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Adaptations to Aerobic and Resistance Exercise in the Elderly

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Cardiovascular Adaptations to Aerobic Exercise

Maximal aerobic exercise capacity (VO_2 max) is the product of maximal cardiac output (Q) and the maximal arteriovenous oxygen difference (A-VO_2diff) (VO_2 = Q X A-VO_2). Generally speaking, cardiac output represents oxygen delivery to the working muscle and A-VO_2 difference is oxygen extraction at the muscle tissue level. Maximal Q is product of stroke volume (SV), the amount of blood pumped per heart beat, and heart rate (HR) or the number of times the heart beats/min (Q = SV X HR).

VO_2 max declines ~1%/year after the age of 25 in non-training individuals [1–3]. Thus, the VO_2 max of an untrained elderly individual is significantly lower than that of an untrained young individual. However, this decline in maximal oxygen consumption is ~0.5%/year in master athletes who participate in aerobic activities [4]. Further, Pollock et al. [5] reported that there was a non-significant 1.7% decline in VO_2 max over 10.1 years in master athletes who remained competitive and maintained their training intensity while in other master athletes who continued to train but reduced their training intensity there was a significant 12.6% decline in VO_2 max over the 10.1 year period. The reason for the decline in maximal aerobic capacity in sedentary individuals is likely due to 3 major factors. A decline in maximal cardiac output [6], a decline in muscle oxidative capacity due to aging and/or inactivity [7], and a decline in metabolically active muscle mass with a concomitant increase in metabolically inactive fat mass [8]. To examine the effect of the reduction in muscle mass/and increase in fat mass in the elderly on VO_2 max, Proctor et al. [8] expressed VO_2 max relative to appendicular muscle mass. These investigators reported that ~50% of the decline in VO_2 max with aging was accounted for by the decline in muscle mass and increase in fat mass. Thus, the other ~50% was related to a decline in oxygen delivery and/or oxygen extraction. Other investigators have reported that the decline in fat free mass accounts for ~35% of the decline in VO_2 max [9]. It is clear that the maximal cardiac output declines with aging but whether muscle oxidative capacity (which is a major determinant of A-VO_2 difference) declines with aging is a question that is presently under scientific debate.

The results of early studies of aerobic exercise training in the elderly suggested that there was little adaptation in aerobic capacity [10–13]. These early studies have been criticized as a result of the exercise intensity being inadequate to stimulate adaptation. Subsequent studies with relatively high exercise intensities suggested that the magnitude of the adaptation in fitness level of elderly individuals is similar to that of younger individuals [14–18]. In a seminal study, Kohrt et al. [17] had elderly individuals (age 60–71) exercise 4 days/wk, 45 min/day for 9–12 months with exercise intensity gradually increasing from 76% of heart rate maximum to ~83% of heart rate maximum over the training period. These investigators reported a significant improvement of VO_2 max of 24%. When subjects were grouped by age (60–62, 63–66, and 67–71 years) there were no differences between groups in the improvement of VO_2 max. Similar increases in VO_2 max have been observed by other investigators utilizing strenuous aerobic exercise training [14–16].

Elderly women appear to adapt to exercise training with similar increases in VO_2 max as elderly men. Interestingly, however, the mechanism by which elderly men and women increase their VO_2 max appears to be different. Using a similar exercise training paradigm as Kohrt et al. [17], Spina et al. [19] reported that ~66% of the improvement in VO_2 max in elderly men was due to an increase in cardiac output and more specifically stroke volume. However, in elderly women these investigators reported that the improvement in VO_2 max was due to an enhanced A-VO_2 difference with no change in cardiac output. Spina et al. [20,21] using echocardiography, the drug atropine (which releases vagal tone) and the β-adrenergic agonist isoproterenol reported that the endurance exercise training in women had no effect on left ventricular function or left

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ventricular dimensions. Further, isoproterenol had no effect on left ventricular systolic function. In contrast, in a very similar study evaluating the effects of β-adrenergic function in elderly men these investigators found that there was a β-adrenergic mediated improvement in left ventricular function (diastolic filling) as a result of aerobic exercise training.

Muscular Adaptations to Aerobic Exercise

At present, from published results, it is not possible to determine whether there is a decline in muscle oxidative capacity with aging *per se* and/or if the lower muscle oxidative capacity in the elderly is simply the result of reduced muscular activity. Kent-Braun and Ng [22] have reported no difference in muscle oxidative capacity when older men and women were matched closely on physical activity (3 dimensional accelerometer readings for 7 days and a 7 day standard physical activity recall). In contrast, other studies report lower muscle oxidative capacity in older individuals than younger individuals [7]; however, these studies did not control physical activity levels as closely as Kent-Braun and Ng [22].

Coggan et al. [7] reported that type IIA and type IIb fiber areas from the gastrocnemius were smaller in older subjects than younger subjects while the area occupied by the type I fibers was greater in older subjects than younger subjects. Further, these investigators found that capillary density was ~25% less in older compared to younger subjects. There was no difference between young and old for the anaerobic enzymes phosphorylase, lactate dehydrogenase, or phosphofructokinase. Various muscle enzymes related to aerobic metabolism were ~25% lower in older than younger men. The investigators emphasized that it was difficult to conclude whether the findings were due to inactivity and/or aging.

Examining the adaptations to aerobic exercise training, Coggan et al. [23], had older individuals (mean age 64) walk/jog, 4 days/wk, 45 min/day, for 9–12 months. They observed a 23% increase in VO_2 max, a significant decrease in the percentage of type IIb muscle fibers with a concomitant significant increase in the percentage of type IIa muscle fibers. Interestingly, the aerobic exercise training increased the muscle cross-sectional area of Type I fibers by 12% and type II a fibers by 10%. Capillary density and lactate dehydrogenase increased by 21% while substantial and significant increases in enzymes related to aerobic metabolism were observed.

To study substrate oxidation during endurance exercise Sial et al. [24] had elderly and young subjects exercise at the same absolute and similar relative submaximal exercise intensities (56% of VO_2 max) for 60 min. These investigators reported that fat oxidation was 25–30% lower in the elderly than the young while carbohydrate oxidation was 35% higher in elderly than young. Free fatty acid rate of appearance was 35% lower in the elderly at the same relative intensity. These investigators suggested that an age related reduction in skeletal muscle oxidative capacity was responsible for the change in substrate oxidation since free fatty acid availability did not appear to limit fat oxidation. These investigators then examined the effects of 16 weeks of endurance training on substrate oxidation during moderate intensity exercise [25]. The training increased VO_2 peak by 21%. Fat oxidation in the elderly increased by 33% during exercise while carbohydrate oxidation decreased by 24%. There was no change in the glycerol or free fatty acid rate of appearance or free fatty acid rate of disappearance suggesting that the use of skeletal muscle lipid was improved.

Adaptations to Resistance Training

In contrast to aerobic exercise, which involves low resistance and high repetitions, resistance exercise involves high-resistance and a low number of repetitions. The adaptations to resistance exercise can be partitioned into those that occur in the nervous system and those that occur directly within muscle tissue.

Neural adaptations

The ability of the muscles to produce force is first initiated in the nervous system. The neurologic factors that modulate muscle induced force production are motor unit recruitment, and the rate of motor unit firing. These two factors together are called central activation. There appears to be impairment of muscle activation in old vs. young for the elbow flexors [26,27] but not for the tibialis anterior [28,29], quadriceps [30], or adductor pollicis [31]. The data are equivocal for the plantar flexors [32,33]. Although activation has been shown to be impaired in the elbow flexors, Jakobi and Rice [26] reported that after one session of contractions, the activation of the elbow flexors was improved during the second session. Thus, one preliminary session of contractions is sufficient to elicit maximal activation on a second session.

Although suboptimal muscle activation with age does not appear to occur for most muscle groups, there are other indicators of impaired nervous system input to muscle [29,34–36]. For example, Klein et al. [36] reported increased muscle coactivation (5%) of antagonist muscles for both the elbow flexors and extensors in the elderly. In addition, greater coactivation of the knee flexors when contractions of the knee extensors occurred was reported in the elderly vs. middle aged individuals by Hakkinen et al. [34] and Izquierdo et al. [35]. Kent-Braun et al. [29] reported that aging reduced foot tapping speed. Foot

tapping speed is commonly used clinically as a measure of upper motor neuron function. They suggested that the reduced foot tapping speed with age represents an impaired ability to rapidly regulate motor unit recruitment and/or motor unit discharge rates, but that lower motor unit loss or joint stiffness may also play a role.

Interestingly, Stackhouse et al. [37], have found that the relationship between central activation and maximal voluntary contraction is curvilinear rather than linear. In a subsequent study using a curvilinear equation to reevaluated previously collected data that was initially analyzed with a linear equation, they found that the central activation deficit was 11% in old vs. young rather than the 2–4% difference previously found using a linear equation. The author suggests that this may explain the larger deficit in strength than the deficit observed for muscle mass in old vs. young as strength declines by 2.0–2.5% per year after the age of 65 [38] while muscle mass declines by ∼0.5–1.0% per year after the age of ∼40 as assessed from cross-sectional studies [39–42].

Effects of resistance training on muscle activation

Since muscle activation is maximal, for most muscle groups in the elderly, an increase in activation cannot occur even with resistance training. However, there are reductions in muscle coactivation. Hakkinen et al. [34] reported a 12.5% reduction in co-activation in ∼70 year old men and a 22.6% decrease in co-activation in ∼70 year old women as a result of 6 months of a combination of heavy resistance training and explosive exercise. Thus, it appears that a reduction in co-activation is an important adaptation which increases force production in the direction of intended movement in resistance trained elderly.

Muscular Adaptations to Resistance Exercise

Muscle size changes with age

As presently stated, cross-sectional studies suggest that muscle mass declines at the rate of ∼0.5–1.0% per year after the age of ∼40 [39–42]. Lexell et al. [43] have reported that for the vastus lateralis, aging results in a greater loss in the number and size of type II fibers when compared to type I fibers. The number and size of Type II muscle fibers are a primary determinant of muscle force production. Type II fibers produce more force than Type I fibers [44]. Further, there is a positive relationship between percentage of Type II fibers for a particular muscle and maximal torque production of that muscle [45–47]. Thus, because of the greater force production for Type II fibers observed at the single fiber level and the positive relationship between percentage of type II fibers and force at the whole muscle level, the reduction in Type II fiber number and size would appear to play a very important role with regard to the loss of muscle force producing capabilities as one ages.

Muscle quality and aging

In a study of men and women age 70–79 years ($N = 2{,}627$), Goodpaster et al. [48], reported that muscle quality, as measured by the attenuation of skeletal muscle using CT analysis, was significantly related to muscle torque production at 60 degrees/sec. However, the impact of this relationship on muscle function is questionable as the partial R^2 for muscle quality vs. torque production was 1.6% for men and for women was 3%. The change in muscle attenuation is thought to represent the infiltration of muscle with fat.

Recently, Trappe et al. [49] compared muscle quality in old and young men and women. The primary dependent variable in that study was single fiber muscle physiology. The single muscle fibers were studied devoid of nervous system input. They found that there were differences in force and power production among the different groups; however, when corrected for muscle cell size there were no differences. They also found that the concentrations of myosin and actin, the two major contractile proteins in muscle, were not different among the four groups. These data along with those of Goodpaster et al. [48] suggest that the loss of muscle quantity with age is substantially more important to reduced force and power when compared to the negligible loss of muscle quality.

In contrast, D'Antona et al. [50] reported that elderly individuals had lower force of single muscle fibers when these forces were corrected for fiber size, suggesting reduced muscle quality. Additionally, the myosin concentration of type I and type II a fibers was also reduced. Thus, the data regarding muscle quality and aging are equivocal.

Strength response to resistance training in the elderly and comparison to the young

Resistance training results in an increase in muscle strength in the elderly. From nine studies in which a similar resistance training protocol was utilized (10–12 weeks, 3 days/wk, 80% of 1 repetition maximum), the mean improvement in muscle strength was 75.9% with a range of 37.4–134% [51–59]. Thus, substantial increases in muscle strength are observed in elderly individuals who engage in resistance training.

A topic that has received considerably less attention is whether there is a difference between young and old in the response to a similar resistance training program. Moritani and deVries [60] reported that eight weeks of strength training did not result in a significant difference in strength gains between old (22.3% increase) and young (29.5% increase) individuals. However, one could argue that the number of subjects was low ($n = 5$ per group) and

that significant differences were not observed because of a lack of statistical power. Lemmer et al. [61] reported that the change in 1 RM was greater in young than old individuals following 9 weeks of intense resistance training. Hakkinen et al. [34] reported no significant difference in the strength increase of young and old following 10 weeks of progressive resistance training. Jozsi et al. [62] reported that the increase in muscle strength in response to 12 weeks of resistance exercise training was similar in older and younger individuals in 4 out of 5 exercises performed. Welle et al. [63] reported that 12 weeks of resistance training resulted in similar strength gains for knee extension and lateral pulldown when comparing young and old. Further the strength gains for knee flexion were greater in the elderly and for the elbow flexion movement strength gains were greater in the young. Taken together the majority of the data suggests that the relative strength gains are similar between young and old individuals in response to a progressive resistance training regimen.

Muscle hypertrophy response to resistance training in the elderly and comparison to the young

It is clear that the skeletal muscle of older individuals can hypertrophy in response to resistance training. In an early and important study, Frontera et al. [55] reported that 12 weeks of strength training in the elderly (3 days/wk, 3sets/work out, 8 repetitions/set, 80% of 1 repetition maximum), resulted in a 9.3% increase in thigh muscle area measured by CT scanning while biopsy samples of the vastus lateralis revealed a 33.5% increase in type I muscle fiber area and a 27.6% increase in Type II fiber area. Additionally, Fiatarone et al. [64] reported that a similar program conducted for 8 weeks in individuals with a mean age of 90.2 resulted in a 10.9% increase in quadriceps muscle area. Similar changes in whole muscle area and fiber area as a resulting from resistance training in the elderly have been reported by others [65–67].

Although it is clear that resistance training can result in muscle hypertrophy in older individuals another important question is do older men gain as much muscle mass as younger men in response to the same resistance training stimulus ? Welle et al. [68] previously reported that the muscles of older individuals (>60 years old) did not hypertrophy as much in response to three months of resistance training as younger individuals (22–31 years old). However, Ivey et al. [69] who used a much more intense training for a shorter length of time (9 weeks) reported that muscle hypertrophy was not attenuated by age [69]. Hakkinen et al. [34] reported that in the quadriceps femoris, muscle cross-sectional area was not significantly different between young and old individuals after 10 weeks of resistance training. Recently, Dionne et al. [70] reported that 6 months of resistance training resulted in a gain in fat free mass in older women which was only ∼58% of that of younger women. Similarly, Lemmer et al. [71] reported that the gain in fat free mass for older men and women was only ∼58% of that for younger men and women. Thus, the majority of these data suggest that the muscle mass/fat free mass gains by older individuals in response to resistance training are less than those for younger individuals.

Fiber size, fiber type, and metabolic adaptations as a result of resistance training in the elderly

Both major muscle fiber types (I, II) increase in size as a result of resistance training in the elderly [34,55,56,72,73]. Although, both type I and type II fibers increase in size in response to resistance training, it would appear that the increase in type II fiber size is more important, as type II fibers produce more force per unit area than type I fibers [44], and due to the fact that there is a reduction in type II fiber area and number with aging [43].

With resistance training there is a decrease in the percentage of type IIb fibers and an increase in type IIa fibers in young [74,75] and old [72]. Interestingly, in elderly individuals resistance training increases mitochondrial volume density [76], while in young bodybuilders and powerlifters, mitochondrial volume density is decreased [77–79]. Further, oxidative enzyme activities are reduced with resistance training in young individuals [80] but are increased in elderly individuals as a result of similar training [81]. Supporting the data of increased oxidative capacity resulting from resistance training in the elderly are data from Jubrias et al. [76] demonstrating a significant improvement in oxidative metabolism after acute exercise. These changes may be related to the low initial habitual physical activity level of older individuals relative to younger individuals.

Effects of resistance exercise on function in the elderly

Many older individuals have reduced abilities to perform activities of daily living. Thus, of practical importance is whether resistance exercise training can improve functional abilities in the elderly. Fiatarone et al. [53] examined individuals with a mean age of 87.1 who performed 10 weeks of progressive resistance training. Muscle strength was improved by 113% while thigh muscle cross-sectional area was increased by 2.7%. These changes translated into a 11.8% increase in gait velocity, a 28.4% improvement in stair climbing power, and a ∼35% increase in spontaneous physical activity.

Vincent et al. [82] examined the effects of low intensity (50% of 1 repetition maximum for 13 repetitions) vs. high-intensity resistance exercise (80% of 1 repetition maximum for 8 repetitions) on muscle strength, muscular endurance and stair climbing speed over 24 weeks.

Significant and similar increases in strength, muscular endurance, and stair climbing ability were observed for both the low and high intensity groups.

Recently, Hruda et al. [83] examined the effects of 10 weeks of traditional resistance exercise training on functional ability in twenty-five residents of a long term care facility. They observed a 44% improvement in thigh eccentric power, a 60% improvement in thigh concentric power, a 31% improvement in an 8 foot get up and go test, a 66% improvement in the chair stand, and a 33% improvement in the 6 meter walk time.

Sullivan et al. [84] examined the effects of progressive resistance training on functional activities in older individuals recuperating from hospitalization. They reported a 74% improvement in muscle strength in addition to improvement in the sit to stand maneuver in 15 of 19 individuals, an improvement in the maximum safe gait speed in 10 of 19 patients, and that 4 of the 6 non-ambulatory patients proceeded to ambulatory status. Additionally, none of the subjects experienced a complication. Thus, from these studies and others it is clear that resistance exercise training can improve function in healthy elderly individuals and in the hospitalized frail elderly.

Summary

Despite lower baseline values, the available data suggest that older individuals have the same relative improvement in maximal strength and maximal aerobic capacity to resistance training and aerobic training regimens, respectively. For men, about two-thirds of the improvement in VO_2 max with training is due to an increase in cardiac output while the remainder is due to an increase in the extraction of oxygen at the tissue level. In contrast, the increase in VO_2 max in response to aerobic training in elderly women is almost entirely due to an increase in A-VO_2 difference. It is unclear whether muscle oxidative capacity is reduced as a result of aging or if it is due to reduced habitual physical activity. Muscle oxidative capacity and fat oxidation improves as a result of aerobic exercise training in the elderly. There is some indication that measures of neuromuscular activation are impaired in the elderly but these can be improved by training. Older individuals can substantially increase muscle mass and muscle strength in response to in response to a resistance training regimen. Relative increases in muscle strength in response to a resistance training regimen appear to be similar in old and young but the data on muscle hypertrophy comparing young and old suggest muscle mass/fat free mass gains may be less in the elderly than the young. Resistance training, interestingly, increases mitochondrial density and oxidative enzymes in the elderly but decreases these components in young individuals. It is clear that resistance exercise training as traditionally performed can improve strength and activities of daily living in the elderly.

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