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Strength and Aerobic Training Attenuate Muscle Wasting and Improve Resistance to the Development of Disability With Aging

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By the age of 50 yrs old, humans become aware that they are losing muscle strength (mass) and endurance (mitochondria). A frequent symptom of neuromuscular disorders is muscle weakness (Walton, 1988). We define the aging-associated muscle wasting as a progressive neuromuscular syndrome that will lower the quality of life in the elderly by (1) decreasing the ability to lift loads (progressing to difficulty arising from a chair), and (2) decreasing endurance (leading to an inability to perform the activities of daily living, which increases health care costs). Campion (1994) states that the most successful outcome would be for the very elderly to take control of the last stage of their life and make it worth living. To obtain this goal, prevention of muscle wasting is an absolute requirement. Muscle mass and motor unit number, activation, and synchronization are highly related to strength; both decrease with aging (Rodgers and Evans, 1993). Resistance-training is the best way to increase muscle mass, neural coordination, and strength. Mitochondrial concentration is highly related to endurance capacity in young and old (Holloszy and Coyle, 1984). Both muscle contractile and mitochondrial protein decrease with aging in sedentary humans (reviewed by Rodgers and Evans, 1993). Endurance training, which is the best exercise to increase/maintain mitochondrial concentration with aging, has generally resulted in relatively small functional benefits to nursing home patients (Fiatarone et al., 1994). We speculate that those events leading to frailty consist of a severe loss of muscle mass (Buchner and Wagner, 1992), which limits mobility, which in turn further decreases muscle mitochondria and maximal cardiac output, both of which produce a further decline in $\dot{V}O_2max$. For example, if muscle mass decreases below some threshold, then it is difficult for nursing home patients to have the strength and mobility to exceed low intensity aerobic training (Fiatarone et al., 1994), so that insufficient mitochondrial concentration leads to a decrease in endurance.

MUSCLE strength is the maximal force, tension, or torque generated by a muscle group. Increasing the functional cross-sectional area of a muscle group enables enhanced strength. With aging, decreases occur in both muscle cross-section, and strength. In addition, some of the strength-loss with aging is due to a loss of motor unit number, activation, and synchronization.

Muscle strength remains similar from 20–45 yrs of age (Larsson, 1978). However, significant losses in muscle strength begin after 45–50 yrs of age. A 22% loss of muscle strength occurs between the ages of 45–50 and 60–65 yrs of age (Larsson, 1978). The knee extensor muscle strength was approximately 30% lower in a group of 78–81 yr old subjects than in the 70-yr-old men and women in the study of Aniansson et al. (1980). Knee strength declined 22–44% in comparisons of 20- and 80-yr-old women (Murray et al., 1985). Another study found that knee extensor and flexor strength decreased 50–60% when women were compared between the ages of 40 and 60 (Stanley and Taylor, 1993). Between the ages of 50 and 80 yrs, the approximate 50% decline in strength is associated with an approximate 40% decrease in mass of skeletal muscles. Thus, strength markedly decreases from 50–80 yrs of age.

The mass of human skeletal muscle begins to atrophy at the age of 25 yrs in men, but this loss is only 10% for the next 25 yrs, which does not significantly cause a measurable loss in muscle strength (Lexall et al., 1986). After age 50 yrs, an additional 30% loss in muscle mass occurs by the age of 80 yrs. Rodgers and Evans (1993) concluded from their review of the literature that the decrease in muscle size with aging could account for much of the reduction in muscle strength. Muscle wasting from 50 to 80 yrs of age is likely a function both of an aging process within the neuromuscular system and of physical inactivity. The approximate contribution

from each is unknown. A loss of both α-motoneurons and motor units in older humans and animals has been documented (Ansved and Larsson, 1990), which contributes to the loss of muscle strength. However, the cause of α-motoneuron loss is not clear. Is α-motoneuron loss initiated by supraspinal components, the spinal cord, or by the loss of a retrograde signal from skeletal muscle?

In addition to declines in muscle strength (described above), inactivity appears to cause decreases in muscle endurance (Coggan et al., 1992). Our recent review (Booth et al., 1994) concluded that some studies, although not all, suggest a causal role for muscle atrophy and declines in $\dot{V}O_2max$. As discussed below, skeletal muscle mitochondrial concentration declines with aging. The functional importance of a loss in mitochondrial concentration would be a loss in aerobic endurance (Holloszy and Coyle, 1984). This review will briefly examine the effects of aging on mitochondrial proteins as well as other proteins, which could affect muscle function.

In skeletal muscle, mitochondrial concentration (amount per gram of muscle) can decline and mitochondrial content (amount per whole muscle) does decline with aging. — Most studies report a decline in the activity (concentration) of mitochondrial enzymes in skeletal muscle with aging in humans (Boffoli et al., 1994), and in animals (Holloszy et al., 1991). Since muscle mass is also declining with age, significant losses in the total amount of mitochondria per whole muscle (content) occur past 50 yrs of age, which likely contributes to the reduction in aerobic endurance with aging (Coggan et al., 1992; Rodgers and Evans, 1993). Aerobic endurance is more related to the mitochondrial concentration of the recruited muscles than to $\dot{V}O_2max$ (Holloszy and Coyle, 1984).

Mitochondrial function of human skeletal muscle, as determined by polarographic methods, showed a progressive decline with age (Boffoli et al., 1994). The activities of complexes I and IV decreased by 59% and 47%, respectively, from the ages of 20–30 yrs to 60–90 yrs (Boffoli et al., 1994). Markers of mitochondrial enzymes (succinate dehydrogenase, citrate synthase, and β-hydroxyacyl-CoA dehydrogenase activities) were 25% lower in the gastrocnemius muscle of 60–69-yr-old men and women as compared to 20–29-yr-old men and women (Coggan et al., 1992). The percentage decrease in mitochondrial content would be even greater since skeletal muscle from older subjects likely atrophied.

Holloszy et al. (1991) reported that inactivity has a differential effect on mitochondrial density in the 3 types of muscle fibers in the rat. They found that the activities of citrate synthase, succinate dehydrogenase, and fumarase were decreased in the plantaris and soleus muscles of 28-month-old rats (Holloszy et al., 1991). In addition, 3-hydroxyacyl-CoA dehydrogenase, carnitine palmityltransferase, and 3-ketoacid-CoA transferase activities were reduced by aging or inactivity in the soleus muscle. They suggested that weight-bearing and locomotor muscles would have losses in mitochondrial concentration with aging. Thus, skeletal muscle mitochondria decrease in sedentary, older humans and animals.

Endurance training can restore the aging-associated decrease in mitochondria. — Rodgers and Evans (1993) have suggested that the age-associated decline in skeletal muscle mitochondria is secondary to reduced physical activity. This topic has recently been summarized in an excellent review by Cartee (1994). Cartee concludes that studies from both rats and humans support the conclusion that vigorous exercise-training in old age can lead to levels of muscle oxidative capacity as high as those in young individuals undergoing similar training. However, because younger persons can train at higher workloads due to higher $\dot{V}O_2max$ than older people, younger muscles can attain higher activities for mitochondrial enzymes (Cartee, 1994). Rat studies indicate that a given endurance training program increases mitochondrial markers similarly in young and old rats (Young et al., 1983; Cartee and Farrar, 1987). Rodgers and Evans (1993) conclude that aging does not limit the adaptive capacity of aerobic metabolism in the skeletal muscle of rats subjected to chronic endurance training over a major portion of their life. Coggan et al. (1992) suggest that the higher level of physical activity in elderly Swedes than in the sedentary age-matched U.S. citizen could explain why mitochondrial respiratory enzyme activities decrease with aging in the U.S., but not in Sweden, although genetic differences have not been considered. Much of the loss in the concentration of mitochondria with aging seems to be due to physical inactivity, since the loss in mitochondrial concentration is reversible with aerobic training.

Male, master athletes (63 yrs old) had 24–31% higher mitochondrial concentration in their gastrocnemius muscle than did young runners (27 yrs old) who finished with the same time in a 10-km race (Coggan et al., 1990). Since the $\dot{V}O_2max$ was 11% lower in the master athletes, Coggan et al. (1990) speculate that similar run times were related to the higher mitochondrial concentration, which compensated for the lower $\dot{V}O_2max$. However, another group of young runners, who trained harder and finished faster than the master athletes mentioned above, had 14–23% higher mitochondrial concentration than the master athletes. Thus, intense endurance training can prevent the loss of mitochondria in 60-yr-old men. However, because training intensity decreases with age, master athletes may be unable to maintain $\dot{V}O_2max$ equal to that of highly trained, young, endurance runners. These observations argue for a lifetime of endurance training, to maintain the highest possible mitochondrial concentration in skeletal muscle in the 7th–10th decades of life.

The limiting factor to the maintenance of high concentrations of mitochondria in skeletal muscle appears to be the ability to undergo intense endurance training. If inactivity occurs over decades, $\dot{V}O_2max$ will decrease at a rate of 10% per decade. The lower $\dot{V}O_2max$ would limit the absolute intensity of training, which in turn limits the magnitude of the increase in mitochondrial concentration by training.

Aerobic training also produces other health benefits (Fentem, 1994), such as decreasing the risk of back pain, breast and female reproductive cancers, claudification, colon cancer, congestive heart failure, coronary heart disease, deep vein thrombosis, depression, hypertension, noninsulin dependent diabetes mellitus, obesity, osteoporosis, and stroke, as well as prolonging independent living by slowing the

decline in maximal aerobic capacity. Aerobic training not only decreases the mortality from certain diseases, it attenuates morbidity and disability in an 8-yr study of 50–72-yr-old runners, who averaged 26 running miles/wk (Fries et al., 1994).

Deletions of mitochondrial DNA occur with aging. — Mitochondrial DNA has a high turnover rate, and the DNA polymerase-gamma, thought to be involved with mitochondrial DNA replication, is believed to have a high error rate, so that when mitochondrial DNA is replicated, mutations in nascent mitochondrial DNA occur (Cooper et al., 1992). Since endurance training prevents the loss of mitochondrial concentration with aging, it appears fortunate that mutations of mitochondrial DNA do not contribute significantly to the aging-associated decrease in skeletal muscle mitochondria in most sedentary animals and humans.

Synthesis of mitochondrial DNA in rat brain decreases with aging. — A 50% reduction in the synthesis rate of mitochondrial DNA was measured in the brain from senescent rats as compared to adult rats (Fernandez-Silva et al., 1991). Fernandez-Silva et al. speculate that the lipid peroxidation observed during aging could alter mitochondrial membrane permeability, which would decrease ATP synthesis and/or derange calcium transport into mitochondria. They suggest that either of these alterations could decrease transcription of mitochondrial DNA, since both ATP and calcium ions are required. This scenario would be less likely to occur if mitochondrial concentration were high rather than low, because higher concentrations of mitochondria could sequester additional Ca^{2+} and produce more ATP.

Strength training compensates for the aging-associated loss of skeletal muscle mass. — A cross-sectional, retrospective study by Klitgaard et al. (1990) and a training study by Fiatarone et al. (1994) suggest that strength training can compensate for the age-related changes in function and morphology of the aging human skeletal muscle. Klitgaard et al. (1990a) reported that after 12–17 yrs of strength training, 68-yr-old men had similar knee and elbow maximal isometric strengths and cross-sectional areas, both of the quadriceps femoris and elbow flexor muscles and muscle fibers, as did 28-yr-old men who were active in aerobic sports. On the other hand, men aged 68 yrs, who were either swim- or run-trained, or who were 68-yr-old sedentary controls, had significantly lower muscle strengths and cross-sectional areas in most of the comparisons with the 28-yr-old endurance-trained group. This study suggests that only resistance training could compensate for age-associated muscle wasting. These results need to be extended through the age of 90 yrs to determine if these individuals are able to maintain the same intensity of resistance training and whether they are still able to maintain the mass and strength of 28-yr-old endurance-trained and sedentary men.

Fiatarone et al. (1994) have shown that the very old can benefit from strength training. Progressive resistance training for 10 wks, without nutritional supplement, by 87-yr-old men and women increased muscle strength 90%, gait velocity 12%, and stair-climbing power 28%, as compared to no significant changes in both a sedentary group without dietary supplement and a second sedentary group that received a 350-kcal liquid nutritional supplement each day (Fiatarone et al., 1994). Longer-duration studies of nursing home patients are needed to determine if there is a limit to muscle enlargement.

A novel recommendation is made here: strength training should begin as a preventive measure by the age of 50 yrs. The rationale is that at this age the loss of skeletal muscle accelerates (Lexall et al., 1986), and the loss of leg α-motoneurons begins (Ansved and Larsson, 1990).

Lack of high-intensity load-bearing contributes to some of the age-related atrophy of skeletal muscle. — Muscle strength and mass of 68-yr-old strength-trained men in the above study, while not significantly different from the 28-yr-old endurance-trained group, were usually significantly greater than any age-matched sedentary or endurance-trained group. On the other hand, muscle strength and mass were not different between the 68-yr-old sedentary control groups and either of the age-matched swim- or run-training groups. Therefore, high intensity resistance training is required to compensate for muscle wasting during aging. However, resistance training did not increase muscle mass of 68-yr-old men above that of 28-yr-old endurance-trained men. The inability of 68-yr-old strength-trained men to obtain muscle size and strength of 28-yr-old endurance-trained men could be related to: (1) lack of psychological drive to train hard enough, (2) decreased training time due to more frequent injuries, (3) decrease in maximal protein expression per myonucleus, (4) limited satellite cell fusion with muscle fibers, (5) diminished supply of growth hormone or insulin-like growth factor, (6) loss of α-motoneurons, (7) loss of muscle fibers, (8) unknown factors, or (9) any combination of the above.

Differential atrophy of skeletal muscles in the rat has been used to generate the hypothesis that disuse is a contributing factor in age-related atrophy (McCarter et al., 1982; Walters et al., 1990; Holloszy et al., 1991). The lateral omohyoideus, flexor digitorum longus, adductor longus, and epitrochlearis muscles do not atrophy in old rats. Holloszy et al. (1991) speculate that since these small muscles are not recruited in normal cage activity by rats, they would be affected little by decreased cage activity with aging. However, in the old rat, atrophy occurs in the gastrocnemius, plantaris, soleus, and quadriceps, which are weight-bearing muscles and whose usage decreases in the old rat (Holloszy et al., 1991). A number of researchers (McCarter et al., 1982; Walter et al., 1990; Holloszy et al., 1991) interpret these findings to suggest that disuse is the cause of the age-associated muscle atrophy seen in weight-bearing muscles.

Protein quantity. — The quantity of a protein existing within a skeletal muscle cell is regulated by pretranslational (includes transcription of mRNA, processing of mRNA from the nucleus to the cytoplasm, and stability, or degradation, of mRNA), translational (includes initiation, elongation, and termination of nascent protein synthesis), and post-translational regulation (includes assembly of the nascent protein, targeting, and degradation).

Alterations in protein expression in old skeletal muscle. — Welle et al. (1993) found that the fractional rate and total myofibrillar protein synthesis in skeletal muscle were 28% and 44% slower, respectively, in the 62–81-yr-old men than in 21–31-yr-old men. Yarasheski et al. (1993) observed that the fractional rate of skeletal muscle protein synthesis was 39% lower in 63–66-yr-old men than in 24-yr-old men. These data indicate that the turnover of total skeletal muscle protein is much slower in the elderly. Some of the specific proteins that have been reported to be downregulated with aging will be reviewed briefly.

Rats aged 125–135 wks had decreased skeletal α-actin mRNA per μg of total RNA, but no change in adult myosin heavy chain mRNA in skeletal muscle as compared to 22–25 wk old rats (Jaiswal and Kanungo, 1990). A dissociation between α-skeletal actin mRNA (decreased) and β-myosin heavy chain mRNA (no change) has been noted in the atrophying soleus muscle when its load-bearing is removed (Thomason et al., 1989). Transcription of the skeletal α-actin gene, as estimated from nuclear run-on methodology, was decreased in the older rats (Jaiswal and Kanungo, 1990). However, aging did not alter the transcription of the adult myosin heavy chain gene (Jaiswal and Kanungo, 1990). Glucose transporter 4 (GLUT4) concentration in skeletal muscle decreases during the first year of life in rats, with no further decline from 12 to 25 months of age, which indicates that maturation, not aging, decreases GLUT4 (Cartee, 1994). In comparisons to 7-wk-old rats, GLUT4 mRNA in skeletal muscle is increased in 20-month-old rats while GLUT4 protein is decreased in the 20-month-old rats (Oka et al., 1992). Oka et al. (1992) interpret these findings to say that the translational efficiency and/or stability of GLUT4 protein is decreased in the skeletal muscle of aged rats compared with the young rats. Anderson et al. (1993) reported that neural cell adhesion molecule (N-CAM) was upregulated in normal rat skeletal muscle between the ages of 300 and 1000 days of age. They suggest that N-CAM upregulation may be correlated with denervation of the myofiber rather than to myogenesis per se, since N-CAM is involved in muscle-neuron interactions.

As far as we are aware, no studies have measured insulin-like growth factor-I (IGF-I) peptide expression in aging muscle. However, the increase in protein synthesis and amino acid uptake induced by IGF-I in the media of incubated muscles was completely abolished during maturation (from 1 to 8 months of age) in rats. IGF-I receptor mRNA per gram of muscle decreased 65%, which was proportional to the decline in total RNA per gram of muscle as rats matured to 8 months of age. IGF-I receptor number decreases from 1 month to 8 months of age in rats, but does not further decline at 18–20 months of age (Dardevet et al., 1994). We have found similar data for IGF-I mRNA in skeletal muscle (unpublished observations). Thus, the decrease in IGF-I receptor and IGF-I is a maturation, not an aging, effect. We interpret these data to suggest that once the rat matures, there is little need for IGF-I to act on muscle protein synthesis since it has completed almost all of its growth. The same study (Dardevet et al., 1994) found that IGF-I-stimulated glucose uptake was less in 18–20-mo-old skeletal muscle compared to 8-mo-old muscle.

Do nuclear domains limit maintenance of muscle mass with aging? — Skeletal muscle fibers (cells) are multinucleated. Each myonucleus in a muscle fiber is thought to control the protein expression within a given volume of cytoplasm. According to Edgerton and Roy (1991), myonuclei of slow muscle fibers have smaller nuclear domains than fast muscle fibers, which corresponds with data that show slow muscle has a more rapid synthesis and degradation of proteins. This idea has been extended by Tseng et al. (1994) with his proposal that the maximal volume of cytoplasm that a given myonucleus can control is limited by the capacity of the myonucleus to support protein turnover and synthesis of structural and mitochondrial proteins following a functional perturbation. Thus, a hypothesis (designated the nuclear domain limitation hypothesis) was formed, stating (Tseng in Booth and Baldwin, 1995): within a window of adaptive potential, myonuclei have a significant ability to alter the muscle fiber's size and phenotype. If challenged to extreme limits for increasing its size (cross-sectional area) in strength training or oxidative potential (mitochondrial content) in endurance training, the muscle cell myonuclei must make a trade-off decision either to give up some oxidative capacity for maximal size or relinquish some size for maximal oxidative capacity, but cannot be maximal in both (designated as the nuclear domain limitation hypothesis). Williams et al. (1987) have maximized mitochondrial synthesis by chronic electrical stimulation of skeletal muscle for 24 hrs per day. After 3 wks of chronic stimulation, mitochondria increased 400% (Williams et al., 1987) while whole muscle (Williams et al., 1987) and fiber cross-sectional area atrophied 25% (Salmons and Henriksson, 1981). The finding in this model demonstrates that the muscle cells made a trade-off decision to give up size for maximal oxidative capacity. The nuclear-domains-limitation concept may help our understanding of limitations in strength- and endurance-trained potential in the very old with very small muscles and few satellite cells.

The nuclear-domain-limitation hypothesis (Booth and Baldwin, in press) raises questions concerning old skeletal muscle. If transcriptional capacity, protein assembly, or some other regulatory step of protein expression is decreased in old muscle, then the maximal capacity for synthesis of both structural and oxidative proteins would be restricted. Both strength and endurance training are required to prevent, or compensate for, losses of muscle mass (strength) and mitochondria (endurance) with aging. It is unknown whether any decline exists in old humans for the maximal capacity of myonuclei in skeletal muscle fibers to supply either structural or oxidative proteins, or whether the nuclear domain of type IIb fibers increases with aging. Either or both of these could limit the maximal training adaptation in skeletal muscle of 60–80-yr-old humans. Some transcriptional changes by myonuclei do occur in old muscle because Klitgaard et al. (1990b) found a major increase in the number of muscle fibers coexpressing myosin heavy chain isoforms in old human skeletal muscle. This implies a loss of coordination of protein expression by myonuclei, possibly by less communication among myonuclei.

Tseng predicts that the limited satellite cell population could play a pivotal role in modulating the numbers and sizes of nuclear domains. This feature could be critical in skeletal

muscle of older humans and animals, who are known to have fewer satellite cells per unit volume than young counterparts (Schultz and McCormick, 1994). Reduced load-bearing for 30 days has been shown to reduce satellite cell number by 45% in the soleus muscle of young rats (Darr and Schultz, 1989). An analogous situation, such as complete bed rest during hospitalization by elderly patients, could be deleterious during their subsequent rehabilitation because insufficient satellite cells would be present to permit muscles to regrow to preatrophy size. Do periods of enforced physical inactivity, due to illness, past the age of 60 yrs severely curtail muscle regrowth due to the reduction in satellite cell number by the unloading of skeletal muscle during bed rest? Research is needed to determine whether satellite cells become limiting to the maintenance of muscle mass in 70–90-yr-old people who undergo strength training. Does the reduction of satellite cell number with aging account for the failure of strength training to produce muscle mass equivalent to 20-yr-old strength-trained individuals? Does intermittent/sporadic weight training deplete satellite cells faster than consistent weight training? Does the low intensity of strength training fail to recruit sufficient satellite cells in old muscle?

Muscle atrophy in old age is a prevalent neuromuscular syndrome. — Walton (1988) defines neuromuscular disorders as those conditions in which the patient's symptoms (with pain and muscle weakness being the most frequent symptoms) result from abnormalities in lower motor neurons, including motor nuclei of the cranial nerves, anterior horn cells of the spinal cord, spinal motor roots, motor fibers of the peripheral nerves, the neuromuscular junction and the muscles themselves. Since older humans and animals have a loss of α-motoneurons, motor units, muscle fibers, and muscle mass, as well as fiber type grouping through a rearrangement of muscle fiber types (Booth et al., 1994), it is obvious that skeletal muscle from old humans and animals meets all criteria for a neuromuscular syndrome. However, many physicians consider old people with muscle weakness as asymptomatic for neuromuscular disease (Hubbard and Squier, 1989; Barclay and Wolfson, 1993). Apparently, Walton's criteria are not applied to old humans. Possibly, many physicians do not consider age-associated muscle wasting as a syndrome because its onset is so gradual over decades that progressive muscle weakening is accepted as normal, when in fact disease is defined as an impairment that affects the performance of vital functions. By this definition, muscle weakness with age is a neuromuscular disease. On the other hand, medicine considers osteoporosis as an aging-induced disorder. Politics target research funds to diseases (Langer, 1992; Marshall, 1993) and has awarded osteoporosis a priority for funding. Osteoporosis is much more prevalent in females, yet muscle atrophy occurs in both genders. Groups who have pushed for funding of osteoporosis have not included the aging-associated syndrome of muscle wasting in new research funding. As people age they become less mobile, often compounded by disabilities, which then leads to accelerated osteoporosis (Ooms et al., 1993) and muscle atrophy (Rodgers and Evans, 1993), which in turn further increases disability and impairs mobility, and a vicious cycle perpetuates. More active adults exhibit less decline in bone and muscle strength (Buchner and Wagner, 1992).

Public health impact. — The progressive and relentless loss of muscle mass with aging is a major public health problem and a prevalent neuromuscular syndrome. Muscle weakness contributes to fall-related fractures, the acute care costs of which are $10 billion (Tinetti et al., 1994). An additional $7 billion in health care costs can be attributed to insufficient muscle strength and endurance, which leads to an inability to perform activities of daily living (ADLs) (Rowland and Lyons, 1991), and a lower quality of life (Fries et al., 1994). In addition, it is painful for the person to watch himself lose mobility and independence! Aerobic exercise prevents the loss in mitochondrial concentration during aging, thereby compensating for some of the loss in endurance. Further, strength training compensates for some, but not all, of the loss in muscle cross-sectional area (and thus muscle strength) during aging. Perhaps the optimal strength-training program for older individuals has not yet been devised. Additional research is needed before conceding that strength training cannot prevent muscle wasting with age. In order to address this and other important issues of public health, molecular biological techniques need to be applied to exercise and fitness questions. This will require a significant commitment of time and resources by both scientists and funding agencies. If our society, political system, and scientific community placed a higher value on physical fitness for all of its citizens, much of the injustice of the poor quality of life of the elderly might disappear instead of muscle mass.

Conclusions

1. At present, loss of skeletal muscle mass is an inevitable accompaniment of aging.
2. The rate of skeletal muscle loss can be slowed by strength training. Strength training should be begun as a preventive measure no later than the age of 50 yrs. Upon reaching 60 yrs of age, strength training is therapeutic, as it will compensate for some of the age-associated muscle wasting.
3. While strength training is more effective in maintaining skeletal muscle mass, aerobic training decreases both mortality and morbidity by preventing many chronic diseases. In addition, aerobic training improves the quality of life of the elderly by resisting the cascade of disability.
4. Limitations of $\dot{V}O_2max$ with age is a phenomenon of changes in multiple organ systems, such as: cardiovascular, endocrine, muscular, and pulmonary.
5. Since skeletal muscle atrophy is prevalent in the elderly and is strongly related to impaired mobility in frail elderly (Fiatarone et al., 1994), it should warrant at least as intense study and concern for prevention as is given osteoporosis.

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