The Effects of Strength Training on Sarcopenia

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Abstract/Résumé

In the past decade strength training has been investigated extensively as a means of reversing the muscle mass loss that occurs with aging (sarcopenia). High intensity resistance training (HIRT) has led to increased protein synthesis, along with muscle hypertrophy measured at the whole body, whole muscle, and muscle fibre levels, in older adults. Typically, the strength increments associated with HIRT have been much larger than the hypertrophic response. However, most HIRT periods have been quite short. Less is known about the long-term hypertrophic response to HIRT in older adults. In order to lessen the effects of sarcopenia, HIRT should continue over the long term in older adults, to improve functional performance and health.

Au cours de dix dernières années, l'entraînement à la force a été beaucoup analysé comme moyen de bloquer la réduction de la masse musculaire qui se manifeste avec l'âge (sarcopénie). Un entraînement intense à la force (HIRT) a les effets suivants, tant au niveau corporel qu'aux niveaux tissulaire et cellulaire : augmentation de la synthèse des protéines et hypertrophie musculaire. De façon générale, les gains de force associés à HIRT sont beaucoup plus importants que l'hypertrophie. Cependant, dans la majorité des études, les périodes de HIRT ont été passablement brèves. Nous savons peu de choses sur l'adaptation hypertrophique à long terme. De façon à atténuer les effets de la sarcopéni.e., les périodes de HIRT devraient être prolongées chez les personnes âgées afin d'améliorer leur capacité fonctionnelle et leur santé.

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Introduction

Strength training for older adults has received considerable attention in the past decade, precisely because of its potential to alleviate the age-related loss of muscle mass, strength, and function, associated with sarcopenia. This review will focus on the effects of strength training on the muscles of older adults. For other reviews associated with strength training for older adults, please see Vandervoort (2000).

Early research on exercise for older adults emphasized endurance training or low intensity resistance exercise (Feigenbaum and Pollock, 1999; Porter and Vandervoort, 1995). However, this type of training has not resulted in appreciable gains in strength or muscle mass (Porter and Vandervoort, 1995). In fact, many cross sectional studies report that the strength or muscle mass of endurance-trained athletes who had trained for years was no different from untrained age-matched peers (Alway et al., 1996; Harridge et al., 1997; Klitgaard et al., 1990). In addition, Pollock and colleagues (1997) demonstrated that only endurance-trained masters athletes who also resistance trained were somewhat able to maintain lean body mass and bone density. Furthermore, in a recent intervention study, Ferketich and colleagues (1998) found that a program of combined endurance and resistance training lead to a two-fold greater increase in strength than an endurance program alone.

Despite an early study on strength training and aging (Moritani and Devries, 1980) reporting that older men were unable to hypertrophy, the past decade has produced many studies that have since demonstrated muscle hypertrophy resulting from high intensity resistance training from whole body increases in fat free mass down to the muscle fibre level. This paper will review these papers based on how hypertrophy was investigated. In some ways it is difficult to compare these papers because of differences in: (a) the subjects characteristics, including an age range of half a century, previous activity patterns, health, and so forth; (b) training variables such as sets, reps, intensity, progression, number of days of training per week, and the number of exercises performed; and (c) measurement methods. However, the consistent theme is that all studies utilized high intensity resistance training (> 60%). Tables 1 to 4 summarize the studies based on how hypertrophy was measured.

Whole Body Muscle Mass

As described by Lee and colleagues (in press), sarcopenia has been measured at the whole body level using various techniques, from hydrodensitometry to whole body potassium counts. Table 1 shows studies that have examined whole body responses to resistance training in older adults. Most of these methods do not directly measure muscle per se but measure lean body mass, fat-free mass, body cell mass, or total body water, for example. Responses of muscle can be indirectly inferred, but other entities such as bone, organs, and body water would be measured but would not be expected to change as a result of resistance training.

Results have been quite variable within and between techniques of measurement as well as studies and have ranged from no change to 40% increases. Typically creatine excretion (CR) related increments have been greater than other

Table 1 Changes in Whole Body Indicators of Muscle Mass With Resistance Training

Study	Subjects age (years), gender	Training period (weeks)	Strength change*	Muscle mass change (method)
Campbell et al., 1994	56–80, M W	12	↑55 % overall (/ kg FFM)	↔ protein + mineral mass (HW + TBW) ↔ BCM (K)
Campbell et al., 1999a	50–75, M	12	↑20% overall	↑17% (CR) ↑4% FFM (HW) ↑10% protein + mineral mass (HW + TBW)
Campbell et al., 1999b (mixed diet group)	51–69 M	9	↑28% overall	↑3 % FFM ↑18 % CR
Dupler & Cortes, 1993	51–81, M W	12	↑70 % overall	↑2 %, LBM (SK), NS
Fiatarone et al., 1994	72–98, M W	10	↑113% overall	↑1 % (K)
Frontera et al., 1988	60–72, M	12	↑107% KE ↑10% Cybex KE	↑41 % (CR)
Joseph et al., 1999	54–71, M W	12	↑21%overall	↑2 % FFM in men, ↔ in women
Martel et al., 1999	65–73, M W	36	↑25%	↑ N/R FFM (DPX)
Nelson et al., 1994	50–70, W	52	↑54% overall	↑9% (CR)

(continued)

Table 1 *(continued)*

Study	Subjects age (years), gender	Training period (weeks)	Strength change*	Muscle mass change (method)
Nichols et al., 1993	67.8 ± 1.6, W	24	↑29% overall	↑4% LBM (DPX)
Phillips et al., 1996	68–82, M	12	↑18% KE and KF	↑24% (CR), NS
Pratley et al., 1994	50–68, M	16	↑40% overall	↑3% FFM (HW)
Pyka et al., 1995	65–79, W	15	↑25% upper limb	↑5% upperlimb LTM ↔FFM (DPX)
Ryan et al., 1995	50–69, W	16	↑80% overall KINCOM	↑3 % FFM (DPX)
Sipila et al., 1995	76–78, W	18	**↑60% LP, ↑40% KF	↔ LBM (bioelectrical impedance)
Taaffe et al., 1999	65–79, M W	24	↑40% overall	↑ N/R LTM (DPX)
Yarasheski et al., 1999	76–96 M W	12	↑25% overall	↑7% CR ↔ FFM (DPX)
Yarasheski et al., 1993	63–66 M W	N/R	N/R	↔CR
Yarasheski et al., 1995	64–75, M	16	↑60 % overall	↑4 % FFM (HW) ↔ TBW

Note: *Strength changes (1RM) are an average of all sites trained as, except where it is specifically indicated by muscle group. **Strength changes from Sipila et al., 1996. M = men; W = women; 1RM = one repetition maximum; KE = knee extension; LP = leg press; KF = leg flexion; CR = creatine excretion; FFM = fat free mass; TBW = total body water; DPX = dual–energy x–ray absorptiometry; LTM = lean tissue mass; K = whole body potassium; BCM = body cell mass; SK = skinfolds; HW = hydrostatic weighing; NS = non–significant; N/R = not reported.

methods. Inherent in all of these techniques are limitations (Lee et al., 2001), particularly with older subjects, that may make inferences about whole body muscle mass changes ambiguous. Also, one would not expect huge enhancements to occur in whole body muscle mass because most training periods have only been two to four months, and many have been training only a few muscle groups. As is seen with other methods of measuring hypertrophy, the relative increases in strength are usually always larger than the relative increase in whole body indicators of muscle mass change.

Site Specific Muscle Hypertrophy

In contrast to the results for whole body muscle mass, measurements of specific muscle groups' cross-sectional area (CSA) or volume have been much more consistent (Table 2). Although increases have ranged from no change to about 20%, almost all studies have seen site specific muscle hypertrophy. Studies with non-significant changes have typically used techniques other than computed tomography (CT) or magnetic resonance imaging (MRI). The errors associated with anthropometric techniques, for example, make them insensitive to detecting hypertrophy on the scale typical of short-term resistance training studies in older adults, since they fail to account for the large amount of intramuscular fat in older adults (Kent-Braun et al., 2000). Harridge and colleagues (1999a) recently reported significant increases in MRI-derived lean tissue CSA but no significant change in gross CSA of the quadriceps, in frail elders after strength training. Again this demonstrates that it is imperative to use such techniques as CT and MRI to examine whole muscle group hypertrophy in response to resistance training in older adults.

For those studies showing significant increases, even using MRI or CT, however, there is still no relationship between the strength increase for the particular muscle group and the concomitant size change ($R < 0.10$, NS, averages for all studies in Table 2 using CT or MRI). This is not surprising since many of the studies lasted for only 2 to 3 months, and much of the early adaptation to training is thought to be neural (Sale, 1988).

Most of the studies investigated knee extensors so it is difficult to determine whether there are regional differences in the extent of hypertrophy. There is limited evidence from these studies that the arm may hypertrophy more than the leg (Roman et al., 1993; Welle et al., 1996); however, more research is needed to determine the regional responses to resistance training in older adults.

Recently, studies have also been reporting maximal voluntary strength relative to site specific muscle mass and referring to this as "muscle quality" (Tracy et al., 1999) and specific tension (Welle et al., 1996). Increases (Tracy et al., 1999; Welle et al., 1996) in strength relative to muscle mass have been found with resistance training in older adults. It is not surprising though, that when resistance training increases strength to a much greater extent than muscle size that an increase in specific strength is seen. However, it would be incorrect to say that this is due to the quality of the muscle, unless the force producing properties of the muscle fibres alone have been measured.

Table 2 Specific Limb or Muscle Group Area/Volume Changes With Resistance Training

Study	Subjects age, gender	Training period (weeks)	Strength change*	Muscle size change** (method)
Bermon et al., 1998	67–80 M W	8	↑15 % LP LE 1RM and PF (body weight corrected)	↔ lower limb (anthropometry)
Bernard et al., 1999	64 ± 7 M W	12	↑20% KE, hydraulic test	↑8% (CT thigh)
Brown et al., 1990	60–70 M	12	↑48% EF	↑17 % (CT EF)
Fiatarone et al., 1994	72–98 M W	10	↑120% 1RM KE LP	↑3% (CT thigh)
Fiatarone et al., 1990	90 ± 1 M W	8	↑174 % KE & KF	↑9 % (CT thigh)
Frontera et al., 1988	60–72 M	12	↑107% 1RM KE ↑10% cybex KE	↑9 % (CT KE)
Grimby et al., 1992	78–84 M	8	↑10% con, 16% ecc	↑3% (CT KE)
Häkkinen & Häkkinen, 1995	44–57 M W 64–73 M W	12	↑40 % KE	↑11% (US KE)
Häkkinen et al., 1998a	72 ± 3 M 67 ± 3 W	24	↑21 % dynamic ↑30 %	↑2 % (US KE) NS ↑6 %
Harridge et al., 1999	85–97 M W	12	↑134% 1RM	↑10% (MRI KE)
Hurley et al., 1995	50–69 M	16	↑45% KE LP	↑7% (MRI thigh)
Keen et al., 1994	59–74 M W	12	↑40 % MVC	↑4 % (MRI volume), ↑3 % (MRI CSA) 1st dorsal

				interosseous muscle
Kraemer et al., 1999	62 M	10	↑15% squat 1RM	↑6, 4, 8 % (MRI thigh, KF, KE)
McCartney et al., 1996	60–80 M W	100	↑32 % LP	↑9% (CT KE)
McCartney et al., 1995	60–80 M W	44	↑20% LP	↑6% (CT KE)
Moritani et al., 1980	67–72 M	8	↑25% EF	↑2% (anthropometry) NS
Rice et al., 1993	65–78 M	24	↑20% EE	↑9% (anthropometry) NS
Roman et al., 1993	67.6 ± 2.3 M	12	↑38 % EF	↑23% (MRI EF) ↑14% (MRI EF volume)
Sipila et al., 1995	76–78 W	18	***↑60% LP 1RM ↑40% LF 1RM	↑6% (CT KE) ↔ (CT KF) ↑6% (CT lower leg)
Taaffe et al., 1996	65–79 W	52	↑85% KE,↑50% LP, ↑65% KF	↔ (DPX thigh)
Tracy et al, 1999	65–75 M W	9	↑30 % 1RM LE	↑12 % (MRI KE volume)
Welle et al., 1996	60–72 M W	12	****↑29% EF, ↑68% KF, ↑42% KE 3RMs	9% EF, 1% KF, 6% KE (MRI)
Welsh & Rutherford, 1996	55–85 M W	24	↑50% KE	↑5% (anthropometry)

Note: *Strength changes are for one repetition maximum testing, unless noted otherwise. **Muscle changes are expressed as cross–sectional area (CSA) unless noted otherwise. ***Strength changes from Sipila et al., 1996. ****Strength changes from Welle et al., 1995. M = men; W = women; LP = leg press; KE = knee extensors; KF = knee flexors; EF = elbow flexors; RM = repetition maximum; PF = peak force; CT = computed tomography; MRI = magnetic resonance imaging; US = ultrasound; NS = not statistically significant; ecc = eccentric; con = concentric

Muscle Fibre Hypertrophy

Muscle fibre hypertrophy has been investigated, and positive results have been seen as a result of even very short-term resistance training (8 or 9 weeks; Table 3). The percent changes are typically greater than the relative hypertrophic results for whole muscles, by about 10%. Therefore, it appears that MRI and CT, while much more sensitive than other methods of determining whole muscle mass changes, may not be as sensitive as actually measuring fibre areas. Since MRI measures both muscle fibres (the contractile proteins) in addition to the connective tissue that surrounds the muscle fibres, we would expect smaller changes in MRI measured hypertrophy. Muscle histochemical techniques only measure the contractile proteins, and we would expect them to increase to a much greater extent than the connective tissue. Even with future resolution improvements (pixel size) in MRI, the estimation of muscle versus fat or connective tissue with this non-invasive technique will never be as sensitive as actually measuring the muscle fibres themselves.

Hypertrophy of both type I and type II fibres occurs. While there are discrepancies between studies as to whether the increases for type I or II fibres are equal, overall there appears to be no preferential hypertrophy of type II fibres. In part this could be due to movement speeds during training, which have quite often been suggested to be slow (Evans, 1999). However, even in younger subjects where training would not be expected to involve extremely slow contractions, hypertrophy of both fibre types occurs in response to a few months of resistance training (Abernethy et al., 1994).

Hakkinen and colleagues (1998b) investigated both CSA and proportion of the various fibre subtypes histochemically. They found hypertrophy of all fibre types as well as a decrease in type IIB proportion and concomitant increase in type IIAB proportion. Similarly, in a cross sectional study, older, long-term strength trainers were found to have a greater proportion of type IIA fibres, along with larger type IIA and IIB fibres compared to controls, swimmers, and runners of the same age (Klitgaard et al., 1990). These same strength trainers expressed a much lower amount of myosin heavy chain type I compared with the same age-matched subjects (Klitgaard et al., 1990). In response to a resistance training intervention, Welle and colleagues (1999) found a trend toward a decline in type IIX mRNA in older subjects. This is similar to research in younger subjects that has also demonstrated declines in IIX (or previously referred to as type IIB) proportions with resistance training (Staron et al., 1990). Other data on myosin expression comes from the work of Fiatarone Singh and colleagues (1999), who have shown that neonatal myosin heavy chain expression increased 2.5 times in very old, frail subjects in response to 10 weeks of resistance training. The authors suggested that this could indicate "hypertrophy of mature fibres or activation of either new myogenic precursor cells or severely atrophied fibres" (Fiatarone Singh et al., 1999). It is unknown whether similar results would be found in healthier and younger subjects than the 72- to 98-year-old nursing home residents in this study (Fiatarone Singh et al., 1999).

There are no data available on changes in specific force of single muscle fibres in older humans as a result of resistance training. This information would provide evidence as to whether muscle quality or specific tension changes with

Table 3 Muscle Fibre Area Changes

Study	Subjects	Training period (weeks)	Strength change	Fibre area change (Type I and II)
Brown et al., 1990	60–70 M	12	↑48%	↑14% I ↑30% II
Campbell et al., 1999a	50–75 M	12	↑30% KE 1RM	↑12% II only
Campbell et al., 1999b (mixed diet group)	51–69 M	9	↑37% KE 1RM	↑2% I, NS ↑16% II
Charette et al., 1991	64–86 W	12	↑60% KE + LP	↑7% I, NS ↑20% II
Ferketich et al., 1998	60–75 W	12	↑112% LE	↑20% I ↑22% II NS
Fiatarone Singh et al., 1999	72–98 M W	10	↑100 % ↑250%	↑5% I NS, ↓12% II NS (RT) ↑13% I NS, ↑10% II (RT + supp)
Frontera et al., 1988	60–72 M	12	↑107%	↑34% I, ↑28% II
Grimby et al., 1992	78–84 M	8 – 11	↑10% con, 16% ecc	↑8% NS I ↑5% NS II
Häkkinen et al., 1998b	61 ± 4 M	10	↑17% KE isometric	↑23% I, ↑39% IIa, ↑19% IIb
Hepple et al., 1997	65–74 M	9	↑62% LP	↑23% I & II combined

(continued)

Table 3 ***(continued)***

Study	Subjects	Training period (weeks)	Strength change	Fibre area change (Type I and II)
Lexell et al., 1995	70–77 M W	11	↑49% EF 1RM, ↑37% EF Cybex ↑160%KE 1RM ↑15% KE Cybex	↑13% I EF ↑17% II EF ↔ VL ↔ VL
Pyka et al., 1994	61–78 M W	15 30	↑33% KE and LP ↑60% KE and LP	↑29% I ↑58%I, ↑66% II
Roman et al., 1993	67.6 ± 2.3 M	12	↑38 % EF	↑23% NS I ↑37% II
Sipila et al., 1997	76–78 W	18	** ↑60% LP 1RM ↑14% KE isometric	↑34% I (0 to 196%) ↔ IIa
Taaffe et al., 1996	65–82 M	14 24	N/R	↑16% I, ↑12% II ↑12% I, ↑11% II
Taaffe et al., 1996	65–79 W	52	↑85% KE, ↑50%LP	↑28% I ↑22% II

Note: *Strength changes are for one repetition maximum unless noted otherwise. **Strength changes from Sipila et al., 1996. M = men; W = women; KE = knee extensors; LP = leg press; EF = elbow flexors; VL = vastus lateralis; RM = repetition maximum; con = concentric; ecc = eccentric; I = type I; II = type II; NS = not significant; RT = resistance training group; RT + supp = resistance training + nutritional supplement resistance training in older adults. With respect to overall strength change relative to fibre hypertrophy, though, there also appears to be no relationship here as with other indicators of hypertrophy. Again this points to the complex interplay of muscular and neural factors in strength gains attributed to resistance training, particularly short-term studies. In should be noted that Pyka and colleagues (1994a) examined muscle fibre hypertrophy over the longest time frame, 30 weeks, and found a very similar increase in strength of the knee extensors (60%) and hypertrophy of type I (58%) and type II (66%) fibres.

However, they did not find a relationship between fibre hypertrophy and strength changes. Only Lexell and colleagues (1995) has found a significant positive relationship between hypertrophy and strength improvements in leg extension. This was found with a variable that most authors do not examine, which is the proportional area of type 2 fibres. The same was not true for the arm flexors in the same subjects (Lexell et al., 1995).

Protein Synthesis

The synthesis of proteins in response to resistance training in older adults has been investigated in the whole body and within the specific muscle of interest, which has been the vastus lateralis (Table 4). No changes have been found in whole body protein synthesis as assessed by leucine kinetics following resistance training in older adults (Welle et al., 1995; Yarasheski et al., 1993; Yarasheski et al., 1995; Yarasheski et al., 1999) This probably reflects the fact that muscle protein synthesis only represents about 20 to 25% of whole body protein synthesis (Yarasheski et al., 1999). The excretion of 3-methylhistidine method, usually referred to as an indicator of myofibrillar protein breakdown, has had mixed results, with Frontera and colleagues (1988) showing a 40% increase and Yarasheski and colleagues (1999) reporting no significant change. The latter result could be due to the fact that the actual change in whole body muscle mass would have been quite low in the frail, very old (76 to 96 years) subjects (Yarasheski et al., 1999). In contrast there was a large increase in vastus lateralis fractional protein synthesis in these same subjects (Yarasheski et al., 1999). Increases in vastus lateralis protein synthesis have also been reported in relatively younger (62 to 75 years), older adults (Yarasheski et al., 1993; Yarasheski et al., 1995; Welle et al., 1999), ranging from 30 to 155%. Yarasheski and colleagues (1993) found that vastus lateralis specific protein synthesis increased three times as much in older subjects as compared to younger subjects in response to 2 weeks of resistance training, so that absolute rates were equal following training.

Implications for Training

The evidence is certainly available that strength training in older adults results in increased protein synthesis and hypertrophy that is measurable at the muscle fibre, whole muscle, and whole body levels. This effect is still possible in unhealthy and frail nursing home residents in their nineties. Typically, though, the strength increments associated with high intensity resistance training have been much larger than the hypertrophic response, leading to the conclusion that most of the adaptation to strength training is neural. While this may be true for short-term strength

Table 4 Protein Synthesis and Proteolysis Changes as a Result of Strength Training in Older Adults

Study	Subjects	Strength change	Training period (weeks)	Protein synthesis
Frontera et al., 1988	60–72 M	↑107% 1RM KE ↑10% cybex KE	12	↑41% 3–methylhistidine
Welle et al., 1995	62–72 M W	↑42% KE 3RM ↑44% overall 3RM	12	↔ vastus lateralis or 3–methylhistidine
Welle et al., 1999	62–75 M W	↑40% (from Welle et al., 1995, all subjects over 3 months)	1	↑30 % vastus lateralis
Yarasheski et al., 1995	64–75 M	↑60 % overall 1RMs ↑17% Cybex KE ↑45 % KE LP 1RM	16	↑50% vastus lateralis ↔ whole body or 3–methylhistidine excretion
Yarasheski et al., 1993	63–66 M W	N/R	2	↑155% vastus lateralis ↔ whole body
Yarasheski et al., 1999	76–96 M W	↑13% Cybex KE ↑35% 1RM KE LP	12	↑55% vastus lateralis ↔ whole body or 3-methylhistidine excretion

Note: M = men; W = women; RM = repetition maximum; KE = knee extension; LP = leg press; N/R = not reported.

training, less is known about the long-term hypertrophic response to high intensity resistance training in older adults. Presumably if functional performance, metabolic rate, and ultimately health outcomes are desired, then this training should continue over the long term in older adults to lessen the effects of sarcopenia.

In long-term strength trainers, studied cross sectionally, little muscle atrophy is evident compared to young untrained subjects (Klitgaard et al., 1990). However, when competitive Olympic-style lifters are studied cross-sectionally according to age, or when weight lifting ability is studied longitudinally, it is apparent that losses do occur with age (Meltzer, 1994). Therefore, it may be that loss of muscle mass and strength is inevitable with aging; however, the strength and power required for Olympic-style lifting would far exceed the strength and power requirements of everyday activities.

Power may be even more important for daily function and preventing falls than changes in strength alone (Bassey, 1997). With aging the decline in strength and muscle mass is accompanied by a slowing of contraction (Vandervoort and McComas, 1986), which may be due to a predominant reduction of type II muscle tissue or other changes in the muscles such as calcium or cross bridge kinetics. Recently training studies in older adults have used faster, high intensity contractions in order to successfully improve power as well as strength (Hakkinen et al., 1998a; Jozsi et al., 1999). Further research is required, however, on the transference of power increases measured in the laboratory to daily activity performance. Also, caution should be taken with these types of contractions because there is more potential for injury, although there are no specific reports on injuries associated with power training in older adults. Injuries have been reported to be higher during one repetition maximum testing than training itself (Pollock et al., 1991) so training programs, without a research intent, may be safer without maximal testing.

Muscle damage is also known to be greater following eccentric contractions (Clarkson & Sayers, 1999). Although almost all studies shown in Tables 1 to 4 have utilized eccentric contractions as part of their training program, the effects of eccentric contractions specifically on the muscles of older adults have not been investigated. When mixed contraction types (concentric and eccentric) have been done with repetition maximum training, direct evidence of muscle fibre disruption has been found (Fiatarone Singh et al., 1999; Roth et al., 1999; Roth et al., 2000). With these studies it appears that women (Roth et al., 2000) and the very old (Fiatarone Singh et al., 1999) may be affected to a greater extent, although all groups of subjects accomplished strength gains, and only minimal levels of muscle soreness were reported by another group of older men at the beginning of a resistance training program (Hurley et al., 1995).

While it may seem prudent to avoid eccentric contractions to avoid muscle damage, there is evidence that eccentric contractions may be required for hypertrophy (Walker et al., 1998) and improved neural activation strategies (Enoka, 1996). Porter and Vandervoort (1997) found that eccentric training alone lead to increases in both concentric and eccentric ankle dorsiflexor strength, while 8 weeks of concentric training in the ankle plantar flexors of the same subjects did not change either concentric or eccentric strength.

Conclusion

Hypertrophy, is a positive effect of high intensity resistance training programs, even in the very old. Most studies have been quite short relative to the ages of the subjects studied, so the long term effects of preventing and/or restoring muscle mass losses that occur with aging are not known. For these short term studies, though, it is clear that protein synthesis, whole body muscle mass, specific muscle CSA or volume, and muscle fibre size increases occur with resistance training. Of the size changes, the largest relative increases, on average, occur in muscle fibre size, while protein synthesis increases have been reported to be as large as 155%.

Although hypertrophy is evident, strength increases usually always surpass the whole body, whole muscle, or muscle fibre size enhancements with training. This points to the neural adaptations that also occur with resistance training. At present it is clear that high intensity resistance training that is done 2 to 3 days per week will lead to strength and muscle mass increases, and therefore the American College of Sports Medicine (1998a, 1998b) recommends that strength training become a integral part of physical activity programming for older adults and in particular frail older adults who stand to gain the most. Future research is needed though to define the most optimal type(s) of resistance training programs to prevent sarcopenia, improve health, and ensure the independence of our oldest citizens.

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