3-RM is the resistance that allows completion of maximally three repetitions. The intensity of an exercise can be expressed as a maximal number of repetitions or as percentage of the 1-RM.

The smaller intensity, the smaller percentage of 1-RM, and so more repetitions can be performed. The 85% 1-RM intensity usually allows performing 3 repetitions; 85% 1-RM equals 3-RM. Using 80% 1-RM may allow performing 10 repetitions: 80% 1-RM equals 10-RM. The intensities from 1-RM to 6-RM are the most effective in increasing strength muscle. Increase of strength muscle obtained with small number of repetitions performed against heavy resistance can not be gained with large number of repetitions performed against light resistance. Intensity of 50% 1-RM suffices to increase in strength muscle, 80% 1-RM can be indispensable to increase bone mineral density (109). The intensities above 25-RM have small or no influence on increasing strength muscle (7).

Expressing intensity with maximal number of repetitions (RM) refers to current capabilities of training person. For example: 1-RM intensity means different resistances used for different persons. Maintaining the same individual intensity will typically require increasing resistance along with training induced increase of muscle strength.

A training session includes all exercises performed in a given time period. A recommended training session for older adults consists of 8 kinds of exercises, which increases strength of large muscle groups that are important in everyday activities (arms, shoulders, spine, hips, and legs). At the beginning of training 80% 1-RM (10-RM - 15-RM, i.e. 10-15 repetitions per set) intensity is recommended, with possible increase to 8-RM - 10-RM or even 2-RM - 5-RM in more advanced stage of training. At the start of training it is suggested to perform only one set of repetitions for every kind of exercise with 2-3 min of rest between sets. Progression can go from one to three sets over training time for each type of exercise. The training consisting of 2-3 session per week is recognized as sufficient for gaining health benefits, each session consisting of single sets of 8-10 exercises (28, 38). Similar recommendations can be found also in (3, 4, 33, 69).

Age dependent loss of skeletal muscle strength and mass

A strength performance peaks in the third decade of life, after which strength remains relatively stable or slightly decreases over the next 20 years. In the sixth and seventh decade of life the muscle strength declines by approximately 15% per decade, and by 30% in the eighth decade (19, 28, 45, 59, 71, 78).

Substantial muscle weakness can compromise the ability of the elderly persons to perform common activities of daily living, which can lead to loss of their independence (55). The risk of falling increases with age. Falls are one of the major causes of injury in elderly, constituting important health hazard, and may eventually lead to death (5, 15, 111).

Decreased muscle mass has been suggested as the primary cause of strength reduction in aged. This phenomenon has been termed sarcopenia (27) and has been amply documented (24, 64, 81, 114). Sarcopenia affects in a similar degree flexors and extensors, upper and lower extremities (39). Young et al. (113) demonstrated that the quadriceps cross-sectional area of women in their 70s was 33% lower than that of women in the 20s. In addition, beside of decrease in cross-sectional muscle area, an increase of intramuscular fat is more pronounced in women (51).

The decline in muscle mass is caused by the reduction in the size of the individual muscle fibers and also by reduction in number of fibers (40, 60, 63). The preferential loss of Type II muscle fibers means a loss of fast myosin heavy chains proteins (42). The nearly 50% reduction in the number of motor units is observed in older subjects compared with younger ones (22).

Strength training reverses age-associated loss of muscle strength and mass

In 1990 Fiatarone et al. (34) demonstrated, after eight weeks of strength training in 87-96 years old persons, an increase of muscle strength and muscle hypertrophy, in contrast to earlier study of Moritani and DeVries (77), who demonstrated only an increase of muscle strength after high-intensity strength training, but no muscle hypertrophy.

Similar results were reported by Frontera et al. (40). They observed the 200% increase of muscle strength accompanied by muscle hypertrophy in 60-72-years old persons. Charette et al. (16) found an increase in Type II fiber area with no significant change in Type I area after 12 weeks of high-intensity strength training in older women. The continuing increase of muscle strength during 12 months of strength training was observed in 59±0,9 years old women by Morganti et al. (76), the greatest changes were seen in the first 3 months of the study, but continuing improvement was noted up to the end of training.

Hurley and Roth (48), comparing the age-associated loss in strength muscle (15% per VI and VII decade of life) with 30% strength gain attained within the 2 months of heavy strength training (61), concluded that this training can essentially reverse 2 decades of age-related strength loss. Similarly, several months of strength training caused 12% increase of muscle mass (104), reversing almost entire loss, which occurred after the age of 50 years (66). Thus, the correctly designed strength training can significantly increase muscle strength in the elderly, in some subjects leading to complete reversal of age-related muscle atrophy (60), enabling or facilitating daily living (53). The efficient strength training does not require special equipment and is not time demanding. Even training performed once weekly allows achieving significant muscular strength gains (28, 103).

Can cardiovascular load during strength training be hazardous?

The mechanism of cardiovascular response to resistance training exercises is complex. Arterial blood pressure (BP) rise can be produced by increase in cardiac output (CO) and/or by increased total peripheral resistance (TPR). Mechanical compression of blood vessels is also taken into account. CO increase can be caused by heart rate (HR) rise or/and stroke volume increase. In isometric exercise central command raises HR and CO by vagal withdrawal. Increase of sympathetic nervous activity, driven mainly by muscle chemoreflex, contributes to HR rise and is the main determinant of TPR (88).

The magnitude of cardiovascular response to resistance training does not depend on absolute value of resistance used, rather it depends on percentage of 1-RM, i.e. on exercise intensity related to current ability of trainee. The higher relative intensity and the greater mass of exercising muscles the greater HR and BP increases (65, 102). HR and BP increase during subsequent repetitions of a set (70, 90). In dynamic resistance training, during the concentric phase of a repetition BP but not HR is greater than during the eccentric phase (30). Stroke volume during the concentric phase does not exceed significantly resting value, however during eccentric phase it can be significantly increased. CO is not significantly changed from its resting values when small muscle mass is involved. In exercise engaging larger muscle mass CO can increase several time over resting value, being greater during eccentric phase than during concentric phase (72). The BP raise during resistance exercise can be explained by CO increase, if large muscle mass is involved. However, if muscle mass engaged is small BP raise is likely to TPR increase. The HR and BP peak values observed during single repetition of maximal resistance exercise are smaller than these observed during the last repetitions of submaximal resistance exercise (37, 67, 91). Probably, time needed to perform single repetition at maximal resistance is too short to allow for full development of cardiovascular response.

Despite the proven benefits of resistance training, its common acceptance was progressing very slowly. In general the attitude towards this form of training was very negative; Evans (28) describes it as follows: "Many health care professionals have directed their patients away from strength training in the mistaken belief that it can cause undesirable elevations in blood pressure". Indeed, during different forms of resistance training high rise of arterial pressure and heart rate was observed (36, 37, 90, 91, 93, 102). Extremely high rises were reported by MacDougall et al. (67) during the double leg-press performed by five experienced body builders. The mean peak pressure in these subjects was 320/250 mm Hg, with pressure in one subject exceeding 480/350 mm Hg.

Opinion about potential dangerous cardiac events occurring during resistance training has been supported by studies performed mainly in seventies of previous century (8, 31, 74, 80, 84), later evidences point towards relative safety of this form of training (54, 98, 99, 101, 108). Evans (28) states clearly: "With proper breathing technique, the cardiovascular stress of resistance exercise is minimal". Fleck and Kramer (38) demonstrated importance of avoiding Valsalva maneuver during resistance exercises. They showed that isometric exercise (one-legged knee extension) in which breathing was allowed elicited weaker BP response than the same exercise performed with a Valsalva maneuver. Interestingly, BP response to a Valsalva maneuver alone was greater than response to combination of isometric exercise and Valsalva maneuver.

Is opinion about minimal cardiovascular load imposed by resistance exercises justified? Rather, it will be more adequate to state, that such load is comparable with cardiovascular load imposed by acceptable and generally recommended endurance training (32, 44, 110). Faigenbaum et al. (29) observed significantly more cardiologic events (angina, ischemia, premature ventricular contractions) in 15 male cardiac patients with mean age of 52 years during maximal graded exercise than during performing maximal voluntary contraction (MVC) or during performing resistance exercise consisting of two sets of seven repetitions at 75% MVC. It has been found, that static exertion generally fails to elicit angina, ischemic ST-segment depression or threatening ventricular arrhythmia in low-risk cardiac patients (21). Moreover, it is hypothesized that superimposition of static on dynamic effort can improve myocardial oxygen supply due to elevated diastolic blood pressure, thereby lessening magnitude of ST-segment depression. Eleven patients (mean age 63 years) with stable coronary artery disease were treadmill walking either carrying no load or carrying 15 to 25 kg. Rate-pressure product value, which was accompanied by significant ST depression during walking without load, was accompanied by only minimal ST depression during walking plus carrying load (11). The relative safety of resistance training allowed it to be recommended, under assumption of appropriate prescription and supervision, for aerobically trained cardiac patients (82). Safety of resistance training has been confirmed in healthy elderly (10), and strength training has been recommended for this segment of population (2).

There exist interindividual differences in cardiovascular response to dynamic and static exertion. For instance, it has been found that in the sample of 180 healthy, young, normotensive men 21% showed an exaggerated BP response to graded bicycle ergometer exercise test due to greater cardiac output increase (79). Hypertensive subjects, especially in early stages of this disease, responded with higher BP to isometric exercise than normotensive controls (6). It has been found (110) that in some persons cardiovascular response to maximal graded exercise test was greater than such response to maximal effort Cybex knee endurance test, in others the reverse was true. Pressure rate product during Cybex exercise ranged from 58 to 102% of maximal graded exercise test values.

Doubts

Strength training can undoubtedly increase muscle strength, mass, and quality, which results in improved physical functional ability. This kind of training has been claimed to result in number of other health benefits. It: increases endurance, lowers high normal BP, reduces insulin resistance, decreases body fat, increases resting metabolic rate in elderly, prevents age-related loss of bone mineral density, reduces risk for falling, reduces pain and improves function in persons with knee region osteoarthritis. However, the magnitude of these health benefits and even their mere existence remains controversial (48).

Strength training does not significantly increases maximal oxygen consumption ($\dot{V}O_2$max) in elderly. Frontera et al. (41) found 5% increase of $\dot{V}O_2$max in older, healthy men after 12 weeks of strength training, which is much below the magnitude of expected $\dot{V}O_2$max increase after aerobic exercise. Lack of significant effect of strength training on $\dot{V}O_2$max, despite comparable HR increases, can be a result of different relations between HR and oxygen consumption, observed in strength and endurance exercises. The same increase of oxygen consumption during strength training stimulates 7-fold higher catecholamine concentration than during aerobic training. Conversely, high HR is associated with much lesser oxygen consumption during strength training than during aerobic one. In consequence, during resistance exertion despite high HR attained, oxygen consumption remains too low, to elicit adaptation of cardiovascular system of magnitude comparable with aerobic training (49).

Hickson et al. (46) found that after 10 weeks of strength training $\dot{V}O_2$max, measured on cycle ergometer increased, whereas $\dot{V}O_2$max measured on treadmill remained unchanged. This finding can be explained as follows: oxygen consumption on treadmill is limited due to limited oxygen transporting capability of the cardiovascular system. In contrast $\dot{V}O_2$max during cycling can be limited by non-cardiovascular factors, such as leg strength or leg power, therefore strength training, by increasing leg strength can bring $\dot{V}O_2$max closer to its true value.

Similar arguments can be offered to explain a significant increase in treadmill walking endurance induced by strength training, taking place despite unchanged $\dot{V}O_2$max (1).

It is doubtful whether strength training improves lipoprotein or lipid profile. In few studies such improvement has been found, other studies found no change. Surprisingly, in study comparing the effect of endurance training with the effect of strength training, significant improvement in plasma lipoprotein-lipid profiles was found in neither of these training modalities (112).

Resting BP increases with age, in consequence 50% of persons aged over 60 years qualifies as hypertensive (52). Elevated systolic BP is associated with higher mortality in men and women aged below 85 years, for men over this age the reverse hold true. (92). Whether strength training lowers BP remains controversial. Some studies demonstrated BP lowering effect of this kind of training (58, 62). It was found that strength training lowers resting BP in elderly men (but not in women) whose average values were in high normal range (68). Surprisingly, studies directly comparing aerobic vs. strength training effect on resting BP failed to detect significant difference. One study, performed on previously sedentary middle-age men showed that both training modalities did not lower resting BP (100), whereas other study performed on men and women with untreated mild hypertension showed that both these modalities caused significant and similar BP reduction (14).

Disturbing observations have been reported by Bertovic et al. (12, 20). They found increased arterial stiffness, resulting in increased pulse pressure at unchanged mean BP in 19 young, male strength-trained athletes, compared to sedentary controls. More recently similar finding has been reported by Miyachi et al. (75). They compared young and middle aged resistance-trained men with the sedentary controls and found that resistance training is associated with greater age-related reductions in central arterial compliance (measured in carotid artery) but not in peripheral artery compliance. They found also that lower central arterial compliance has been associated with left ventricular hypertrophy. They concluded, that in marked contrast to the beneficial effect of regular aerobic exercises, their findings contradict such effect of strength training on arterial wall buffering function.

Insulin resistance increases with age, resulting in lower glucose tolerance (87). It has been hypothesized that age-associated muscle loss can contribute to impaired carbohydrate metabolism. Therefore strength training induced reversal of this loss should improve carbohydrates metabolism. This hypothesis has not been confirmed. Older athletes who did not participate in training leading to muscular hypertrophy had unimpaired glucose metabolism (95), and in older athletes with training induced increased muscle mass glucose metabolism deterioration was observed (50). Also, endurance training, which did not increase muscle mass, was effective in reducing plasma insulin response to an oral glucose challenge (96). According to some studies strength training improved glucose metabolism, other studies noted no improvement, no study found deterioration of glucose metabolism. It seems that strength training induced improvements in glucose metabolism are more pronounced in men than women and that ACE genotype may play a role in individual response to this training modality (47, 89).

The depot of intra-abdominal fat increases with age, especially in men (17). Abdominal obesity increases the risk of cardiovascular disease (23). Strength training reduced abdominal obesity in older men and women (105, 106). Martel et al. (68) compared in middle-age obese men effects of diet alone and diet combined either with aerobic or strength training. All 3 groups experienced significant and similar loss of abdominal fat, with least reduction in diet alone group. Groups in which diet was combined with training preserved their muscle mass, in diet only group muscle mass was reduced. It was somehow surprising that strength training, requiring only about 30% energy needed to cover demand of aerobic training, caused minimally greater fat loss. One explanation could be increased resting metabolic rate, due to increased muscle mass (107) or due to increased resting sympathetic activity (83). Differences in sympathetic system activity between man and women could explain lack of strength training induced resting metabolic rate increase in women (83).

Recently safety of hormone replacement therapy in menopausal and post-menopausal women has been seriously questioned (25). Osteoporosis prevention by non-hormonal means such as physical activity would be welcome alternative. Better correlation between muscular strength and bone mineral density (BMD) than between $\dot{V}O_2max$ and BMD was reported (13), which suggest preferential role of strength rather than endurance training in osteoporosis prevention (56, 57). However, studies concerned with this problem yielded conflicted results, ranging from observations that strength training increases BMD, through being ineffective in this respect, up to causing BMD decline. At any rate, observed BMD increase due to any exercise modality applied did not exceeded 5%, which falls far from estimated 20% BMD increase, required to prevent bone fracture resulting from fall (18). However, even modest BMD gains attained as result of strength training compare favorably with slowly progressing BMD decline in sedentary controls. Strength training improves mechanics and walking speed, thus reducing risk of fall, rather than prevents fractures, once fall had occurred (35).

It has been demonstrated that strength training (94) to similar degree as endurance training (26, 97) decreases joint pain and stiffness in patients with osteoarthritis, therefore it seems justified to include muscle strengthening exercises in a physical activity program for patients with severe osteoarthritis (86, 73).

Flexibility or joint range of motion decreases with age, what can be associated with difficulty in climbing stairs, getting up from chair or in unassisted walking (9). It seems that strength training reduces flexibility. Such conclusion stems from observation (43) that combined flexibility and strength training did not improve flexibility, whereas flexibility training alone did. It seems therefore, that strength training should be supplemented with enhanced flexibility training (2).

Conclusions

Properly performed strength training reverses age-related loss of muscle strength and mass. Cardiovascular system strain is of similar magnitude during resistance and endurance exercises. Strength training does not leads to: worsening of lipid profile, impaired glucose tolerance, rise of resting blood pressure, decline of bone mineral density, increase of abdominal fat, decline of basal metabolic rate, and in each of these aspects can be beneficial. It seems to reduce symptoms of osteoarthritis in the knee. Evidence suggests that strength training can worsen flexibility and increase stiffness of arteries.

References

1. Ades P., Ballor D., Ashikaga T. et al. Weight training improves walking endurance in healthy elderly persons. Ann. Intern. Med. 124: 568-572, 1996.
2. American College of Sports Medicine Position Stand. Exercise and physical activity for older adults. Med. Sci. Sports Exerc. 30: 992, 1998.
3. American College of Sports Medicine. The recommended quantity and quality of exercise for developing and maintaining cardiorespiratory and muscular fitness, and flexibility in healthy adults. Med. Sci. Sports Exerc. 30: 975, 1998.
4. American College of Sports Medicine Position Stand on Progression Models in Resistance Training for Healthy Adults. Med. Sci. Sports Exerc. 34: 364-380, 2002.
5. Aniansson A., Zetterberg C., Hedberg M., Henriksson K.G. Impaired muscle function with aging. A background factor in the incidence of fractures of the proximal end of femur. Clin. Orthop. 191: 193-201, 1984.
6. Aoki K., Sato K., Kondo S. et al. Increased response of blood pressure to rest and handgrip in subjects with essential hypertension. Jpn. Circ. J. 47: 802-809, 1983.
7. Atha J. Strengthening muscles. Exerc. Sport Sci. Rev. 9: 1-73, 1981.

8. Atkins J.M., Matthews O.A., Blomqvist C.G., Mullins C.B. Incidence of arrhythmias induced by isometric and dynamic exercise. Br. Heart J. 38: 465-71, 1976.
9. Bergstrom G., Aniansson A. Functional consequences of joint impairment at age 79. Scand. J. Rehabil. Med. 17: 183-190, 1985.
10. Bermon S., Rama D., Dolisi C. Cardiovascular tolerance of healthy elderly subjects to weight-lifting exercises. Med. Sci. Sports Exerc. 32: 1845-1848, 2000.
11. Bertagnoli K., Hanson P., Ward A. Attenuation of exercise-induced ST depression during combined isometric and dynamic exercise in coronary artery disease. Am. J. Cardiol. 65: 314-317, 1990.
12. Bertovic D.A., Waddell T.K., Gatzka C.D. et al. Muscular strength training is associated with low arterial compliance and high pulse pressure. Hypertension 33: 1385-1391, 1999.
13. Bevier W., Wiswell R., Pyka G. et al. Relationship of body composition, muscle strength, and aerobic capacity to bone minral density in older men and women. J. Bone Miner. Res. 4: 421-432, 1989.
14. Blumenthal J., Siegel W., Appelbaum M. et al. Failure of exercise to reduce blood pressure in patients with mild hypertension. JAMA 266: 2098 -2101, 1991.
15. Campbell A.J., Borrie M.J., Spears G.F. Risk factors for falls in a community-based prospective study of people 70 years and older. J. Gerontol. 44: M112-M117, 1989.
16. Charette S.L., McEvoy L., Pyka G. et al. Muscle hypertrophy response to resistance training in older women. J. Appl. Physiol. 70: 1912-1916, 1991.
17. Cohn S., Vaswani A., Zanzid I. et al. Changes in body chemical composition with age measured by total-body neutron activation. Am. J. Physiol 25: 85-95, 1976.
18. Courtney A., Wachtel E., Myers E. et al. Effects of loading rate on strength of the proximal femur. Calcif. Tissue Int. 55: 53-58, 1994.
19. Danneskiold-Samsoe B., Kofod V., Munter J. et al. Muscle strength and functional capacity in 78-81 year old men and women. Eur. J. Appl. Physiol. Occup. Physiol. 52: 310-314, 1984.
20. Dart A.M., Kingwell B.A. Pulse pressure-a review of mechanisms and clinical relevance. J. Am. Coll. Cardiol. 37: 975-984, 2001.
21. DeBusk RF, Valdez R., Houston N., Haskell W. Cardiovascular responses to dynamic and static effort after myocardial infarction. Application to occupational work assessment. Circulation 58: 368-375, 1978.
22. Doherty T.J., Vandervoort A.A., Taylor A.W., Brown W.F. Effects of motor unit losses on strength in older men and women. J. Appl. Physiol. 74: 868-874, 1993.
23. Donahue R., Abbort R., Bloom E. et al. Central obesity and coronary heart disease in men. Lancet 1: 822-824, 1987
24. Dutta C., Hadley E.C. The significance of sarcopenia in old age. J. Gerontol. A. Biol. Sci. Med Sci. 50: 1-4, 1995.
25. Enserink M. Women's health: The vanishing promises of hormone replacement. Science 297: 325, 2002.
26. Ettinger W.J., Burns R., Messier S. et al. A randomized trial comparing aerobic exercise and resistance exercise with a heath education program in older adults with the knee osteoarthritis. JAMA 277: 25-31, 1997.
27. Evans W.J., Campbell W.W. Sarcopenia and age-related changes in body composition and functional capacity. J. Nutr. 123: 465-468, 1993.
28. Evans W.J. Exercise training guidelines for the elderly. Med. Sci. Sports Exerc. 31: 12-17, 1999.
29. Faigenbaum A.D., Skrinar G.S., Cesare W.F. et al. Physiological and symptomatic responses of cardiac patients to resistance exercise. Arch. Phys. Med. Rehabil. 71: 395-398, 1990.
30. Falkel J.E., Fleck S.J., Murray T.F. Comparison of central hemodynamics between powerlifters and body builders during resistance training. J. Appl. Sport Sci. Res. 6: 24-35, 1992.
31. Fardy P. Isometric exercise and the cardiovascular system. Phys. Sports Med. 9: 43-56, 1981.
32. Featherstone J.F., Holly R.G., Amsterdam E.A. Physiologic response to weight training in coronary artery disease. Am. J. Cardiol. 71: 287-292, 1993.
33. Feigenbaum M.S., Pollock M.L. Prescription of resistance training for health and disease. Med. Sci. Sports Exerc. 31, 38, 1999.
34. Fiatarone M.A., Marks E.C., Ryan N.D. et al. High-intensity strength training in nonagenarians. Effects on skeletal muscle. J. Am. Med. Assoc. 263: 3029-3034, 1990.
35. Fiatarone M., O'Neil E., Ryan N. et al. Exercise training and nutritional supplementation for physical frailty in very elderly people. N. Engl. J. Med. 330: 1769-1775, 1994.
36. Fleck S.J., Dean L.S. Influence of weight training experience on blood pressure response to exercise. Med. Sci. Sport Exerc. 17: 185, 1985.
37. Fleck S.J., Dean L.S. Resistance-training experience and the pressor response during resistance training. J. Appl. Physiol. 63: 116-120, 1987.
38. Fleck S.J., Kraemer W.J. *Designing resistance training programs*. Human Kinetics, Champaign, IL, 1997.
39. Frontera W.R., Hughes V.A., Lutz K.J., Evans W.J. A cross-sectional study of muscle strength and mass in 45- to 78-year-old men and women. J. Appl. Physiol. 71: 644-650, 1991.

40. Frontera W.R., Meredith C.N., O'Reilly K.P. et al. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. J. Appl. Physiol. 64: 1038-1044, 1988.
41. Frontera W.R., Meredith C.N., O'Reilly K.P. et al. Strength training and determinants of VO_{2max} in older men. J. Appl. Physiol. 68: 329-333, 1990.
42. Fry A.C., Allemeier C.A., Staron R.S. Correlation between percentage fiber type area and myosin heavy chain content in human skeletal muscle. Eur. J. Appl. Physiol. Occup. Physiol. 68: 246-251, 1994.
43. Girouard C., Hurley B. Does strength training inhibit gains in range of motion from flexibility training in older adults? Med. Sci. Sports Exerc. 27: 1444-1449, 1995.
44. Green D.J., Watts K., Maiorana A.J., O'Driscoll J.G. A comparison of ambulatory oxygen consumption during circuit training and aerobic exercise in patients with chronic heart failure. J. Cardiopulm. Rehabil. 21: 167-174, 2001.
45. Harries U.J., Bassey E.J. Torque-velocity relationship for the knee extensors in women in their 3rd and 7th decades. Eur. J. Appl. Physiol. Occup. Physiol. 60: 187-190, 1990.
46. Hickson R., Rosenkoetter M., Brown M. Strength training effects on aerobic power and short-term endurance. Med. Sci. Sports Exerc. 12: 336-339, 1980.
47. Hurlbut D.E., Lott M.E., Ryan A.S. et al. Does age, sex, or ACE genotype affect glucose and insulin responses to strenth training? J. Appl. Physiol. 92: 643-650, 2002.
48. Hurley B.F., Roth S.M. Strength training in the elderly: effects on risk factors for age-related diseases. Sports Med. 30: 249-268, 2000.
49. Hurley B.F., Seals D., Ehsani A. et al. Effects of high intensity strength training on cardiovascular function. Med. Sci. Sports Exerc. 16: 483-488, 1984.
50. Hurley B.F., Hagberg J., Seals D. et al. Glucose tolerance and lipid-lipoprotein levels in middle-aged powerlifters. Clin. Physiol. 7: 11-19, 1987.
51. Imamura K., Ashida H., Ishikawa T., Fuji M. Human major psoas muscle and sacrospinalis muscle in relation to age: a study by computed tomography. J. Gerontol. 38: 678-681, 1983.
52. Kaplan N. *Clinical hypertension*. Williams and Wilkins, Baltimore, MD, 1990.
53. Karani R., McLaughlin M.A., Cassel C.K. Exercise in the healthy older adult. Am. J. Geriatr. Cardiol. 10: 269-273, 2001.
54. Keleman M.H., Stewart K.J., Gillilan R.E. et al. Circuit weight training in cardiac patients. J. Am. Coll. Cardiol. 7: 38-42, 1986.
55. Kell R.T., Bell G., Quinney A. Musculoskeletal fitness, health outcomes and quality of life. Sports Med. 31: 863-873, 2001.
56. Kelley G.A., Kelley K.S., Tran Z.V. Resistance training and bone mineral density in women: a meta-analysis of controlled trials. Am. J. Phys. Med. Rehabil. 80: 65-77, 2001.
57. 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. 16: 175-181, 2001.
58. Kokkinos P.F., Narayan P., Papademetriou V. Exercise as hypertension therapy. Cardiol. Clin. 19: 507-516, 2001.
59. Larsson L. Morphological and functional characteristics of the ageing skeletal muscle in man. A cross-sectional study. Acta Physiol. Scand. 457: S1-S36, 1978.
60. Larsson L. Physical training effects on muscle morphology in sedentary males at different ages. Med. Sci. Sports Exerc. 14: 203-206, 1982.
61. Lemmer J.T., Harlbut D.E., Martel G.F. et al. Age and gender responses to strength training and detraining. Med. Sci. Sports Exerc. 32: 1505-1512, 2000.
62. Lesniak K.T., Dubbert P.M. Exercise and hypertension. Curr. Opin. Cardiol. 16: 356-359, 2001.
63. Lexell J., Henriksson-Larsen K., Winblad B., Sjostrom M. Distribution of different fiber types in human skeletal muscles: effects of aging studied in whole muscle cross section. Muscle Nerve 6: 588-595, 1983.
64. Lexell J. Human aging, muscle mass, and fiber type composition. J. Gerontol. A. Biol. Sci. Med Sci. 50: 11-16, 1995.
65. Lind. AR McNicol GW Muscular factors which determine the cardiovascular responses to sustained and rhythmic exercise. Can. Med. Assoc. J. 96: 706-715, 1967.
66. Lynch N.A., Metter E.J., Lindle R.S. et al. Muscle quality. I. Age-associated differences arm and leg muscle groups. J. Appl. Physiol. 86: 188-194, 1999.
67. MacDougall J.D., Tuxen D., Sale D.G. et al. Arterial blood pressure response to heavy resistance exercise. J. Appl. Physiol. 58: 785-790, 1985.
68. Martel G.F., Hurlbut M.S., Lott M.E. 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. 47: 1215-1221, 1999.
69. Mazzeo R.S., Tanaka H. Exercise prescription for the elderly. Current recommendations. Sports Med. 31: 809-818, 2001.
70. McCartney N., McKelvie R.S., Martin J. et al. Weight-training-induced attenuation of the circulatory response of the older males to weight lifting. J. Appl. Physiol. 74: 1056-1060, 1993.
71. Metter E.J., Conwit R., Tobin J., Fozard J.L. Age-associated loss of power and strength in

the upper extremities in women and men. J. Gerontol. A. Biol. Sci. Med. Sci. 52: B267-B276, 1997.
72. Miles D.S., Owens J.J., Golden J.C., Gotshall R.W. Central and peripheral hemodynamics during maximal leg extension exercise. Eur. J. Appl. Physiol. Occup. Physiol. 56: 12-17, 1987.
73. Minor M.A. Exercise in the treatment of osteoarthritis. Rheum Dis Clin North Am 25: 397-415, 1999.
74. Mitchell J.H., Wildenthal K. Static (isometric) exercise and the heart: physiological and clinical considerations. Annu. Rev. Med. 25: 369-381, 1974.
75. Miyachi M., Donato J., Yamamoto K., Takahashi K., Gates P.E., Moreau K.l., Tanaka H. Greater age-related reductions in central arterial compliance in resistance-trained men. Hypertension 41: 130-135, 2003.
76. Morganti C.M., Nelson M.E., Fiatarone M.A. et al. Strength improvements with 1 yr. of progressive resistance training in older women. Med. Sci. Sports Exerc. 27: 906-912, 1995.
77. Moritani T., deVries H.A. Potential for gross muscle hypertrophy in older men. J. Gerontol. 35: 672-682, 1980.
78. Murray M.P., Duthie E.H., Gambert S.T. et al. Age-related differences in knee muscle strength in normal women. J. Gerontol. 40: 275-280, 1985.
79. Nazar K. Kaciuba-Uscilko H., Ziemba A. et al. Physiological characteristics and hormonal profile of young normotensive men with exaggerated blood pressure response to exercise. Clin. Physiol. 17: 1-18, 1997.
80. Nutter D.O., Schlant R.C., Hurst J.W. Isometric exercise and the cardiovascular system. Mod. Concepts Cardiovasc. Dis. 41: 11-15, 1972.
81. Overend T.J., Cunningham D.A., Paterson D.H., Lefcoe M.S. Thigh composition in young and elderly men determined by computed tomography. Clin. Physiol. 12: 629-640, 1992.
82. Pollock M.L., Franklin B.A., Balady G.J. et al. 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. Circulation 101: 828-833, 2000.
83. 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. 76: 133-137, 1994.
84. Quinones M.A., Gaasch W.H., Waisser E. et al. An analysis of left ventricular response to isometric exercise. Am. Heart J. 88: 29-36, 1974.
85. Rogers M.A., Evans W.J. Changes in skeletal muscle with aging: Effects of exercise training. In: Holloszy J.O. (Ed.) *Exercise and sport sciences reviews*. Vol. 21, Williams and Wilkins, Baltimore, 1993.
86. Rogind H, Bibow-Nielson B., Jensen B. et al. The effects of a physical training program on patients with osteoarthritis of the knees. Arch. Phys. Med. Rehabil. 79: 1421-1427, 1998.
87. Rowe J., Minaker K., Palotta J. et al. Characterization of the insulin resistance of aging. J. Clin. Invest. 71: 1581-1587, 1983.
88. Rowell L.B., O'Leary D.S. Reflex control of the circulation during exercise: chemoreflexes and mechanoreflexes. J. Appl. Physiol. 69: 407-418, 1990.
89. Ryan A.S Hurlbut D.E., Lott M.E. et al. Insulin action after resistive training in insulin resistant older men and women. J. Am. Geriatr. Soc. 49: 247-253, 2001.
90. Sale D.G., Moroz D.E., McKelvie R.S. et al. Comparison of blood pressure response to isokinetic and weight-lifting exercise. Eur. J. Appl. Physiol. Occup. Physiol. 67: 115-120, 1993.
91. Sale D.G., Moroz D.E., McKelvie R.S. et al. Effect of training on the blood pressure response to weight lifting. Can. J. Appl. Physiol. 19: 60-74, 1994.
92. Satish S., Freeman D.H. Jr., Goodwin J.S. The relationship between blood pressure and mortality in the oldest old. J. Am. Geriatr. Soc. 49: 367-374, 2001.
93. Scharf H.P., Eckhardt R., Maurus M., Puhl W. Metabolic and hemodynamic changes during isokinetic muscle training. A controlled clinical trial. Int. J. Sports Med. 15: S56-S59, 1994.
94. Schilke J.M., Johnson G.O., Housh T.J. et al. Effects of muscule-strength training on the functional status of patients with ostearthritis of the knee joint. Nurs. Res. 45: 68-72, 1996.
95. Seals D., Hagberg J., Allen W. et al. Glucose tolerance in young and older athletes and sedentary men. J. Appl. Physiol. 56: 1521-1525, 1984.
96. Seals D., Hagberg J., Hurley B.F. et al. Effects of endurance training on glucose tolerance and plasma lipid levels in older men and women. JAMA 252: 645-649, 1984.
97. Sevick M.A., Bradham D.D., Muender M. et al. Cost-effectiveness of aerobic and resistance exercise in seniors with knee osteoarthritis. Med Sci. Sports Exerc. 32: 1534-1540, 2000.
98. Sheldahl L.M., Wilke N.A., Tristani F.E., Kalbfleisch J.H. Response of patients after myocardial infarction to carrying a graded series of weight loads. Am. J. Cardiol. 52: 698-703, 1983.
99. Sheldahl L.M., Wilke N.A., Tristani F.E., Kalbfleisch J.H. Response to repetitive static-dynamic exercise in patients with coronary artery disease. J. Cardiac Rehabil. 5: 139-145, 1985.

100. Smutok M., Reece C., Kokkinos P. et al. Aerobic vs strength training for risk factor intervention in middle-aged men at high risk for coronary heart disease. Metabolism 42: 177-184, 1993.
101. Sparling P.B., Cantwell J.D. Strength training guidelines for cardiac patients. Phys. Sports Med. 17: 190-196, 1989.
102. Stone M.H., Fleck S.J., Triplett N.R., Kraemer W.J. Health- and performance-related potential of resistance training. Sports Med. 11: 210-231, 1991.
103. Taaffe D.R., Duret C., Wheeler S., Marcus R. Once-weekly resistance exercise improves muscle strength and neuromuscular performance in older adults. J. Am. Geriatr. Soc. 47: 1208-1214, 1999.
104. Tracy B.L., Ivey F.M., Hurlbut D. et al. Muscle quality. II. Effects of strength training in 65- to 75-yr-old men and women. J. Appl. Physiol. 86: 195-201, 1999.
105. Treuth M., Ryan A., Pratley R. et al. Effects of strength training on total and regional body composition in older men. J. Appl. Physiol. 77: 614-620, 1994.
106. Treuth M., Hunter G., Kekes-Szabo T. et al. Reduction in intra-abdominal adipose tissue after strength training in older women. J. Appl. Physiol. 78: 1425-1431, 1995.
107. Treuth M., Hunter G., Weinsier R. et al. Energy expenditure and substrate utilization in older women after strength training: 24-h calorimeter results. J. Appl. Physiol. 78: 2140-2146, 1995.
108. Vander L.B., Franklin B.A., Wrisley D., Rubenfire M. Acute cardiovascular responses to Nautilus exercise in cardiac patients: implications for exercise training. Ann. Sports Med. 2: 165-169, 1986.
109. Vincent K.R., Braith R.W. Resistance exercise and bone turnover in elderly men and women. Med. Sci. Sports Exerc. 34: 17-23, 2002.
110. Vinson S., Lindsay B., Mettler P., Murray T. Cardiovascular response to isokinetic endurance exercise testing. J. Sports Med. Phys. Fitness 30: 93-96, 1990.
111. Wolinsky F.D., Fitzgerald J.E. Subsequent hip fracture among older adults. Am. J. Public Health 84: 1316-1318, 1994.
112. Wosornu D., Bedford D., Ballantyne D. A comparison of the effects of strength and aerobic exercise training on exercise capacity and lipids after coronary artery bypass surgery. Eur. Heart J. 17: 815-817, 1996.
113. Young A., Stokes M., Crowe M. Size and strength of the quadriceps muscles of old and young women. Eur. J. Clin. Invest. 14: 282-287, 1984.
114. Young A., Stokes M., Crowe M. The size and strength of the quadriceps muscles of old and young men. Clin. Physiol. 5: 145-154, 1985.

Received: September 12, 2003
Accepted: November 17, 2003

Address for correspondence:
Wiktor Niewiadomski Ph.D.
Polish Academy of Sciences
Pawinskiego 5
02-106 Warsaw
Poland
Phone: (48-22) 60-86-501
E-mail: wiktorn@cmdik.pan.pl