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Resistance exercise: good for more than just Grandma and Grandpa's muscles

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Abstract: Progressive resistance training promotes strength gains in both the young and the aged. Importantly, gains in strength in aged persons are, with the appropriate duration, intensity, and progression, not simply due to neuromuscular mechanisms, but also encompass muscle fibre hypertrophy. Critically, the resistance exercise-induced changes in aged skeletal muscle are associated with numerous health benefits, the most obvious of which are the gains in strength and, with the correct training program, power; as a result, functional independence is improved and the risk for falls is apparently reduced. Aside from the well-documented effects of resistance training on strength and power, a body of research is now beginning to emerge that shows resistance exercise also promotes metabolic health. This is crucial information, since it effectively highlights an underappreciated aspect of resistance exercise. Specifically, resistance exercise not only promotes strength gains, but also reduces risk for diabetes and cardiovascular disease. The benefits of resistance exercise do not end at metabolic health, however, and "spill over" into many other realms. In fact, resistance exercise programs have been shown to reduce participants' use of the health care system. Viewed collectively, the multiple benefits of resistance exercise represent an attractive option for our aging population to enhance and maintain their health from a number of perspectives that are not achievable through pharmacological intervention or with solely aerobic-based exercise.

Key words: aging, skeletal muscle, functional independence, hypertrophy, disease risk.

Résumé : L'entraînement progressif à la force améliore la force musculaire tant chez les jeunes que chez les personnes âgées. Si le stimulus d'entraînement est d'intensité, de durée et de progression suffisantes, les gains de force musculaire observés chez les personnes âgées ne sont pas seulement dus aux adaptations des mécanismes neuromusculaires, mais aussi, et notons-le, à l'hypertrophie des fibres musculaires sollicitées. Soulignons en outre que les adaptations consécutives à l'entraînement à la force sont associées aussi à de nombreux bénéfices sur le plan de la santé. De toute évidence, la force musculaire est améliorée et il en est de même de la puissance mécanique en autant que le programme d'entraînement soit approprié ; ces adaptations contribuent à l'amélioration de l'autonomie fonctionnelle et à la diminution, semble-t-il, du risque de chute. Hormis les adaptations bien documentées au sujet des effets de l'entraînement à la force sur la force et la puissance musculaires, de plus en plus d'études suggèrent que les exercices de force auraient un impact sur la santé métabolique. Cette information est de prime importance, car elle met en évidence un aspect négligé des exercices de force. Plus précisément, les exercices de force ne contribuent pas seulement à l'amélioration de la force musculaire, mais ils contribuent aussi à la diminution du risque de diabète et de maladie cardiovasculaire. L'impact des exercices de force ne se limite pas à la santé métabolique. Ainsi, des études rapportent que les adeptes des exercices de force ont moins recours aux soins offerts dans les services de santé. Globalement, les nombreux bénéfices suscités par les exercices de force constituent une option très intéressante pour les personnes âgées désireuses d'améliorer leur santé et de consolider leurs acquis ; notons que les médicaments ne procurent pas ces bénéfices ni les exercices aérobies à eux seuls.

Mots-clés : vieillissement, muscle squelettique, autonomie fonctionnelle, hypertrophie, risque de maladie.

[Traduit par la Rédaction]

Introduction

Resistance exercise can be defined as performance of dynamic or static muscular contractions against external resistance of varying intensities. The major principle, however, is that the external resistance is a relatively high load, therefore multiple repetitions are not possible before muscular fatigue is manifest and contraction no longer possible. A number of reviews and published guidelines exist that define structured models for the application of resistance exercise in the elderly (Anonymous 1998; Evans 1999; Mazzeo and Tanaka 2001); however, as a basic premise, the concept of resistance exercise in the elderly is no different from that in the young, which is to provide an overload stimulus (i.e., a load that is usually heavier than that encountered in typical

Received 26 March 2007. Accepted 7 June 2007. Published on the NRC Research Press Web site at apnm.nrc.ca on 13 November 2007.

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 doi:10.1139/H07-129

everyday life) that strengthens muscles. It is debatable at what exact threshold the intensity of the externally applied stimulus will elicit hypertrophy, but somewhere in the range of 60%–70% of a single repetition maximum (1RM), which most people can lift at least 8–12 times to failure, performed repeatedly and with a progressive intensity as strength develops, appears to elicit hypertrophy (Campos et al. 2002).

Skeletal muscle in the elderly: the importance of hanging on to what you've got

The development of strength and hypertrophy in the elderly is of particular importance, since age-related sarcopenia (the slow decline in skeletal muscle contractile protein content and subsequent reduction in muscle and muscle fibre size of ~1%–2%/year beginning in the 4th decade of life (Frontera et al. 1991, 2000; Iannuzzi-Sucich et al. 2002*a*, 2002*b*; Kenny et al. 2003; Rolland et al. 2003)) has numerous adverse consequences, not all of which are related to strength. A recent insightful review by Wolfe (2006) describes the underlying rationale for why preservation, or reclamation, of skeletal muscle mass alone, not simply in terms of the strength it imbues, is crucial for long-term health and lowering disease risk for obesity, cardiovascular disease, insulin resistance and diabetes, and osteoporosis. Many of the reasons for preserving a large mass of high metabolic quality (i.e., a high capacity for transport, storage, and oxidative disposal of glucose and lipid) skeletal muscle are that skeletal muscle is the largest disposal site of ingested glucose (Holloszy 2005), a large site of lipid oxidation (Pruchnic et al. 2004; Helge et al. 2006; Sahlin et al. 2007), and in addition to the liver, the single biggest contributor to resting metabolic rate (RMR) (Illner et al. 2000; Bosy-Westphal et al. 2004). Relevant to this discussion is that reduced skeletal muscle mass and quality appears to be the single biggest contributor to the decline in RMR. Thus, the embodiment of the sentiment of this review is captured by Tseng et al. (1995), who describe sarcopenia 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 [in an effort to define 'successful' aging] 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 [sarcopenia] is an absolute requirement.

The same authors go on to state that the best way to increase strength and muscle mass is resistance exercise and that the single best strategy to enhance endurance is aerobic-based exercise, owing to its ability to stimulate mitochondrial proliferation (Tseng et al. 1995). Although the authors' conclusions are largely true when viewed solely as the optimal forms of exercise designed to promote endurance or strength gains, the thesis put forward here is that resistance exercise imparts many of the metabolic advantages thought to be the sole realm of aerobic- or endurance-based exercise and physical activity. In fact, increments in oxidative potential and tighter coupling between energy demand and oxidative ATP supply, as well as improved glucose transport, all of which are considered hallmarks of endurance training, are also all consequences of resistance training. Thus, when considered in the context of an intervention designed to maximize health benefits from an aged person's perspective, it is possible that resistance exercise is unique — along with many metabolic health benefits, unlike endurance exercise, it can combat sarcopenia with all of its morbid consequences.

Resistance training-induced responses in the elderly

When loaded externally, aged skeletal muscle responds somewhat differently than young skeletal muscle at a genetic and protein-signaling level (Hameed et al. 2003; Bamman et al. 2004; Narici et al. 2004; Kim et al. 2005). For the most part, these differences are subtle; however, it can be generally stated that the elderly have a lesser response of synthetic and mitogenic signaling pathways, and that older unaccustomed exercisers have a greater inflammatory response than their younger counterparts. Regardless of the signaling and genetic differences, however, numerous studies exist to show that aged skeletal muscle retains its plasticity and can adapt to progressive overload with strength development (McCartney et al. 1995; McCartney et al. 1996; Taaffe et al. 1996; Brandon et al. 1997; Hakkinen et al. 1998; Ivey et al. 2000; Esmarck et al. 2001; Ferri et al. 2003; Kostek et al. 2005; Valkeinen et al. 2005) and, with appropriate strategies, increased power (Izquierdo et al. 2001; Fielding et al. 2002; Newton et al. 2002; Ferri et al. 2003; Macaluso and De 2004; de Vos et al. 2005), as well as fibre hypertrophy (Fiatarone et al. 1990; Taaffe et al. 1996; Hakkinen et al. 1998; Ivey et al. 2000; Adams et al. 2001; Esmarck et al. 2001; Izquierdo et al. 2001; Fielding et al. 2002; Newton et al. 2002; Ferri et al. 2003; Macaluso and De 2004). What then is the major significant consequence of these adaptations? Most notably, a number of investigations have shown inverse relationships between muscle strength and power with risk for falls and functional independence (Skelton et al. 1995, 2002; Shaw and Snow 1998; Miszko et al. 2003; Moreland et al. 2004; Volpato et al. 2005; Orr et al. 2006; Chan et al. 2007), and even all-cause mortality (Metter et al. 2002, 2004). To date, however, no long-term randomized trial exists to support a conclusive link between resistance exercise training and reduction in fall risk; thus, when held against a clinical evidence-based yardstick, an absolute conclusion cannot be made. This is clearly an area for future research and one that, at least based on the bulk of available data (Skelton et al. 1995, 2002; Shaw and Snow 1998; Miszko et al. 2003; Moreland et al. 2004; Volpato et al. 2005; Orr et al. 2006; Chan et al. 2007), would yield interesting and much-needed information if resistance exercise is going to continue to be prescribed for the elderly. Falling in the elderly is considered a watershed moment; for many elderly persons, it signals a sharp downward decline in independence, as well as overall health-related quality of life. As such, any intervention that can eliminate or reduce the severity of the consequences of a fall would be of exceptional importance to the aged. The strongest predictor for falls in older individuals with diabetes, who are at an even greater risk for falls than their non-diseased counterparts, was shown to be lowerextremity performance (Volpato et al. 2005). In addition, older individuals taking psychotropic drugs are at a much greater risk for falls (Leipzig et al. 1999*a*), as are those taking multiple (3 or more) medications (Leipzig et al. 1999*b*). Hence, although it appears that strength- and power-based training programs are effective in lowering fall risk, a long-term plan for aging persons might also include reducing both disease risk and reliance on medications used to treat disease.

Muscle-level adaptations with resistance training

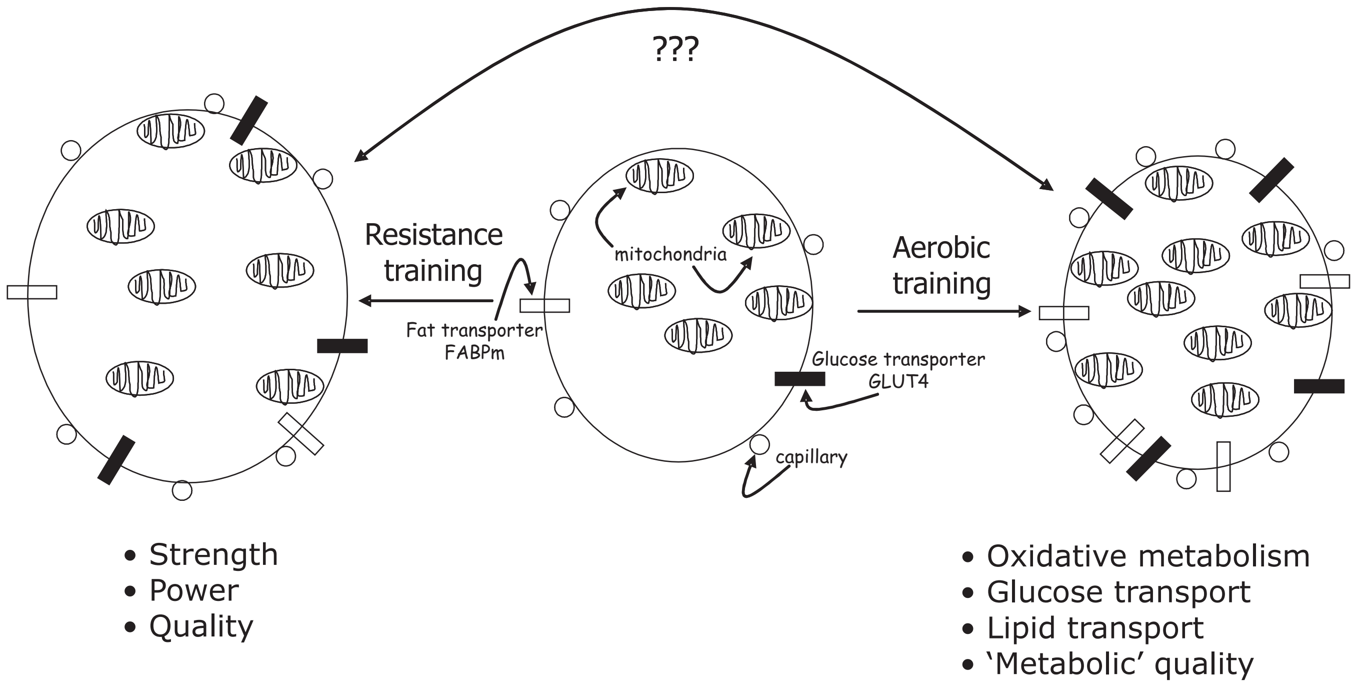
It is known that endurance training can promote increases in muscle oxidative capacity (Holloszy and Booth 1976; Holloszy and Coyle 1984); however, there are reports indicating that an adaptation with resistance training would include a dilution of muscle mitochondria (MacDougall et al. 1979; Chilibeck et al. 1999). A closer examination of data in this area actually indicates that no change in maximal mitochondrial enzyme activity with resistance training has been reported in a number of studies and many studies have reported an increase in muscle oxidative capacity (see Tang et al. 2006 for a review). In a study in which subjects trained for 12 weeks, performing only leg exercises to induce hypertrophy 3 d/week, increases in fibre area were ~17%, but there was no change in maximal succinate dehydrogenase activity nor where there substantial changes in capillary density or other indices of capillarization (Green et al. 1999). More importantly, when the same subjects were challenged with an aerobic stimulus, the changes at the muscle level of the same subjects showed an improvement, not a decrement, in metabolic coupling (i.e., reduced lactate, reduced PCr hydrolysis, and reduced accumulation of Pi and fADP) indicative of improved oxidative ATP supply (Goreham et al. 1999). There are data from studies in the elderly in which resistance exercise has also been shown to stimulate increases in components of the mitochondrial respiratory chain (Parise et al. 2005). These data indicate that resistance training not only increases strength, but also the capacity for aerobic exercise endurance, since fibre type and muscle endurance are directly related to mitochondrial content (Hood et al. 2000; Hood 2001). The notion that hypertrophy brought about by resistance exercise would stimulate mitochondrial biogenesis, particularly with whole-body circuit resistance training, which can be highly aerobic in nature, is somewhat counterintuitive; if it did not, this would reduce fatigue resistance following resistance training. Clearly, this does not occur with most programs of resistance training (Tang et al. 2006). There is no doubt that the adaptations traditionally associated with aerobic training, such as increased mitochondrial density, increased capillarization, and increased glucose and fat transporters, impart an overall increase in metabolic quality to the muscle (Fig. 1). However, the adaptations that occur with resistance training do not likely include a mitochondrial dilution and a reduction in capillary density as much as has been thought (MacDougall et al. 1979; Chilibeck et al. 1999). As detailed previously, there exists evidence to the contrary. In fact, there is likely more in common between the two apparently divergent exercise stimuli in terms of the adaptations they can elicit than has previously been recognized. These resistance training-induced adaptations include maintenance of or increased capillary density (McCall et al. 1996; Green et al. 1999), increased mitochondrial content and oxidative capacity (Goreham et al. 1999; Parise et al. 2005; Tang et al. 2006), and glucoregulatory proteins such as GLUT4 and glycogen synthase (Holten et al. 2004), as well as hexokinase (Tang et al. 2006). Thus, it could be argued that resistance training imparts a degree of metabolic quality to skeletal muscle at the biochemical level, perhaps not as robust as that associated with endurance training, but almost certainly not as dissimilar as some have concluded (MacDougall et al. 1979; Chilibeck et al. 1999). In fact, when carefully documented (Tang et al. 2006), most studies of resistance training have shown either no change or an increase in mitochondrial potential.

Disease risk with resistance training

Recently, a good deal of attention has been focused on the benefits that resistance exercise can have in aiding glucoregulation in persons with type 2 diabetes (T2D). Specifically, a number of trials have shown improved insulin sensitivity (Holten et al. 2004; Ferrara et al. 2006), enhanced glucose clearance, and reduced HbA1c (Castaneda et al. 2002; Dunstan et al. 2002; Cauza et al. 2005*a*, 2005*b*) following programs of resistance training (reviewed in Dela and Kjaer 2006). Again, it is apparent that T2D, a disease condition that has been known for some time to be drastically improved by endurance-based exercise (reviewed in Holloszy and Greiwe 2001; Holloszy 2005), is also responsive to resistance exercise. It does not appear that the improvement in glycemic regulation is due to an increase in muscle mass per se, but is instead the result of local adaptations at the level of the muscle (Holten et al. 2004; Ferrara et al. 2006). Interestingly, in a head-to-head comparison of strength and aerobic training (4 months in duration) in persons with T2D, it was found that only in strength-trained subjects did indices of glycemic control (acute and chronic blood glucose, HbA1c, and insulin) improve (Cauza et al. 2005*a*, 2005*b*). Moreover, improvements in blood lipid concentrations (total and low-density lipoprotein cholesterol, as well as triglycerides) were also only seen in the strength-trained group (Cauza et al. 2005*b*).

Resistance training has also been shown to be a successful intervention to lower blood pressure (Cornelissen and Fagard 2005*a*). Of note is that the reductions in resting blood pressure (BP) were –6.0/–4.7 mmHg. By comparison, the same authors reported a reduction in resting BP of –3.0/–2.4 mmHg in persons who had undergone a program of endurance training (Cornelissen and Fagard 2005*b*). Although the data on resistance training-induced reductions in BP are encouraging, a number of studies have reported that resistance training appears to result in reductions in central (i.e., carotid) arterial compliance (Bertovic et al. 1999; Miyachi et al. 2003, 2004; Cortez-Cooper et al. 2005). Since reduced central arterial compliance has been shown to be an independent risk factor for cardiovascular disease (Seals 2003), the results of these investigations need careful evaluation (Bertovic et al. 1999; Miyachi et al. 2003, 2004; Cortez-Cooper et al. 2005). These findings

Fig. 1. Schematic representation of the hallmark changes associated with resistance training (left) and aerobic-based training (right) from untrained (centre). Resistance training results in fibre hypertrophy and increased strength and power and improved muscle quality (i.e., force per cross-sectional area) in the elderly. Aerobic-based training results in improved oxidative metabolism, enhanced capacity for glucose transport and storage, and enhanced capacity for lipid transport. As a result, aerobic training improves the metabolic quality of the muscle, making it better able to oxidatively metabolize substrates including glucose and lipid. Increasingly, resistance exercise is being shown to induce peripheral-level (i.e., muscle) adaptations that are commonly associated with aerobic-based exercise, even in the elderly. As a result, much of the benefit of aerobic-based exercise appears to overlap with that of resistance exercise. The degree of overlap will, of course, depend on the type of stimulus. However, adaptations that appear to be the exclusive realm of resistance exercise are gains in strength and power, as well as muscle hypertrophy.



are contradicted by a number of studies in young men (Rakobowchuk et al. 2005*a*, 2005*b*), overweight women (Olson et al. 2006), and elderly men (Maeda et al. 2006) that have shown either no change or improvements in arterial compliance and vascular function with resistance training. Moreover, a recent study from the same authors that produced much of the original data on arterial function with resistance training (Miyachi et al. 2003, 2004; Cortez-Cooper et al. 2005) recently reported that resistance training increased limb blood flow and vascular conductance in older adults (Anton et al. 2006), findings that appear at odds with reductions in vascular health with resistance exercise. It also appears that even if resistance exercise does increase arterial stiffness, this can be offset by performing some endurance-type exercise (Cook et al. 2006; Kawano et al. 2006). Clearly, further evaluation of how changes, or lack thereof, in arterial compliance with resistance training are affecting long-term health is needed, particularly if we are going to continue to prescribe resistance exercise for health in older persons.

Other benefits of resistance training

Some of the less recognized benefits of resistance training may be some of the most significant; these include a reduction in depression (Singh et al. 1997*a*, 2001, 2005) and improved sleep (Singh et al. 1997*b*, 2005). Given that the incidence of depression is high in the elderly and that it is associated with increased risk for mortality (Saz and Dewey 2001), the significance of the alleviation of depression symptoms with resistance training and residual effectiveness even after training cessation is stunning (Singh et al. 1997*a*, 2001, 2005). It also appears that resistance exercise needs to be of a sufficient intensity (at least 75%–80% of 1RM) to have an antidepressant effect (Singh et al. 2005). Sleep disorders are also much more prevalent in elderly persons; hence, the results of Singh et al. (Singh et al. 1997*b*, 2005) are also highly relevant for the elderly.

Increases in submaximal endurance are considered a standard feature of many aerobic-based training programs that include increased participation in physical activities such as walking, jogging and running, and cycling (Landin et al. 1985; Stratton et al. 1994, Correia et al. 2002). These results are to be expected, given the central and peripheral changes that are associated with endurance exercise training; however, similar changes in submaximal exercise endurance are seen with weight training (McCartney et al. 1993, 1995, 1996; Vincent et al. 2002*a*, 2002*b*; Hruda et al. 2003). Thus, in a head-to-head comparison of aerobic- versus resistance-based activity to improve, for example, submaximal walking endurance, resistance training would appear to be just as efficacious as aerobic-based training.

Conclusions and future directions

Resistance training imparts many physical, physiological, and functional benefits to elderly persons. Many of the training-induced changes brought on by resistance training have significant overlap with those seen with aerobic-based programs designed to improve endurance, cardiac function, and peripheral mechanisms that could improve insulin sensitivity and buffer against weight gain. The added benefits of resistance training are also just beginning to be recognized, but will, it is hypothesized, have much in common with the benefits that are commonly associated with aerobic-based exercise. The one area of adaptation elicited by resistance training that aerobic training cannot enhance is gain in strength, power, and lean mass. The importance of these training-induced changes cannot be underestimated in terms of the incremental health benefits with which they are associated, particularly in the elderly. As a result, it may be that resistance training can induce meaningful functional and health benefits over and above those offered by aerobic training. It may be perceived as true that aerobic-based walking, jogging, and cycling interventions are easier to implement and possibly easier to adhere to. This perception may be because most aerobic-based interventions require little to no equipment and are more easily performed than equipment-based resistive exercise; however, if the relative benefits of aerobic-based exercise are less than those imparted by resistance training, it makes more sense to pursue the exercise stimulus that has greater efficacy. Future research would thus benefit from more head-to-head comparisons of resistance- versus aerobic-based exercise interventions, as well as from a greater understanding of the barriers to performance of resistance exercise in elderly persons. This is emphasized given the potential benefits of resistance training in reducing chronic disease risk, improving function for aged persons, and the added benefits of muscle mass, strength, and power retention that cannot be matched by endurance exercise.

Acknowledgements

S.M.P. is a Canadian Institutes of Health Research (CIHR) New Investigator Award recipient and gratefully acknowledges that award during the writing of this paper. Grant support from Canadian Institutes of Health Research, the Canadian Foundation for innovation, the National Science and Engineering Research Council of Canada, and the US National Dairy Council is also acknowledged.

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