REHABILITATION MEDICINE *Adding Life to Years*

Effect of Exercise on Muscle Function Decline With Aging

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As people age, changes in muscle occur that are associated with a decrease in strength and endurance. These changes result in decreased functional capacity and quality of life. A substantial portion of this decrease is the result not of aging but of the sedentary life-style so frequently associated with aging. In "healthy old" persons and in older animals in experiments, an appropriate exercise program can result in increased strength and endurance. This is true both in longitudinal and short-term studies. As physical impairment increases, the exercise program must be individualized, and results are not as readily predictable. Much work remains before we may be certain how much exercise can be tolerated in these more impaired persons and what the effects may be.

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Life expectancy at birth has been steadily increasing from 25 years 2,000 years ago to 49 years in 1900 and to about 75 years now. Longevity trends suggest a finite limit to the human life span of about 85 years.[1] In addition to life-expectancy changes, changes have occurred in work patterns. The percentage of our population older than 65 years that continues to work is shrinking. In 1900, 75% of people older than 65 continued to work; this fell to 45% in 1950 and to only 10% in 1970.

The time period from retirement from employment, responsibilities, and economic activities to serious functional impairment can now reach 10 to 20 years. There has been a progressive increase in the period of possible serious functional impairment. The natural life span cannot be our only consideration. More important is our active life expectancy.[2] The ability to be independent largely determines the quality of our lives. Therefore, although many systems are important in determining functional status, the cardiovascular and neuromusculoskeletal systems play key roles.

Millennia ago, the combination of a relatively short life span and compassionate and protective attitudes toward the older population made a passive role by older persons acceptable. With the increase in the number and age of older nonworking persons, the rapidity of technologic change, and the weakening of kinship ties, older persons are now responsible for maintaining their independence.

The role of exercise in the life-style of young adults has been recognized by Western civilization for more than 2,500 years. The possible benefits of exercise in prolonging the independence of older persons have only recently been more widely addressed. Almost all organ systems show anatomic and physiologic changes with aging—changes that may be the specific result of aging but which also may represent illness or inactivity associated with aging. In this short discussion I will address primarily the cardiovascular and neuromuscular systems, note changes with aging, and examine the effects of exercise on these two systems in older animals or humans. The important issues of exercise and cardiac rehabilitation as well as exercise and osteoporosis will not be addressed.

Changes With Aging

Manifestations of aging appear in all systems and tissues. Biopsy studies of muscle in persons between ages 60 and 90 and older show evidence of both neuropathic and myopathic changes.[3] Frequent findings include group atrophy and type II atrophy, with a decrease in type II fiber diameter from 49 to 22 microns. Electron-microscopic study may show disorganization of sarcomere structure, aggregation and deformity of muscle nuclei, an increased number of mitochondria, abnormalities of satellite cells, moderate thickening of capillary basement membrane, and a decrease in and thickening of subsynaptic folds of the motor end plates. Aniansson and coworkers, in a single biopsy specimen of the right vastus lateralis, found fewer anatomic changes.[4]

In older persons the percentage of body fat increases; muscle mass, normally 46%, may decrease to 35%[5]; and urinary creatinine levels may fall. Muscle force decreases significantly,[6] and grip strength decreases.[7] After age 74, 28% of men and 66% of women may not be able to lift objects weighing more than 4.5 kg.[8] Although the diaphragm shows fewer morphologic changes than other striated muscle, inspiratory and expiratory pressures do decrease with age, the decrease being greater for the former.[9]

In aging rats, the weight of soleus and plantar muscles is decreased, rates of contraction and relaxation are slowed, and maximal twitch and tetanus tension are decreased.

With aging there is a decrease in the functional capacity of the cardiovascular system, with a decrease in the maximal oxygen uptake capacity ($\dot{V}o_{2max}$).[5,10] This decrease proceeds at a rate of about 10% per decade and may be due to a decrease in maximal heart rate and stroke volume or a decrease in oxygen extraction by the contracting muscle, with a lower maximal arteriovenous oxygen difference. Needle biopsy of the vastus lateralis shows a decrease of resting muscle oxidative capacity of 41% in older persons.[5] In older per-

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ABBREVIATIONS USED IN TEXT

ATPase = adenosine triphosphatase
$\dot{V}E$ = expired volume per unit of time
$\dot{V}O_2$ = oxygen consumption per unit of time
$\dot{V}O_{2max}$ = maximal oxygen consumption

sons, maximal ventilation ($\dot{V}E$) decreases, the ventilatory equivalent ($\dot{V}E/\dot{V}O_2$) increases substantially,[11] and there is a decrease in the expiratory flow rate, the forced expiratory volume in one second, and maximal voluntary ventilation.[12] In rats, myocardial mechanical performance decreases with age with a slowing in the velocity of muscle shortening, associated with a shift in the myosin isozyme form from the V_1 to the V_3 isozyme and a decline in the calcium-activated actomyosin adenosine triphosphatase (ATPase) activity.

Muscle strength and endurance, two aspects of muscle function, play important roles in the functional capacity of older persons. We will consider only these issues. Strength represents the maximal force or tension that can be developed by a muscle, measured in terms of pounds, kilograms, grams, or dynes. When a rotatory force (torque) is measured, the units may be foot-pounds or kilogram-meters. Strength may be measured with maximal isometric contractions (using strain gauge or isokinetic techniques at zero velocity) or approximated by noting the maximal weight that can be lifted in a single contraction. The five- or ten-repetition maximum introduces elements of work capacity and is less precise. The most reliable predictor of force development in muscle, though not the only one, is the cross-sectional area of the contracting unit, whether it be actomyosin threads, isolated glycerinated muscle fibers, isolated muscle in animal studies, or human kineplasty. The force developed is of the order of 30 to 40 grams per mm^2.

Exercise designed to increase strength emphasizes high force development (high-resistance exercise), relatively short durations of exercise (30 or fewer contractions at a rate of 10 per minute), and, if possible, repetition of this cycle a few times a day. In general, fatigue is not part of this process. Increased strength can usually be demonstrated early, with a plateau reached within four to eight weeks. During the early phase of this increase in strength, changes are presumed to be due to neurogenic factors, although it is possible that there may be shifts in extracellular fluid that mask changes in cross-sectional areas of muscle. Somewhat later, increases in cross-sectional muscle areas can be detected by computed tomography or circumferential measurements.

Endurance is measured by the work capacity of a single muscle or of the whole body when many muscles are active. This is measured as work performed—force times distance (foot-pounds, kilogram-meters)—or maximal aerobic capacity ($\dot{V}O_{2max}$: liters O_2 per minute, ml O_2 per kilogram per minute). With regard to a single muscle, the time it takes for force exerted to be decreased to 50% of the initial force, or the time that is required for muscle contraction to cease completely, could be measured. Maximal aerobic capacity may be measured with the subject on a treadmill, progressively increasing the velocity and grade until oxygen consumption per unit of time plateaus. Unlike strength, which depends primarily on the cross-sectional area of muscle and neurogenic factors, endurance depends on the ability to transport oxygen to active muscles (cardiovascular factors) and the ability of muscle to use the oxygen supplied (intrinsic muscular biochemical factors). Unlike training to increase strength, exercise to increase endurance requires sessions that are relatively long (30 to 40 minutes), repeated at least three times a week, and intense enough to raise oxygen consumption or heart rate to 60% or more of the maximum.

In general, improvement in a specific test is greatest when training provides an experience similar to that which is tested. This concept of specificity is not rigid, for it has also been shown that training in strength, for example, may also produce an improvement in endurance, though to a lesser degree.[13]

Effects of Exercise

In experiments in animals, controlled daily exercise may be associated with an increase in mean life span. A long-term exercise program in rats, beginning at three months, results in increased cardiac performance, total oxygen consumption, and oxidative capacity of skeletal muscle but does not change actomyosin ATPase activity or shift cardiac V_1 myosin isozyme composition significantly. The shift from V_1 to V_3 isozymes, characteristic of aging, is not altered.

Short-term studies in animals also have shown that older animals can respond favorably to exercise programs. Exercise can increase the plasma concentration of high-density lipoprotein cholesterol. In old rats trained at a level of 75% maximal capacity five times a week for ten weeks, the plasma triglyceride levels were lower than in old untrained rats and the acetyl-CoA carboxylase level (rate limiting in fatty acid synthesis) was higher than in old and young untrained rats but lower than in young trained rats.

The contraction time of slow- and fast-twitch muscle increases with age. In older rats, strength training increases soleus and plantar weight and swim training increases the heart weight. Strength training increases the rate of contraction and relaxation and the maximal twitch and tetanus tension in the soleus muscle. Strength training also increases the maximal twitch and tetanus tension in the plantar muscle.[14] There is a selective decrease in type II fibers with aging and a selective decrease in slow- and fast-twitch fibers in the soleus. Swim exercises, unlike strength exercises, increase aerobic capacity with increases in citrate synthase in the soleus and plantar muscles. Both strength and swim exercises increase hexokinase. Strength training, but not swimming, increases creatine phosphate and adenosine triphosphate levels.[15]

Rats were trained in a swimming program up to one hour a day five days a week for three months. In programs beginning at 1, 6, or 12 months of age, there was an increase in actomyosin ATPase levels. In programs begun at 6 months of age, there was an increase in creatine kinase levels. In programs begun at 17 to 22 months, there was a decrease in ATPase levels and a considerable decrease in creatine kinase concentrations, suggesting that there was a threshold age for strenuous exercise in rats.[16]

Improved mental health, feelings of relaxation, and decreased tension have been reported frequently as consequences of exercise. A lower incidence of cardiovascular disease after a regular program of physical activity has been noted,[17] and a higher incidence of fatal myocardial infarction has been reported in workers with low levels of physical activity. In a large study of Harvard alumni, an active lifestyle was associated with an increased life expectancy.[18]

In 37 men evaluated 31 years after the initial study, there was a decrease in $\dot{V}O_{2max}$ levels, an increase in $\dot{V}E/\dot{V}O_2$ with maximal work, a gradual decrease in the oxygen pulse (ml O_2 per beat), and a decrease in the maximal heart rate. There was a major difference in one subgroup during the last nine-year examination. This group, which increased its participation in sports—including squash, tennis, and skiing—showed an increase in $\dot{V}O_{2max}$ levels, an almost steady $\dot{V}E/\dot{V}O_2$, and an increase in oxygen pulse, manifesting an improvement in fitness and work capacity because of the change in exercise habits.[11] Champion middle-distance runners and nonathletes showed declines in $\dot{V}O_{2max}$ values and an increase in the $\dot{V}E/\dot{V}O_2$ after 30 years. In the middle-distance runners, the decrease in $\dot{V}O_{2max}$ was considerably less, the increase in $\dot{V}E/\dot{V}O_2$ was significantly smaller, and the blood lactate levels and heart rate were lower on walking.[19] Lung volumes and pulmonary function values may be 10% to 15% higher and the $\dot{V}O_{2max}$ 35% higher in older former athletes than in sedentary older persons.

Regular vigorous endurance exercise slows the $\dot{V}O_{2max}$ decline to about 5% per decade. Over an eight-year period, the $\dot{V}O_{2max}$ in former master athletes who continued physical activity decreased approximately 4.1%, but in sedentary controls the decrease was 9.7%.[10] The decrease in the $\dot{V}O_{2max}$ was presumably due to a decrease in the stroke volume or a decrease in oxygen extraction by muscle, or both. In an older group trained at an exercise level of 70% of $\dot{V}O_{2max}$ for an hour, the $\dot{V}O_2$ (milliliters per kilogram per minute) was greater than in older sedentary subjects, almost the same as in young sedentary subjects, but 24% less than in young trained subjects. The same pattern existed with respect to the $\dot{V}E$. Both trained groups had a greater increase in blood glycerol concentrations and showed an increase in the rate of lipolysis. The physiologic responses of the older trained persons were similar to those of the younger trained ones. Older healthy men could participate in an endurance type training program that was appropriate in intensity and duration for their age.[20]

Effects of Exercise—Short Term, Human

Generally favorable results following exercise have also been reported in "healthy older persons." Persons older than 60 exercising 30 minutes three times a week for 16 weeks at 70% of their $\dot{V}O_{2max}$ had a significant increase in maximal oxygen uptake. After a 4-month period, those who took their stationary bicycles home for continued exercise maintained this increase at 12 months. Those who were encouraged to exercise but did not take bicycles home did not show the increase in maximal oxygen uptake at one year. In addition to the change in $\dot{V}O_{2max}$, in those who exercised a new cardiac condition occurred in only 2.4%, but in a nonexercising group such a new condition occurred in 12.9%.[17]

In older subjects with an average age of 65 years, exercising for 45 minutes at 75% of heart rate reserve three times a week for 12 weeks resulted in an increase in muscle glycogen (needle biopsy of the vastus lateralis), though the levels were still lower than in younger subjects. The oxidative capacity of muscle, $\dot{V}O_{2max}$, and maximal ventilation were all substantially lower at baseline in the older subjects, but all increased considerably with the training program. There was evidence of peripheral adaptation.[17] Subjects aged 70 to 79 who exercised for 35 to 45 minutes three times a week for 26 weeks at levels beginning at 50% of $\dot{V}O_{2max}$ and reaching 75% to 85% of maximal heart rate were compared with others who exercised for about 30 minutes three times a week on a Nautilus apparatus.[6] The $\dot{V}O_{2max}$ values increased 22% in the endurance group and 4% in the strength-building group. The oxygen pulse increased 17% in the endurance group but did not change in the strength-building group. Lower body strength increased 5% in the endurance group and 9% in the strength group. Upper body strength decreased 6% in the endurance group and increased 18% in the strength group.

Women aged 63 to 88 (mean of 71) exercised three times a week for 25 weeks. A period of 10 minutes was devoted to aerobic exercise at 65% of maximal heart rate and 25 to 30 minutes in strength and flexibility exercise. Some women had small weights attached to their wrists and ankles, and others had no weights. A third group did not exercise. The two exercising groups had a significant increase in strength of shoulder internal and external rotators, elbow extensors (17%), and knee flexors (11%) compared with controls.[21] Range of motion increased significantly in shoulder flexion and abduction, in ankle plantar flexion, and in cervical rotation.

In sedentary men aged 60 to 72, training on a thigh-knee dynamic machine at 80% of one repetitive motion three times a week for 12 weeks produced an increase in dynamic strength (1 RM) of more than 100% in knee extensors and more than 200% in knee flexors. Static strength, with the knee flexed to 30 degrees, increased approximately 10% to 15%, and strength increase at 60 degrees per second was only about 10%. The increase in area, measured by computed tomography, was approximately 10% after six weeks. The area of type I fibers increased 33.5% and of type II fibers 27.6%. The distribution of fiber type did not change. Presumably there was a neural adaptation to specific training.[8]

Subjects aged 65 to 75 trained in a program stressing maximal sustained ventilatory capacity for eight weeks at least four days a week, with two 15-minute sessions a day, had an increase in ventilatory muscle endurance of approximately 20% and in maximal voluntary ventilation of 17%. The forced expiratory volume in one second did not change. Two months later, the improvement in ventilatory function was retained.[12]

There are fewer controlled studies on "nonhealthy older persons" who either have significant chronic disease or reside in nursing homes. Nursing home subjects, excluding those with serious cardiac disease or cognitive dysfunction, were trained at 80% of maximal heart rate three times a week for a year. The goal was to have a 15-minute program every day, but only 5 to 10 minutes per day was possible. There was little effect on overall endurance and possibly some small training effect in the arms. Problems with lower extremity disorders and intercurrent illnesses frequently intruded.[22]

A total of 49 chronically ill patients older than 64 exercised for 90 minutes three times a week for four months. They spent 10 to 15 minutes on stationary bicycles at 65% of maximal heart rate reserve and 20 minutes on strength and stretch exercises for low back and abdominal muscles. Of the 49 patients, 15 (31%) had 30 minutes of aerobic exercise in water once or twice a week. There were no controls. Cardiovascular function improved, as measured by increased met* levels, an increase in treadmill times, a decrease in resting

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*A "met" is the metabolic heat produced by a resting-sitting subject, being 50 kg calories per m^2 of body surface per hour (*Dorland's Medical Dictionary*, 27th edition, WB Saunders Company, Philadelphia, Pa, 1988).

heart rates, and a decrease in submaximal exercise heart rates. Abdominal strength improved. Of the 49 patients, 13 (26%) dropped out of the study.[23]

In a group of 35 ambulatory patients aged 64 to 85 years, 28 (80%) of whom had degenerative joint disease, 11 (31%) hypertension, and 9 (26%) back syndrome, 18 were placed in an exercise group and 17 in a control group. Exercises were performed for an hour three times a week for 16 weeks and included endurance (with the target heart rate to 50% of the heart rate reserve), range of motion, coordination, and neuromuscular strengthening (chair strengthening exercises carried out for 20 minutes). There were no adverse reactions but no significant differences between the two groups in maximal metabolic work or neuromotor tests.[24]

It has been demonstrated repeatedly that anatomic and physiologic deterioration takes place in muscle tissue with aging, with a functional decline in cardiovascular and neuromuscular systems. It is now apparent, however, that much of this decrease in functional capacity is due not to the intrinsic processes of aging but to the inactivity and sedentary lifestyle of older persons.

In healthy older persons, especially the "young old" (65 to 75 years), exercise programs similar to those used in young athletes can substantially and meaningfully improve strength and endurance. With a further increase in age and progression of chronic illnesses, such routines of exercise can no longer be practiced. Shephard describes well the precautions and the individualized programs required in more functionally incapacitated older persons.[25] We still need more quantitative information with regard to the degree of improvement that might be anticipated in this more impaired population.

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