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A Study of Muscle Mass, Composition, Fiber Characteristics and Isometric Strength

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To my parents Ritva and Olavi Särkkä

ABSTRACT

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The relationship between physical training and the properties of skeletal muscle in elderly women was examined by comparing 66-85-year-old female athletes and untrained controls and by investigating the effects of 18 weeks of strength and endurance training in 76-78-year-old women. The strength group trained the thigh and calf muscles on apparatus using compressed air as a resistance and the training of the endurance group included track walking and step aerobics. Quadriceps muscle mass and composition were measured using ultrasonography (US) and computed tomography (CT). Knee flexor muscle mass and composition was measured using CT. A quantitative US was developed for the analysis of muscle composition. In the experimental study, needle biopsies were taken from the vastus lateralis, and the relative proportion of different fiber types and their cross-sectional areas (CSA) were determined. To evaluate muscle strength, maximal isometric knee extension (KE) and flexion force were measured. The athletes had higher quadriceps muscle CSA and KE force and less fat in the thigh muscles than the controls. Strength training increased the CT-measured CSA of the quadriceps and type I fiber CSA of the vastus lateralis. When comparing the baseline and 18-week measurements within the strength group, the mean grey shade of the vastus lateralis, obtained from the US scans, was lower and that of the femur higher after training, suggesting a decreased proportion of fat in the muscle. The effects of endurance training on muscle mass, composition and fiber characteristics were negligible. Both strength and endurance training increased isometric KE force. The results indicate that female athletes preserve superior muscle mass and performance up to old age and that physical training, started in old age, also improves the properties of skeletal muscle. The results also point to the usefulness of quantitative US in studying skeletal muscle composition in elderly women.

Key words: aging, athletes, computed tomography, endurance training, exercise, fiber types, isometric force, muscle biopsy, quadriceps femoris, strength training, ultrasonography

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CONTENTS

LIST OF ORIGINAL ARTICLES

The thesis is based on the following articles which will be referred to in the text by their Roman numerals:

I Sipilä, S. & Suominen, H. 1993. Muscle ultrasonography and computed tomography in elderly trained and untrained women. Muscle & Nerve 16, 294-300.

II Sipilä, S. & Suominen, H. 1994. Knee extension strength and walking speed in relation to quadriceps muscle composition and training in elderly women. Clinical Physiology 14, 433-442.

III Sipilä, S. & Suominen, H. 1995. Effects of strength and endurance training on thigh and leg muscle mass and composition in elderly women. Journal of Applied Physiology 78, 334-340.

IV Sipilä, S., Multanen, J., Kallinen, M., Era, P. & Suominen, H. 1996. Effects of strength and endurance training on isometric muscle strength and walking speed in elderly women. Acta Physiologica Scandinavica (in press).

V Sipilä, S. & Suominen, H. Quantitative ultrasonography of muscle: effects of training in elderly women. Submitted for publication.

VI Sipilä, S., Elorinne, M., Alén, M., Suominen, H. & Kovanen, V. Effects of strength and endurance training on muscle fiber characteristics in elderly women. Submitted for publication.

1 GENERAL INTRODUCTION

There has been an increase in the relative proportion and life-expectancy of elderly people during recent decades in the industrialized countries. Consequently, the number of diseases and disabilities related to aging has increased. Functional decline and impaired mobility affect the ability of elderly people to live independently. This is especially true of elderly women who have a lower functional capacity (Bassey et al. 1992, Danneskiold-Samsoe et al. 1984, Frontera et al. 1991, Häkkinen & Pakarinen 1993, Rice et al. 1989) and longer life span (Valkonen et al. 1992) than elderly men.

Age-related deterioration in muscle performance is one of the major factors resulting in diminished functional capacity among elderly people. Muscle performance is affected by both structural and functional changes, such as muscle atrophy and decreased muscle strength. The contribution of external factors, the most important of which is the level of physical activity, to these changes observed during aging needs to be elucidated.

Muscle mass and its possible adaptation have traditionally been assessed by anthropometry or muscle fiber cross-sectional area obtained from needle biopsy. The former method has, however, been criticized for insufficient specificity and the latter for poor representativeness in relation to human muscle. Imaging modalities, such as computed tomography, employing ionizing radiation and nuclear magnetic resonance imaging which is still rather uncommon as well as expensive, enable a more specific evaluation of the cross-sectional area of entire muscle or muscle group compartment. Total cross-sectional area of the muscle compartment is not, however, sufficient to show muscle tissue adaptation. Fat infiltration into the muscle, often observed in elderly people, and possible changes in it may mask real changes in the muscle tissue itself. Therefore, specific and noninvasive feasible methods are required to evaluate exercise-induced changes in the muscles of elderly people.

This study examines the relationship between physical training and muscle mass, composition and strength in elderly women by comparing 66- to 85-year-old female athletes and untrained controls. In addition, the effects of 18 weeks of strength and endurance training on muscle mass, composition, fiber characteristics and strength in 76-78-year-old women were studied. The usefulness of quantitative ultrasonography as a muscle research method in elderly women is also evaluated.

2 REVIEW OF THE LITERATURE

2.1 Properties of skeletal muscle and related measurements

2.1.1 Macroscopic structure

Skeletal muscle is composed of both contractile, force generating and non-contractile, force transmitting elements. Large muscle groups are surrounded by a thick connective tissue fascia, called the epimysium. For example, in the thigh three fasciae separate the anterior muscle group (quadriceps femoris) from the medial (adductors) and posterior (hamstrings) groups. Each separate muscle inside the muscle compartment, such as the four different muscles in the quadriceps femoris, is also enveloped by a separate sheet of connective tissue. A bundle of several muscle fibers is in turn surrounded by a dense layer of perimysial connective tissue. Adipose tissue lies between the skin and epimysium and also between separate muscles and muscle fibre bundles.

Muscle mass has generally been roughly estimated by anthropometric measurements, such as limb girth. Even though subcutaneous fat can be excluded by using measurements of skinfold thickness, the need for a more specific method for studying muscle mass has been emphasized. A more specific measurement of the cross-sectional area (CSA) and thickness of a total muscle compartment excluding bone and subcutaneous fat can be obtained using two-dimensional ultrasonography (US), which was the first imaging technique used to measure muscle mass more directly in humans (Ikaia & Fukunaga 1968). In US imaging a short pulse of acoustical energy is used to construct an image of the body on the basis of the strength of the echoes. An echo is formed whenever two tissues with a different acoustical impedance property, determined mainly by tissue density, exist side by side. More recently, computed tomography (CT) has been the preferred imaging modality for the evaluation of the CSA or volume of skeletal muscle. CT scanning is based on the computation of the cross-sectional distribution of X-ray attenuation to form an image that represents the tissue composition of the body. However, it seems that CT overestimates CSA by 10-20% when compared to the anatomical CSA obtained from cadavers (Engstrom et al. 1991, Hudash et al. 1985) or cow bones (Cheng et al. 1995).

In order to get more information about the muscle compartment, the echogenicity pattern of US scans has been evaluated as an indicator of connective and fat tissue infiltration (Heckmatt et al. 1988, Sipilä & Suominen 1991). The data have, however, been more or less descriptive. Quantitative data on muscle composition can be obtained for lean and fat tissues by CT using radiological density (Hounsfield unit, HU, see Styz & Frieden 1990). However, ethical and practical problems related to the use of ionizing radiation may inhibit the use of CT. Consequently, the development of US imaging to obtain more quantitative information concerning muscle composition is needed.

2.1.2 Microscopic structure

A thin sheath of connective tissue, called the endomysium, envelopes individual muscle fibers. The basal membrane and the sarcolemma, which is a permeable membrane capable of transmitting electrical current, are located beneath the endomysium. The alpha-motoneuron and associated muscle fibers, which are similar with respect to their metabolic and structural characteristics, constitute a motor unit. Different fiber types can be separated histochemically by the reaction for myosin ATPase and pH lability in this reaction (Padykula & Herman 1955). Type I fibers with a predominantly oxidative energy metabolism include slow myosin heavy and light chain. Fast type II fibers are further divided into oxidative glycolytic (IIa) and glycolytic (IIb) fibers with typical combination of myosin heavy and light chains. In addition, several intermediate fiber types, such as, IIab, IIc and Ic, have been proposed on the basis of myosin ATPase reaction (Staron & Pette 1986). Type I fibers have a lower ATPase activity when compared to type II fibers (Schluter & Fitts 1994).

Human muscles contain a random scattering of type I and type II fibers, creating a mosaic appearance in the cross-sections. A study of the whole vastus lateralis in cadavers showed that the proportion of different fiber types varies as a function of depth, type II fibers predominating the superficial and type I fibers the deeper parts of the muscle (Lexell et al. 1983). In younger people especially, type II fiber proportion is higher around the border of fascicles than internally (Sjöström et al. 1992). Fiber cross-sectional area also seems to vary as a function of depth, larger fibers being observed in the deeper parts of muscle (Lexell & Taylor 1989).

2.1.3 Muscle contraction

Muscle contraction is initiated when the actiopotential from the motor nerve excites the sarcolemma of the muscle fibers, resulting in interaction between actin and the globular head of the myosin molecule with its ATPase activity. Muscle contraction is a result of the relative sliding of the two filaments during the ATP hydrolysis. Contraction velocity is proportional to the amount of APTase activity (Barany 1967, Schluter & Fitts 1994). Tendons, which are formed by the intramuscular connective tissue sheath, transmit the force produced during the muscle contraction.

The contractile tension of muscle increases with muscle length and reaches its peak when the muscle is in resting position. This is in accordance with the force-length relationship of the sarcomeres, which states that the force produced by the sarcomere is proportional to the overlap between the actin and myosin molecules (Gordon et al. 1966). It is also widely accepted that the maximal force produced by the muscle is directly proportional to its CSA. Some discrepancies, however, exist concerning the relationship between the maximal force and fiber composition of muscle. Some of the earlier studies have suggested that type II fibers are able to exert greater force than type I fibers (Komi et al. 1977, Tesch & Karlsson 1978). However, it has also been reported that there is no significant relationship between muscle force and fiber composition (Maughan & Nimmo 1984, Thorstensson 1977).

The maximal voluntary force produced during muscle contraction can be measured using dynamometers. The one repetition maximum (1 RM), the resistance which can be performed by a muscle throughout the full range of motion on a single occasion, has also been used as an indicator of muscle strength. Isokinetic devices are used whenever muscle force produced during specific shortening velocities is under consideration.

2.2 Effects of aging on skeletal muscle

2.2.1 Muscle mass, composition and fiber characteristics

Several cross-sectional studies have shown a reduced total muscle CSA in elderly men (Borkan et al. 1983, Overend et al. 1992, Vandervoort & McComas 1986, Young et al. 1985) and women (Häkkinen & Häkkinen 1991, Vandervoort & McComas 1986, Young et al. 1984) when compared to younger subjects. The difference in muscle CSA seems to be more pronounced between the ages of 50 and 70 than between the young and middle-aged groups (Häkkinen & Häkkinen 1991), reflecting acceleration in muscle atrophy after the fifth decade. This phenomenon is also clearly shown by Lexell et al. (1988). In a follow-up study by Greig et al. (1993), the CSA of the quadriceps muscle decreased 0.8% per annum between the mean ages of 74 and 82.

The age-related decrease in muscle mass is related to the reduction in muscle fiber CSA. Essen-Gustavsson & Borges (1986) have shown that both type I and type II fiber CSA is smaller in older men and women when compared to the younger subjects. However, several studies suggest that type II fibers are more vulnerable to aging process than type I fibers (Aniansson et al. 1986, Grimby et al. 1982, Larsson & Karlsson 1978, Larsson et al. 1979, Lexell et al. 1988) resulting in decreased type II/I fiber area ratio (Aniansson et al. 1986, Clarkson et al. 1981, Larsson & Karlsson 1978). In their autopsy studies Lexell et al. (1983, 1988) have, however, shown that the main cause for the aging atrophy in m. vastus lateralis is decreased number of both type I and type II fibers. An age-related decrease in fiber number has also been observed in m. pectoralis minor in women (Sato et al. 1984) and in experimental animal studies (Edström & Larsson 1987). The loss of entire motor units seen in old age (Brown et al. 1988, Edström & Larsson 1987) may result in compensatory hypertrophy (Aniansson et al. 1992, Sato et al. 1984) and fiber type grouping (Edström & Larsson 1987, Grimby et al. 1982, Lexell et al. 1986) as well as increase in the size of the remaining motor units (Campbell et al. 1973, Edström & Larsson 1987).

In elderly people, fast and slow fiber types are fairly homogeneously represented throughout the whole vastus lateralis muscle (Lexell et al. 1983, 1988). In addition, higher type I and lower type II fiber proportions have been shown in elderly men when compared to younger ones (Larsson & Karlsson 1978, Larsson et al. 1979). Klitgaard et al. (1990) have also shown that elderly men have higher myosin heavy chain (MHC) type I and lower MHC IIa and IIb content than younger men in the vastus lateralis muscle. Although an age-related shift towards slower fiber types has been proposed by Aniansson et al. (1992) in elderly men and by Edström & Larsson (1987) and Kovanen & Suominen (1987) in experimental animal studies, some disagreement also exists (Clarkson et al. 1981, Essen-Gustavsson & Borges 1986, Grimby et al. 1982).

Age-related muscle atrophy is accompanied by fat infiltration (Baumgartner et al. 1992, Borkan et al. 1983, Overend et al. 1992, Rice et al. 1990) as well as an increased amount of endomysial and perimysial connective tissue in the muscle (Alnaqeeb et al. 1984, Kovanen et al. 1987). In the study by Lexell et al. (1988), muscle fibers accounted for only 50% of the CSA of the whole vastus lateralis muscle of elderly men.

2.2.2 Muscle strength

Elderly men and women have lower muscle strength when compared to the younger subjects and the greater muscle strength of men when compared to the women is perceived up to old age (Frontera et al. 1991, Stålberg et al. 1989, Vandervoort & McComas 1986). Some cross-sectional studies have shown that muscle strength peaks at the age of 30 and begins a steeper decline after the age of 50 (Larsson & Karlsson 1978, Larsson et al. 1979, Vandervoort & McComas 1986). Skelton et al. (1994) have shown in their cross-sectional study that muscle strength declines 1 to 2% per annum in healthy women older than age 65. Between the ages of 69 and 80, both isometric and isokinetic knee extension strength decreased 25-35% in elderly men (Aniansson et al. 1992), although Greig et al. (1993) showed a mean decrease of only 0.3% per annum during an 8-year period (74-82-years) in elderly men and women who had retained good health during the follow-up. Some evidence exists concerning lower specific tension (strength/CSA) in elderly compared to younger people (Overend et al. 1992, Phillips et al. 1992, Young et al. 1985). This has also been shown in both the soleus and plantaris muscle in old rats (Klitgaard et al. 1989b). However, Young et al. (1984) failed to show significant differences in strength/CSA between elderly and younger women.

The speed of contraction is also affected by aging. Elderly people have a lower movement velocity (Larsson et al. 1979) and maximal rate of force production (Häkkinen & Pakarinen 1993, Bemben et al. 1991) compared to younger subjects. Both human (Vandervoort & Hayes 1989, Vandervoort & McComas 1986) and experimental animal studies (Edström & Larsson 1987, Klitgaard et al. 1989b) have shown electrically-evoked contraction time and half-relaxation time to be longer in an elderly compared to younger study group.

2.3 Effects of physical training on aging skeletal muscle

The effects of physical training on skeletal muscle in elderly people have been studied using both cross-sectional and experimental designs. In cross-sectional studies several other aspects, such as genetic factors, occupation and nutrition, together with physical training, may contribute to the results. However, cross-sectional designs are an economic way to approach long-term training effects. Causal relations can be more specifically evaluated in longitudinal training studies, providing that the study design is properly planned and an adequate control group is included. The results of published experimental trials show some discrepancies arising out of differences in study design, training protocol, age of subjects, muscle under investigation, and method used. Moreover, most such trials have been conducted in men or the results obtained from men and women have been combined. Furthermore, surprisingly few have included a control group in the study design. As a result, more knowledge concerning the effects of physical training on aging skeletal muscle, especially in women, is required.

2.3.1 Muscle mass, composition and fiber characteristics

It is well known that young resistance-trained athletes have larger muscle mass than their endurance-trained (Alway et al. 1988, Tsunoda et al. 1985) or untrained (Alway et al. 1988, Sale et al. 1987) age-peers. However, the results obtained from studies investigating training-induced changes on muscle mass in elderly people vary considerably. Table 1 presents a list of both cross-sectional and experimental studies conducted in elderly men and women relating to physical training and total muscle CSA. In the study by Klitgaard et al. (1990), elderly strength-trained athletes had a higher quadriceps and elbow flexor CSA when compared to untrained controls. In the same study, the strength-trained athletes also had a larger quadriceps CSA than the elderly swimmers and larger elbow flexors than the swimmers and runners. No difference, however, was observed in quadriceps CSA between the strength-trained men and the runners. In our earlier study (Sipilä & Suominen 1991), we also found quadriceps CSA to be on the average 8% larger in both endurance- and strength-trained veteran athletes compared to untrained controls. The difference was not, however, statistically significant.

Some experimental studies have shown considerable differences in the total muscle CSA measured before and after only 2 to 3 months of strength training in elderly people (Brown et al. 1990, Frontera et al. 1988, Häkkinen & Häkkinen 1995, Häkkinen et al. 1995, Roman et al. 1993). The differences observed were almost equal to those observed between elderly athletes and untrained subjects. However, no control groups were included in those studies and also much smaller changes have been reported. Fiatarone et al. (1994) failed to show any noticeable change in total thigh muscle CSA after a resistance training regimen in a group of very old men and women. In addition, the 9-11% increase in the quadriceps and thigh muscles observed in their earlier study (Fiatarone et al. 1990) was significant only at the level of $p=0.09$ and $p=0.05$, respectively, when using the one-tailed t-test. Also a very small, although significant, difference was observed in quadriceps CSA measured before and after 8-12-weeks of strength training in elderly men (Grimby et al. 1992).

Quadriceps muscle composition measured using US (Sipilä & Suominen 1991) revealed lower intramuscular echo intensity and higher echo intensity reflected from the connective tissue structures and bone in endurance and strength-trained athletes compared to untrained men. The results suggest increased infiltration of fat in the muscle of the untrained men. On the other hand, no changes in intramuscular fat measured by CT (Fiatarone et al. 1990, Grimby et al. 1992) or in the other noncontractile tissues analyzed from muscle biopsies (Roman et al. 1993) were observed after strength training in elderly subjects. No control groups were, however, included in those studies and the strength training applied lasted only for 2 to 3 months.

The difference between elderly athletes and untrained age-peers is also observed at muscle fiber level. Elderly strength-trained athletes had a larger CSA, especially of type IIa and IIb fibers in the vastus lateralis muscle, than endurance-trained athletes or untrained controls, whereas the fiber CSAs of the endurance athletes were similar to those of the age-matched controls (Klitgaard et al. 1990). On the other hand, Coggan et al. (1990) have shown endurance-trained elderly athletes to have larger type I fibers compared to younger runners. However, life-long endurance training in Wistar rats resulted in smaller type I fibers in the soleus and type IIb fibers in rectus femoris (Kovanen & Suominen 1987).

Experimental studies investigating the effects of physical training on muscle fiber characteristics in elderly people have usually compared post- and pretraining levels within the training groups. Hypertrophy of both type I and type II fibers in the vastus lateralis (Frontera et al. 1988, Larsson 1982) and in

TABLE 1 Summary of studies on muscle CSA and physical training in elderly men and women. Mean ± SD or range is given.

Reference	Age (years)	n	Sex	Group/training	Training time	Muscle	Technique	Training effect, %	Comments
Brown et al. (1990)	60-70	14	M	Weight-lifting	12 wks	Elbow flx. Knee flx. Knee ext.	CT	+ 15* + 4* + 10*	Other arm as control No control group
Fiatarone et al. (1990)	86-96	10	M+F	Strength training	8 wks	Thigh-muscle Quadriceps Knee flx.	CT	+ 9 + 11 + 8*	No control group
Fiatarone et al. (1994)	72-98		M+F	Resistance training	10 wks	Thigh-muscle	CT	+ 3	Change in exercise vs. control group
Frontera et al. (1988)	60-72	12	M	Strength training	12 wks	Thigh-muscle Quadriceps	CT	+ 10-11* + 9-12*	No control group
Grimby et al. (1992)	78-84	9	M	Strength training	8-12 wks	Thigh-muscle	CT		Exact values not reported,
						Quadriceps		+ 3*	no control group
Häkkinen & Häkkinen (1995)	64-73 66-73	10 11	M F	Combined strength and explosive	12 wks	Quadriceps	US	+ 10* + 9*	No control group
Häkkinen et al. (1996)	59-75 62-75	12 12	M F	Strength training	12 wks	Quadriceps	US	+ 10-11* + 12-17*	No control group
Klitgaard et al. (1990)	69 ± 3	6	M	Swimmers	12-17 yrs	Quadriceps Elbow flx.	CT	- 2 - 6	Difference between trained and untrained
	70 ± 2	5		Runners		Quadriceps Elbow flx.		+ 5 - 2	
	68 ± 2	7		Strength		Quadriceps Elbow flx.		+ 14* + 24	
	68 ± 1	8		Untrained					

Continued overleaf

Table 1 contd

Reference	Age (years)	n	Sex	Group/training	Training time	Muscle	Tech-nique	Training effect, %	Comments
Magnusson et al. (1994)	42-69	6		Strength and endurance Endurance and control	8 wks	Quadriceps	MRI	+ 4	Change in strength vs. endurance/ control
Roman et al. (1993)	68 ± 5	5	M	Heavy-resistance training	12 wks	Elbow flx. Elbow flx.	MRI	+ 23* + 14*	No control group Muscle volume studied
Sipilä & Suominen (1991)	77 ± 4 74 ± 3 73 ± 2	7 14 11	M	Power Endurance Untrained	43-70 yrs 15-65 yrs	Quadriceps	US	+ 8 + 8	Difference between trained and untrained

* Statistically significant ($p<0.05$). CT=computed tomography, ext.=extensor, F=female, flx.=flexor, M=male, MRI=magnetic resonance imaging, US=ultrasonography.

the biceps brachii (Brown et al. 1990) muscles has been suggested to occur after only 2 to 3 months of strength-training in men ranging from 56 to 72 years of age. In somewhat older men and women, Pyka et al. (1994) found an increase in type I fiber CSA during the first 15 weeks of strength training after which type II fibers were mostly affected. Strength training-induced hypertrophy of both major fiber types is supported by experimental animal studies (Goldspink & Howells 1974, Klitgaard et al. 1989a). An increase in both type I and type IIa fiber CSA of the lateral gastrocnemius was also found after endurance-type training in 60 to 70 year old men and women (Coggan et al. 1992) as well as in 29-month old rats (Klitgaard et al. 1989a). In the study by Charette et al. (1991) and Roman et al. (1993) only type II fiber CSA increased significantly after resistance training, and Aniansson et al. (1981) even reported a significantly smaller type I fiber CSA after a light resistance training program in elderly people. On the other hand, Grimby et al. (1992) failed to show any changes in either type I or type II fibers after around 3 months of strength-training in 78-84-year-old men. Increased fiber number, shown in experimental animals (Gonyea 1980, Klitgaard et al. 1989a), may partly explain a training-induced increase in muscle mass. Unfortunately, only some of the above-mentioned human studies included a control group and even in those studies the change observed in the control group was not taken into account when reporting the training effect.

The relative proportion of type I fibers was higher in the vastus lateralis of elderly endurance athletes compared to untrained controls (Klitgaard et al. 1990, Suominen et al. 1980). Life-long endurance training also resulted in a higher proportion of slower fiber types in Wistar rats (Kovanen & Suominen 1987). In elderly men and women, endurance training for 1 year did not effect the proportion of type I fibers in the lateral gastrocnemius, but in the fast fiber subpopulation a significant shift towards slower fiber types was observed (Coggan et al. 1992). Elderly strength-trained athletes, on the other hand, seem to have a lower proportion of type I and higher proportion of type IIa fibers when compared to the controls or endurance-trained veteran athletes (Klitgaard et al. 1990). Although light resistance training for 12 weeks in elderly men increased the proportion of type IIa fibers and decreased that of type I (Aniansson et al. 1981), most of the experimental studies failed to show any strength training-induced changes, whatsoever, in the proportion of fiber types in elderly people (Brown et al. 1990, Charette et al. 1991, Frontera et al. 1988, Grimby et al. 1992, Larsson 1982, Roman et al. 1993).

2.3.2 Muscle strength

It is evident that young and middle-aged strength-trained athletes are stronger than endurance athletes or untrained age-peers (Alway et al. 1988, Sale et al. 1987, Suominen et al. 1989). However, when older athletes are considered, not only strength- and speed-trained but also endurance athletes seem to have higher muscle strength than untrained men (Sipilä et al. 1991). Elderly physically active women (endurance and power athletes combined) also seem to be stronger than untrained controls (Rantanen et al. 1993). On the other hand, in their study Klitgaard et al. (1990) found only strength-trained elderly athletes to be stronger than untrained controls, with no significant difference between swimmers, runners and untrained age-peers. In the same study, however, no significant difference was observed in knee extension torque between strength-trained athletes and runners.

Experimental studies investigating the effects of physical training on muscle strength in elderly people have shown strength gains after only 2 to 3 months of strength training. However, most such studies were not properly controlled, and the changes observed vary considerably. Mean increases of over 100% in the 1 RM have been observed after only few months of strength training in both elderly men (Frontera et al. 1988) and women (Charette et al. 1991) and in a group of very old men and women (Fiatarone et al. 1990, 1994). However, in their controlled 1-year resistance training study Morganti et al. (1995) found considerably smaller (30-60%), although significant changes in the 1 RM in 50-70-year old women. Similar smaller changes have also been observed in both controlled (Rice et al. 1993, Skelton et al. 1995) and uncontrolled studies (Brown et al. 1990, Häkkinen & Häkkinen 1995, Häkkinen & Pakarinen 1993) in isometric and isokinetic (Brown et al. 1990, Frontera et al. 1988, Roman et al. 1993) muscle strength after dynamic strength training programs in elderly people. In general, studies investigating the effects of dynamic strength-training programs on different muscle contraction types in elderly people have shown the changes in the 1 RM measured using training apparatus to be clearly greater than those obtained under isokinetic or isometric conditions (Brown et al. 1990, Frontera et al. 1988). A high degree of specificity observed in 1 RM measurements, however, probably also includes a strong learning effect.

The effects of more traditional gymnastics, including weight-bearing exercises, on muscle strength have also been evaluated in elderly people. A few months of training resulted in increased isometric and isokinetic muscle force in elderly men (Aniansson et al. 1981, Brown & Holloszy 1991) and women (Brown & Holloszy 1991). However, 6 months of light resistance and aerobic training did not increase knee extension strength in 63-to 88-year old women (Agre et al. 1988).

The results in respect of change in muscle contraction velocity after physical training in elderly subjects. are somewhat contradictory. Strength training for 24 weeks increased electrically-evoked time to peak tension and decreased the maximal rate of torque development (Rice et al. 1993). When strength training was conducted together with explosive types of exercise, the maximal rate of force production increased after only 8 weeks of training in both elderly men and women (Häkkinen & Häkkinen 1995). In old experimental animals strength training decreased the time to peak tension and also half-relaxation time, whereas the effects of swimming were negligible (Klitgaard et al. 1989b).

3 PURPOSE OF THE STUDY

The present study was undertaken to gain further knowledge about the effects of physical training on skeletal muscle in elderly women. The study compared 66- to 85-year-old female athletes and untrained controls, investigated the effects of 18-weeks of strength and endurance training in 76-78-year-old women and evaluated the usefulness of quantitative ultrasonography as a muscle research method in elderly women. More specifically, the purpose was:

1) To examine the differences between elderly female athletes and untrained controls in
   i) the CSA and composition of the quadriceps (I,II) and knee flexor compartment, and
   ii) voluntary isometric knee extension force (II).

2) To study the effects of 18 weeks of strength and endurance training on
   i) the CSA and composition of the quadriceps (III, V), knee flexor and hamstrings compartments (III),
   ii) the relative occurrence and CSA of the major fiber types in the vastus lateralis muscle (VI), and
   iii) voluntary isometric knee extension and flexion force (IV) in elderly women.

3) To evaluate US imaging as a muscle research method
   i) in comparing muscle mass and composition in elderly female athletes and untrained controls in relation to CT scanning (I, II), and
   ii) in the quantitative analysis of muscle mass and composition when studying the effects of short-term physical training in elderly women (V).

4 MATERIAL AND METHODS

4.1 Subjects

4.1.1 Physically active women and controls (I, II)

Sixty female athletes, aged 66 to 85 years, were selected from the members of Finnish sports organisations. Most of the athletes had a lifelong training history and all of them were still physically active, participating in various sports (long-distance running, cross-country skiing, track and field, and gymnastics). A random sample of 70- to 81-year-old women constituted a control group. From these groups, 21 athletes still active in competitive sports (mean age 73.7, range 66-85) and 15 randomly selected control women (mean age 73.6, range 70-81) were selected for this study.

The athletes were generally healthier than the controls the mean number of chronic diseases being 2 and 4, respectively. The most prevalent chronic condition was arthritis in the athletes (52%) and hypertension in the controls (73%). Of the athletes one woman had been taking estrogen (15 years), one estrogen and progestin (7 years) and two thyroxine (20 years) medication. One control woman had been taking thyroxine (3 years) and another insulin (2 years).

Detailed information on sampling procedures, participation rates and the training history of the subjects are given in the original reports referred to.

4.1.2 Exercise intervention (III, IV, V, VI)

A random sample of 240 women aged 76 to 78 years was drawn from the population register of the city of Jyväskylä. Of this sample, 64 women reporting no severe diseases or functional impairments were invited for clinical and laboratory examinations. The sample was further reduced to 42 women with no contraindications to strenuous exercise. Subjects were excluded if they had unstable chronic diseases, rapidly progressive illnesses, endoprothesis or any impairment that interfered with mobility. The subjects were randomly assigned to strength (n=16), endurance (n=15) and control groups (n=11). Twelve subjects from the strength, 12 from the endurance and 11 from the control group completed the study. Of the seven women who withdrew from the study, six were excluded because of disease and illness and one was unwilling to continue because of lack of time in her daily schedule.

The study groups did not differ with respect to health status. One woman from the strength, one from the endurance and two from the control group had been taking estrogen medication on average for 17 years (range 15-20 years) preceding the study. One woman from the strength and another from the endurance group were using thyroxine for hypothyreosis. They were euthyreotic during the study. Two women from the strength group had permanent oral prednisolon treatment due to chronic pulmonary asthma.

4.2 Measurements

The laboratory assessments and the variables reported in the original papers are listed in Table 2. This summary reports only those related to the anthropometry and the CSA, composition, fiber characteristics and strength of the thigh muscles.

In the experimental study, the CT measurements and muscle biopsies were obtained at the beginning of the study and after 18 weeks of training. Besides the baseline and 18-week measurements, anthropometry, US and muscle force measurements were also performed after 9 weeks of training. In the baseline measurements the study groups did not differ with respect to any of the physical, muscle tissue or strength characteristics under investigation.

Detailed information about the measurements and their reproducibility in duplicated determinations are given in the original reports referred to.

4.2.1 Anthropometry

Conventional methods were used to measure body mass and body height. Lean body mass and body fat were determined using bioelectrical impedance.

4.2.2 Muscle CSA and composition

The CSA and composition of the thigh muscles were evaluated from the midpoint between the great trochanter and lateral joint line of the knee on the side of the dominant hand.

The CSA of the quadriceps femoris compartment was assessed using a compound US (I, V) and a CT scanner (I,II,III). In addition, the CT scanner was used to measure the CSA of the knee flexor muscle compartment (i.e., hamstrings, gracilis, sartorius, and adductors, III) and lean tissue CSA together with relative proportion of fat inside both the quadriceps (I,II,III) and knee flexor compartments (III). In experimental study (III), respective CT measurements were also conducted for the hamstrings. The results for the knee flexor compartment obtained from the elderly athletes and controls have not been reported earlier.

Muscle composition was analyzed from compound and real-time US scans. The discernibility of fasciae, intramuscular septa formation, intramuscular echo intensity and the discernibility of the femur were evaluated on a four-point scale by two blind observers (I). The sum of the intramuscular echo intensity and the discernibility of the femur obtained from the real-time scans were further used as a muscle index (II).

Quantitative US was further developed for the experimental study (V). A composite videosignal was captured from the real-time scanner and the US image transferred to the computer for the grey scale analysis. The vastus lateralis and the echo reflected from the femur were encircled and a computer image analysis program was used to analyze the grey scale histogram from the encircled areas. Shade 1 represented the black, echo-poor area and shade 64 the most white, high intensity echo area. The weighted mean grey shades of the vastus lateralis (MGS_{VL}) and femur (MGS_F) were calculated from the histograms.

4.2.3 Muscle fiber characteristics

In the experimental study (VI), needle muscle biopsies were obtained from the mid-region of the vastus lateralis muscle under local anaesthesia before and after the training period. A US scanner and the scale marked on the biopsy needle were used to evaluate the site and depth for taking the sample. The results are given for those 7 women in the strength, 9 in the endurance and 7 in the control group who yielded acceptable samples in both the baseline and 18-week measurements.

Transverse sections of 10 µm were stained for myofibrillar ATPase at pH 9.4 after preincubation at pH 4.3, 4.5, and 10.3. Cross-sectional areas for type I, IIa, IIb, IIab and IIc fibers were analyzed from the whole section. An image processor was used for the analysis. Due to the scarcity of the muscle fiber subtypes IIab and IIc and the absence of IIb fibers, the IIab and IIc fibers were combined and named as intermediate fibers in the results. The frequency histograms for the cross-sectional areas were analyzed for type I and type IIa fibers.

TABLE 2 The variables measured in the original studies and the methods used.

Variables	Studies	Methods/References	CV[1]
Anthropometry			
Body height	I-VI		
Body mass	I-VI		
Lean body mass	IV, V	BIA, Spectrum II, RJL System	<2
Body fat	II-VI	BIA, Spectrum II, RJL System	<3
Thigh girth	I, II, V		
Thickness of thigh subcutaneous fat	I, V	Real-time US, Aloka SSD-280 LS	
Muscle mass and composition			
Thickness of quadriceps	I, V	Real-time US, Aloka SSD-280 LS	4.8
CSA:			
- QFc	I, II, III	CT, Siemens SOMATOM CR	2.0
	I, V	Compound US, Aloka SSD-190	4.3
- KFc, Hc, LLc	III	CT, Siemens SOMATOM CR	1.8, 1.3, 2.9
Lean CSA:		CT, Siemens SOMATOM CR 0-200 HU	
- QFc	II, III		1.5
- KFc, Hc, and LLc	III		1.3, 2.1, 0.9
Mean HU:		CT, Siemens SOMATOM CR	
- QFc	I, III		2.1
- KFc, Hc, LLc	III		1.9, 2.9, 2.6
Mean HU for lean tissue; QFc, KFc, Hc, LLc	III	CT, Siemens SOMATOM CR	0.2-0.5
Fat area for QFc	I	CT, Siemens SOMATOM CR, -1 - -200 HU	
Relative proportion of fat:		CT, Siemens SOMATOM CR	
- QFc	I, II, III		9.3
- KFc, Hc, LLc	III		4.2, 8, 9

Continued overleaf

Table 2 contd

Variables	Studies	Methods/References	CV[1]
Echogenicity pattern for QFc	I	Compound US, Aloka SSD-190, Sipilä & Suominen 1991	0.84-0.98[2]
Muscle index for QFc	II	Real-time US, Aloka SSD-280 LS	
MGS_{VL} and MGS_F	V	Real-time US, Aloka SSD-280 LS	7.7, 7.3
<u>Muscle fiber characteristics</u>	VI	Needle biopsy, Bergström 1962	
Fiber-type composition	VI	Padykula & Herman 1955, Staron & Pette 1986	
Absolute and relative CSA of muscle fibers	VI	FG-100-A5 Image Processor	
<u>Muscle performance</u>			
KE force and torque	II, IV	Sipilä et al. 1991, Viitasalo et al. 1985	6.3
KF force and torque	IV		8.5
Maximal walking speed	II, IV	10 m	<5

[1] Coefficient of variation (%) for duplicated determinations. [2] Correlation coefficient (Pearson r). BIA=Bio-impedance analysis, Hc=hamstring compartment, KE=knee extension, KF=knee flexion, KFc=knee flexor compartment, LLc=lower leg muscle compartment, MGS_F=mean grey shade of femur, MGS_{VL}=mean grey shade of vastus lateralis, QFc=quadriceps compartment

4.2.4 Isometric muscle strength

Maximal isometric knee extension (KE) force (II, IV) and knee flexion (KF) force (IV) were measured from the side of the dominant hand in a sitting position on a custom-made dynamometer chair at a knee angle of 60° from full extension. After familiarization with the test, the subjects were encouraged to produce maximal force. In the experimental study, fast force production was emphasized. During the test, no further encouragement was given. The best performance of three trials was accepted as the result. To obtain maximal isometric muscle torque, the highest recording was multiplied by cos 30° × lever arm. KE and KF force and torque were further divided by body weight to obtain a measurement of relative force and torque and by lean tissue CSA of the respective muscle to obtain specific tension.

4.3 Training programs

Both experimental groups participated in an 18-week progressive physical training program comprising supervised training sessions of one hour's duration three times a week.

The strength group trained on exercise apparatus using compressed air as a resistance. The dynamic training was specifically directed at increasing the mass and strength of the quadriceps femoris by means of the leg press and the leg extension curl, the hamstrings through the leg flexion curl in the standing position and the calf muscles using the heel raise. The subjects performed 3 to 4 sets of 8 to 10 repetitions with a pause of at least 30 s between sets. The intensity of the training was gradually increased during the 18-week period from 60 to 75% of the 1 RM as assessed individually at two-week intervals.

The training of the endurance group included track walking twice a week and step aerobics once a week. After the first two weeks of training walking time was increased to 30 minutes. During the first training session, the subjects walked on the average 1500 meters (range 1200-2200 meters). By the end of the training period, the mean walking distance had reached 2700 meters (range 2400-3300 meters). The step aerobics sessions lasted for 40 minutes, during which stepping on a bench 0.10 m in height was performed continuously to music. The choreography was designed to stress the cardiovascular system by utilizing the major muscle groups of the lower extremities. The stepping height was kept constant throughout the training period for all of the subjects with the exception of three women who raised their steps to 0.15 meters during the training period. The training intensity of the endurance group was gradually increased during the trial from 50% to 80% of the initial maximal heart-rate reserve determined in the baseline measurements by a bicycle ergometer test which was continued up to a voluntary maximum (Era et al. 1993).

The controls were instructed to continue their daily routines and not to change their physical activity levels.

To determine the actual physical activity level of the subjects and possible changes in it during the experiment, all the subjects were instructed to keep a diary concerning their daily physical activities. They were to record the type and duration of the physical activity performed, including kilometers for walking, cycling and swimming. The overall level of physical activity remained constant throughout the experiment in every study group.

4.4 Statistical analyses

Standard procedures were used to calculate means, standard deviations (SD), correlation coefficients (Pearson r), and coefficients of variations (CV). The statistical significances of the differences between the athletes and untrained women were calculated by Student's t-test (two-tailed) for independent samples. In the experimental study, the differences between the three study groups in the baseline measurements were assessed using one-way ANOVA. The effects of the training programs were assessed using sphericity-corrected ANOVA for repeated measures. The results were also analyzed by multivariate analysis of variance (MANOVA), and these results are also given where notable differences were observed between the results of the two statistical methods. Where the significance of the interaction of group by time was $p<0.10$, the training effect was localized utilizing simple contrasts. The level of statistical significance chosen for the contrasts was $p<0.05$. Within-group differences between the three measurements were also assessed using both ANOVA and MANOVA for repeated measures. The level of significance was set at $p<0.05$. Muscle biopsy results were obtained from a relatively small number of subjects and therefore non-parametric tests were also used. Within-group differences between the baseline and post-training measurements were assessed using the Wilcoxon matched-pairs signed-ranks test and the difference in the CSA between type I and type IIa fibers was assessed using Mann-Whitney U test. The differences between the frequency histograms for fiber areas before and after training were statistically tested by the Kolmogorov-Smirnov two-sample test.

5 RESULTS

5.1 Anthropometry

The anthropometric properties of the groups studied are shown in Table 3. The female athletes tended to be taller (I, II) with a lower percentage of body fat (II) compared to the controls. No significant difference was observed in body mass between the study groups (I, II). In the experimental study, the strength-trained women increased their lean body mass and decreased their body fat compared to the controls (IV, V). When localized more specifically, the changes were significant after the first 9 weeks of training (p=0.005 for LBM and p=0.029 for body fat). When the three time-points were compared within the study groups, both the strength and endurance groups showed a significant decrease in body mass (p=0.004).

5.2 Muscle CSA and composition

5.2.1 Quadriceps compartment

The results for quadriceps muscle CSA and composition are shown in Tables 4 and 5 and Figures 1, 2, 3 and 4. CT scanning yielded a CSA of the quadriceps compartment on the average 31% larger than US scanning (I, V). However, there was a high correlation between the two methods (r=0.829-0.916, I, V). The quadriceps compartment CSA and lean tissue CSA of the elderly athletes were on average larger by 13% and 15%, respectively, than those of the controls (I).

In the experimental study, strength training for 18 weeks resulted in a mean increase of 5% in CT-measured CSA and 6% in the lean CSA of the quadriceps compartment (III). The change in CSA was significant when compared to the controls and that in lean CSA when compared to the endurance and control groups. No significant interaction of group by time was observed in US- measured CSA. However, an average decrease of 5% (p=0.002) within the endurance and 7% (p=0.029) within the control group was observed (V)(Figure 1).

TABLE 3 Physical characteristics of the different groups studied (mean ± SD).

	Body height, cm	Body mass, kg	LBM, kg	Body fat, %
Athletes (A), n=21	159.3 ± 5.7	61.1 ± 9.2	45.5 ± 5.0	25.0 ± 5.7
Controls (Co), n=15	155.9 ± 4.3	68.2 ± 15.6	46.4 ± 6.5	30.4 ± 7.7
Strength (S), n=12				
Baseline	159.5 ± 3.4	66.9 ± 9.4	45.3 ± 3.8	31.9 ± 6.4
9 weeks	159.6 ± 3.5	66.5 ± 9.2	46.1 ± 2.9	29.9 ± 7.0
18 weeks	159.9 ± 3.3	65.3 ± 9.4	45.8 ± 3.1	29.2 ± 7.8
Endurance (E), n=11-12				
Baseline	156.7 ± 5.5	67.3 ± 9.6	44.4 ± 2.6	34.4 ± 6.2
9 weeks	156.6 ± 5.2	66.6 ± 9.2	44.6 ± 2.6	33.7 ± 5.9
18 weeks	156.9 ± 5.4	65.9 ± 9.1	44.2 ± 2.8	32.9 ± 5.6
Control (C), n=11				
Baseline	158.7 ± 5.6	67.6 ± 12.8	45.0 ± 5.0	32.2 ± 8.0
9 weeks	158.7 ± 5.5	66.9 ± 13.0	44.5 ± 5.1	32.4 ± 7.9
18 weeks	159.1 ± 5.6	66.7 ± 13.4	45.0 ± 5.1	31.2 ± 7.9
Significance (p)				
A vs. Co (t-test)				0.022
S vs. C (ANOVA)[1]			0.040	0.007

[1] Difference in change with time

TABLE 4 Muscle mass and composition of quadriceps compartment in elderly female athletes and controls and in different study groups in experimental trial (mean ± SD).

	CSA (US), cm^2	CSA (CT), cm^2	Lean CSA, cm^2	Proportion of fat, %
Athletes (A), n=19-21	34.2 ± 6.7	48.6 ± 9.4	45.7 ± 9.8	6.2 ± 2.6
Controls (Co), n=15	29.4 ± 6.8	43.2 ± 7.5	39.0 ± 7.1	9.4 ± 3.8
Strength (S), n=12				
Baseline	31.5 ± 6.2	44.9 ± 2.4	39.4 ± 1.4	10.3 ± 1.4
9 weeks	32.3 ± 5.2			
18 weeks	31.3 ± 4.2	46.9 ± 2.1	41.7 ± 1.2	9.4 ± 1.6
Endurance (E), n=12				
Baseline	31.7 ± 3.6	44.1 ± 1.8	39.2 ± 1.2	9.7 ± 0.9
9 weeks	30.8 ± 4.1			
18 weeks	30.0 ± 3.8	45.0 ± 1.8	39.8 ± 1.4	10.4 ± 1.1
Control (C), n=10-11				
Baseline	31.4 ± 5.1	42.4 ± 1.3	38.1 ± 1.0	9.6 ± 1.0
9 weeks	30.2 ± 4.6			
18 weeks	29.0 ± 4.5	42.5 ± 1.5	38.0 ± 1.3	10.0 ± 1.0
Significance (p)				
A-Co (t-test)	0.042	0.076	0.034	0.007
S-C (ANOVA)[1]		0.021	0.009	
S-E (ANOVA)[1]			0.050	0.044

[1] Difference in change with time

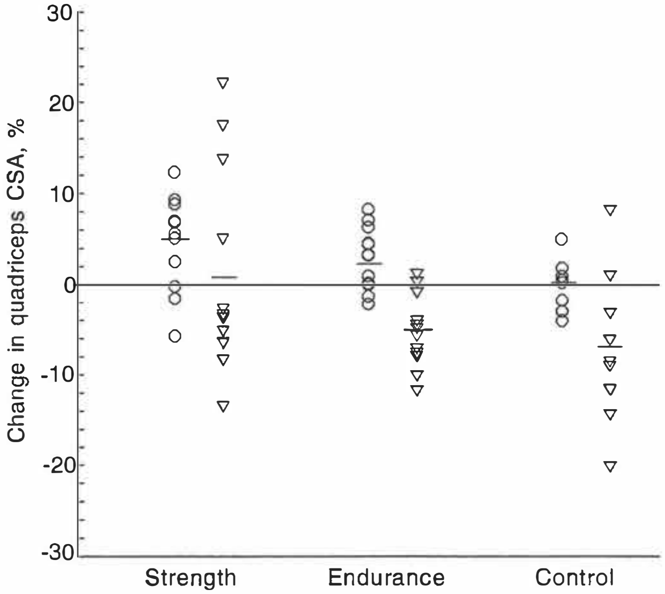

FIGURE 1 Individual changes in quadriceps muscle CSA measured using CT (circles) and US (triangles) in 76- to 78-year-old strength-trained, endurance-trained, and control women. – indicates means.

The individual changes observed in CT-measured CSA after strength training tended to correlate with those measured by US (r=0.560, p=0.058, V). When compared to the controls (I), the athletes had a lower fat area (2.9 ± 0.9 cm^2 vs. 4.1 ± 1.6 cm^2) and relative proportion of fat inside the quadriceps compartment (Table 4). Compound US scans revealed better discerned fasciae and femur, more pronounced septa formation, and lower intramuscular echo intensity in the athletes when compared to the controls (I) (Figure 2). The same phenomenon was observed in the real-time scans in the lower muscle index (II) of the athletes when compared to the controls (8.0 ± 2.7 vs. 10.2 ± 2.9, p=0.030). Good discernibility of the femur was associated with a low relative proportion of fat in both athletes and controls (I) (Table 5).

In the experimental study, the relative proportion of fat within the quadriceps compartment decreased in the strength-training group when compared to the endurance group (III) (Table 4). No significant interaction of group by time was observed for MGS_{VL} or MGS_F obtained from the real-time US scans after the 18-week training period (V). However, within the strength-training group MGS_{VL} decreased (ANOVA p=0.070, MANOVA p=0.007) and MGS_F increased (ANOVA p=0.122, MANOVA p=0.012) during the experiment (Figure 3). High US-measured MGS_F was accompanied by a low relative proportion of fat inside the quadriceps compartment measured using CT (Figure 4).

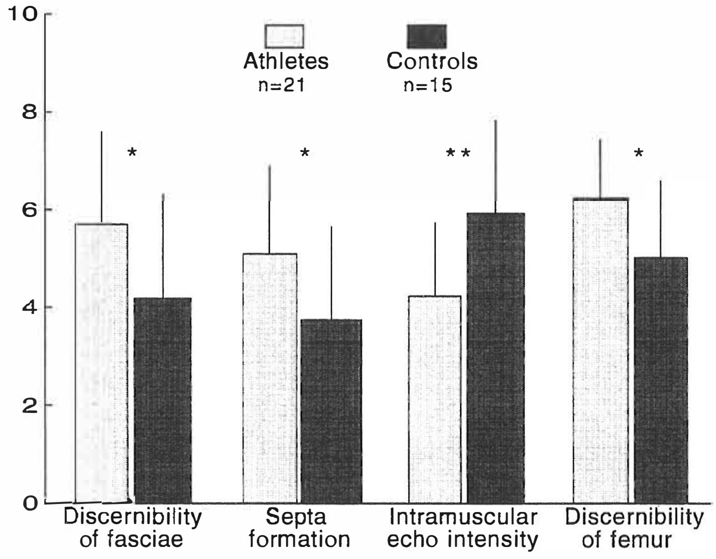

FIGURE 2 Scores for four different characteristics of compound US scans reflecting quadriceps muscle composition in elderly female athletes and controls (mean, SD). * p<0.05, **p<0.01.

TABLE 5 Correlations between muscle mass and composition analyzed using compound US and CT in female athletes and controls (r values).

US variables	CT variables CSA		Proportion of fat	
Athletes (n=19)				
CSA	0.909	***	-0.510	*
Discernibility of fasciae	0.489	*	-0.271	
Septa formation	0.552	*	-0.369	
Intramuscular echo intensity	-0.353		0.194	
Discernibility of femur	0.599	**	-0.680	**
Controls (n=15)				
CSA	0.901	***	0.100	
Discernibility of fasciae	0.409		-0.281	
Septa formation	0.216		-0.148	
Intramuscular echo intensity	-0.318		0.125	
Discernibility of femur	0.083		-0.617	*

* p < 0.05, ** p<0.01, *** p<0.001

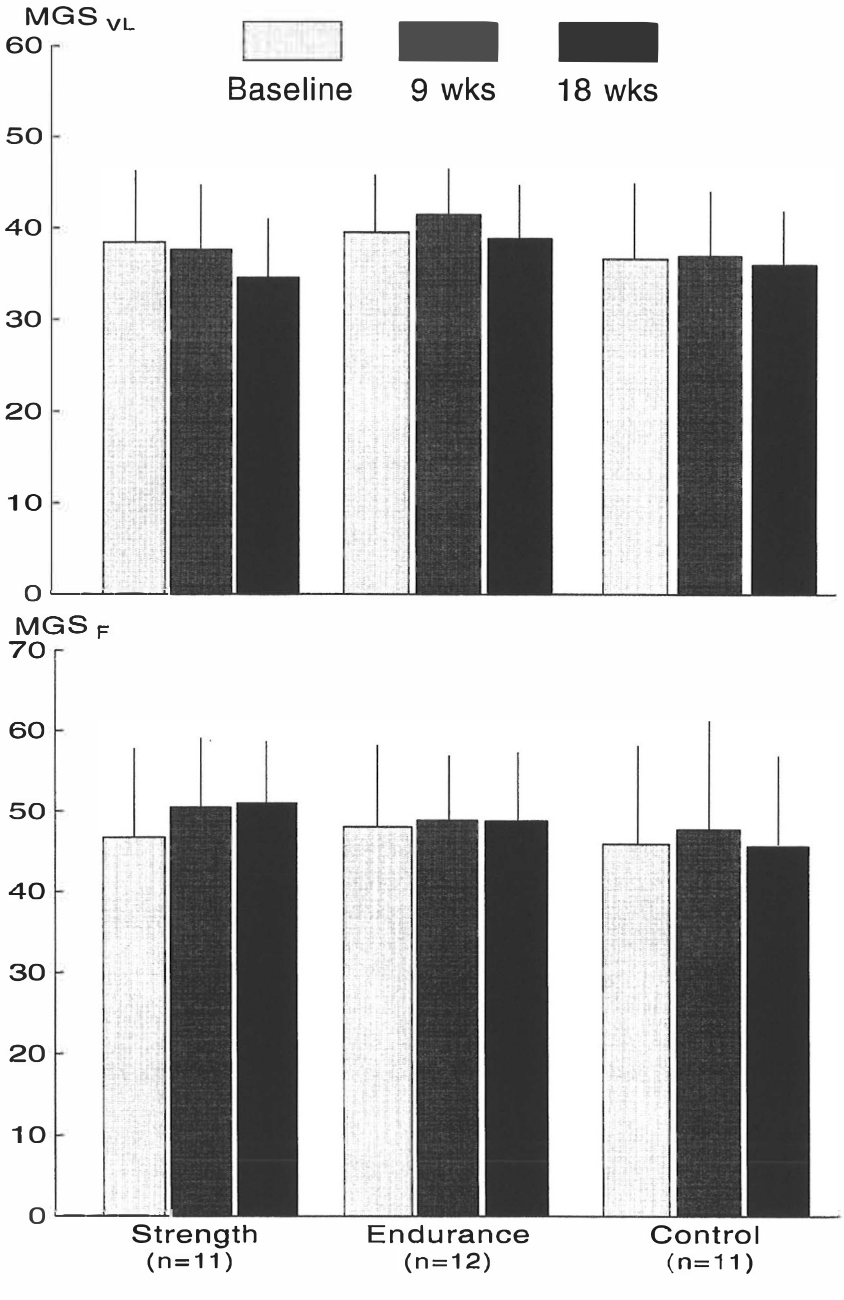

FIGURE 3 Effects of strength and endurance training on echo intensity of quadriceps compartment determined by mean grey shade of vastus lateralis (MGS_{VL}) and femur (MGS_F) in elderly women (mean, SD).

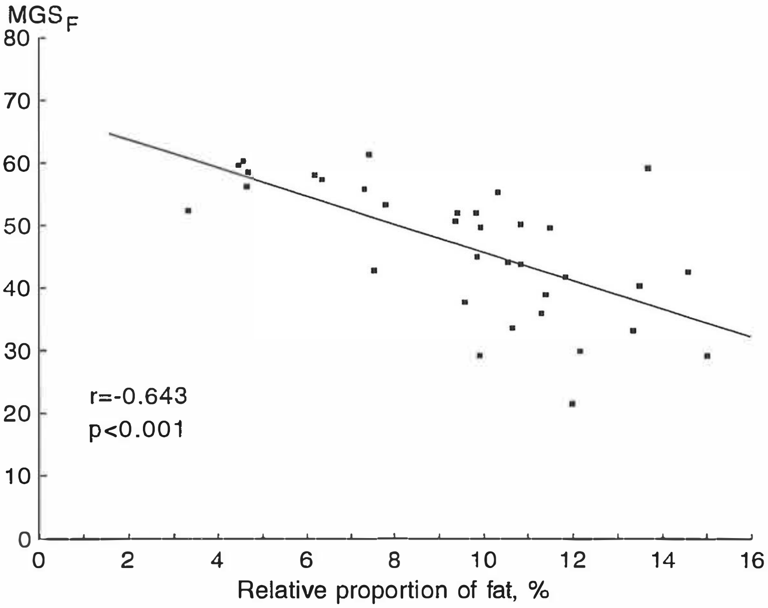

FIGURE 4 The association between US-measured mean grey shade of femur (MGS_F) and CT-measured relative proportion of fat inside the quadriceps compartment.

5.2.2 Knee flexor compartment

The results for the muscle CSA and composition of the knee flexor compartment are shown in Table 6. No significant difference was observed in the CSA or lean CSA of the knee flexor compartment when athletes and controls were compared.

No significant interaction of group by time was observed after the 18-week training period in the muscle CSA of the hamstrings or of the knee flexor compartment. The control group showed an increase in the lean CSA of the hamstrings (p=0.034) when baseline and 18-week measurements were compared (III).

The relative proportion of fat inside the knee flexor compartment was lower in the athletes when compared to the controls. Although no significant interaction of group by time was observed in the proportion of fat in the muscle after the 18 weeks of training, a significant decrease (p=0.003) was observed when the baseline and 18-week measurements were compared within the strength-training group. The strength-trained women also tended to have a lower relative proportion of fat in the hamstrings (p=0.055) at the end of the training period.

TABLE 6 Muscle mass and composition of knee flexor compartment measured by CT in elderly athletes and controls and in different study groups in experimental trial (mean ± SD).

	CSA, cm^2	Lean CSA, cm^2	Proportion of fat, %
Athletes (A), n=19	56.8 ± 9.8	48.7 ± 9.0	14.3 ± 3.8
Controls (Co), n=15	58.9 ± 10.8	46.2 ± 8.8	21.2 ± 7.6
Strength (S), n=12			
Baseline	55.7 ± 1.8	45.1 ± 1.7	16.7 ± 1.3
18 weeks	55.2 ± 2.3	45.5 ± 1.7	15.0 ± 1.5
Endurance (E), n=12			
Baseline	57.8 ± 2.5	47.5 ± 1.9	15.8 ± 1.5
18 weeks	56.7 ± 2.8	46.6 ± 1.8	15.8 ± 1.3
Control (C), n=10			
Baseline	55.3 ± 2.5	46.1 ± 1.8	15.6 ± 1.3
18 weeks	54.7 ± 3.0	45.6 ± 2.0	15.4 ± 1.5
Significance (p)			
A-Co (t-test)			0.004

5.3 Muscle fiber characteristics

In the experimental study, type I and IIa fibers accounted for more than 90% of the total cell population and were almost equally represented. No type IIb fibers were found. No changes were observed in the proportions of fiber types with training.

No significant interaction of group by time was observed in type I or type IIa fiber CSA (Figure 5). A significant increase ($p=0.028$) was, however, observed in type I fiber CSA when the baseline and 18-week measurements were compared within the strength-training group.

Individual changes in both type I and type IIa fiber areas varied considerably in every study group (Figure 6). Both positive and negative changes were observed, except in the type I fiber area in the strength group, where the individual changes varied between 0 and +196%. In the control group a huge positive change in the type IIa fiber area was observed in one woman (198%). In all the other control women the type IIa fiber area either remained unchanged or decreased.

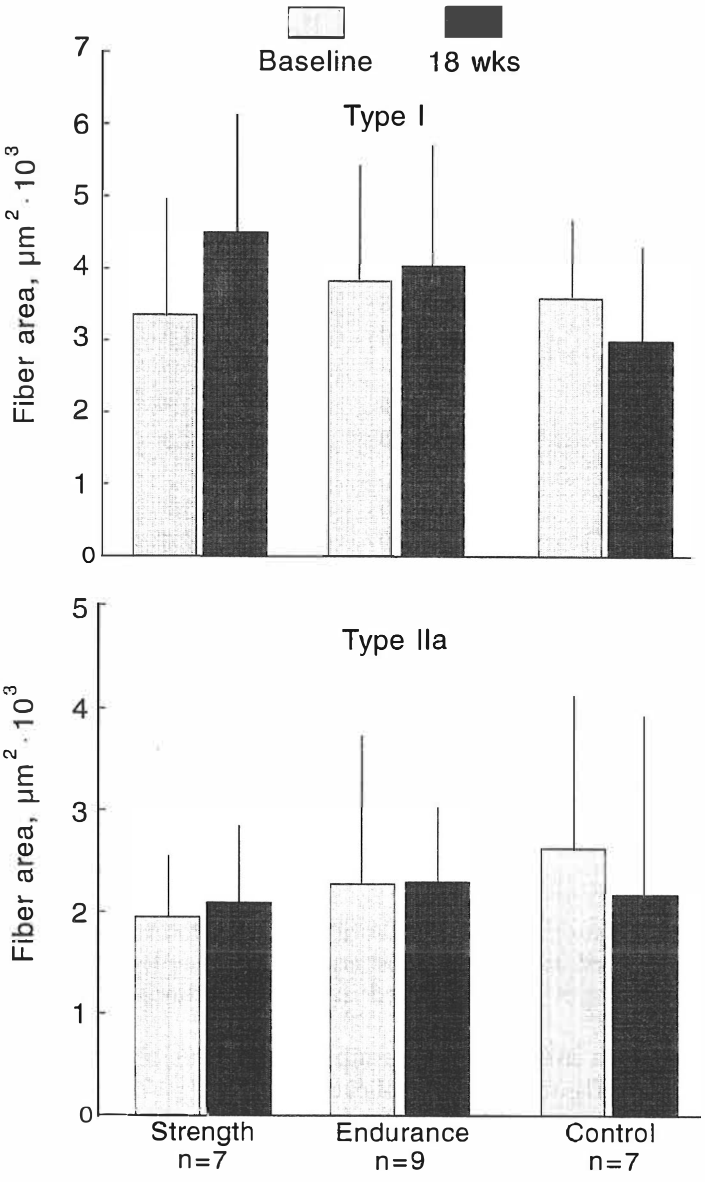

FIGURE 5 Effects of strength and endurance training on type I and IIa muscle fiber area in 76-78-year-old women (mean, SD).

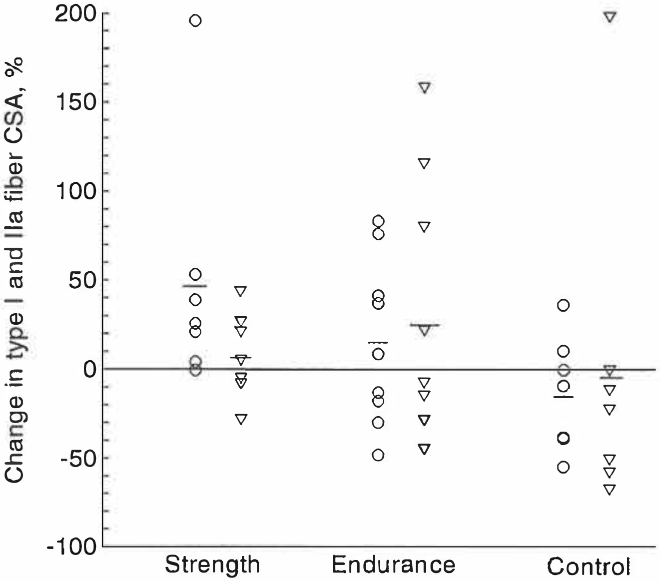

FIGURE 6 Individual changes in type I (circles) and IIa (triangles) fiber CSA of the vastus lateralis muscle in 76- to 78-year-old strength-trained, endurance-trained, and control women. – indicates means.

The frequency histograms of type I and IIa fiber CSA are presented in Figure 7. The proportion of larger type I fibers was higher after strength training when compared to the baseline situation. After endurance training the proportion of smaller type IIa fibers was lower and the proportion of mid-size type I fibers higher when compared to the baseline histogram. In the controls, the proportion of smaller type I and type IIa fibers was higher when compared to the baseline distributions.

In the baseline measurements, type I fiber CSA correlated with the US-measured CSA of the quadriceps compartment (r=0.414, p=0.050) and type IIa fiber CSA with both US- (r=0.429, p=0.041) and CT- (r=0.434, p=0.038) measured quadriceps CSA. There was no significant correlation between the change observed in the muscle fiber CSA of the vastus lateralis and that in total quadriceps CSA in any of the study groups.

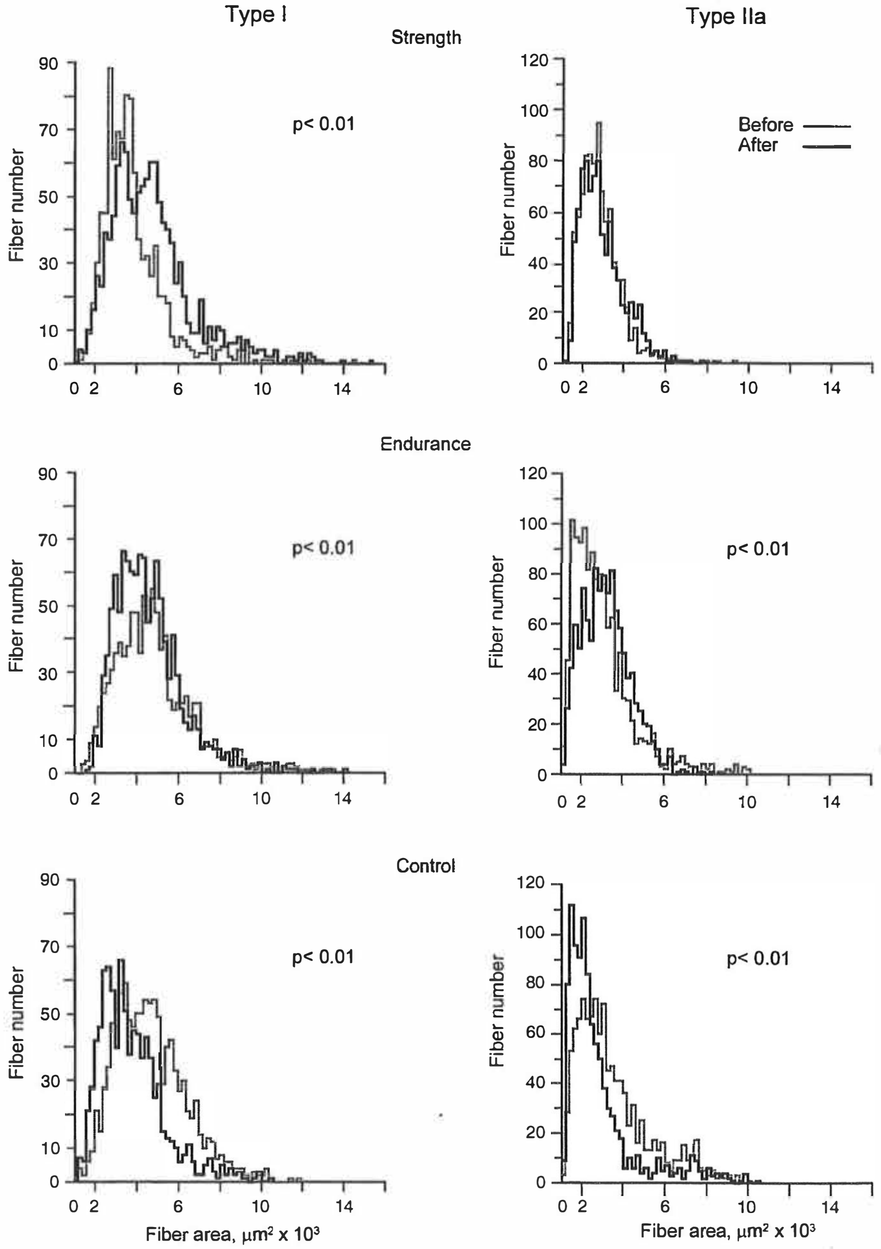

FIGURE 7 Frequency histograms for the CSA of type I and IIa muscle fibers in 76- to 78-year-old strength-trained, endurance-trained, and control women.

5.4 Muscle strength

KE torque expressed in absolute and relative terms for athletes and controls is shown in Figure 8, and after 18 weeks of training in Table 7. When compared to the untrained women, the athletes had higher mean maximal KE torque (24%) and torque related to body mass (29%)(II). The study groups did not differ with respect to KE torque related to lean CSA of the quadriceps (athletes, 1.89 ± 0.54 Nm·cm^{-2}, controls, 1.69 ± 0.58 Nm·cm^{-2}, p=0.312). The correlation between knee extension torque and quadriceps CSA was 0.453 (p=0.051) in the athletes and 0.283 (p=0.328) in the controls.

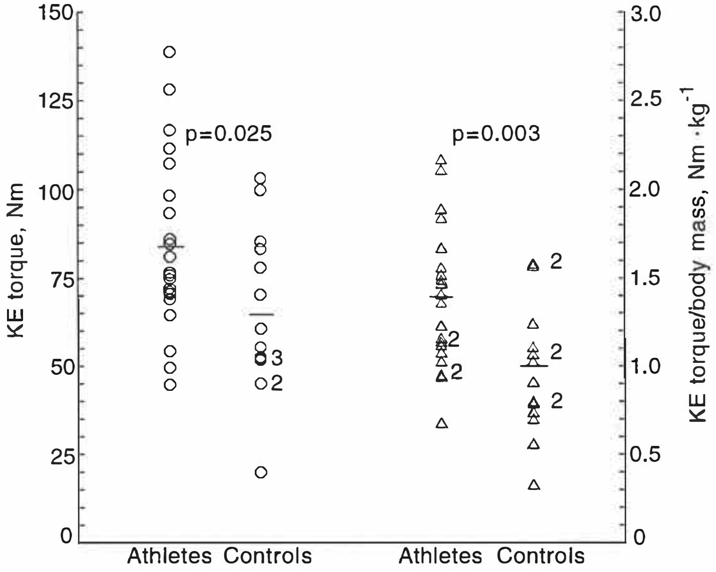

FIGURE 8 KE torque and KE torque related to body mass in elderly female athletes and controls. – indicates means.

TABLE 7 Effects of intensive strength and endurance training on knee extension (KE) torque expressed in absolute and relative terms in elderly women (mean ± SD).

	KE torque, Nm	KE torque/ body mass Nm·kg^{-1}	KE torque/ CSA Nm·cm^{-2}
Strength (S), n=12			
Baseline	87.2 ± 22.4	1.34 ± 0.43	2.24 ± 0.60
9 weeks	97.0 ± 24.0	1.48 ± 0.38	
18 weeks	99.3 ± 28.6	1.56 ± 0.53	2.38 ± 0.63
Endurance (E), n=12			
Baseline	72.3 ± 26.6	1.10 ± 0.43	1.86 ± 0.68
9 weeks	89.4 ± 25.1	1.35 ± 0.34	
18 weeks	86.5 ± 25.7	1.31 ± 0.32	2.16 ± 0.54
Control (C), n=10			
Baseline	86.2 ± 22.5	1.30 ± 0.29	2.16 ± 0.54
9 weeks	87.7 ± 26.3	1.32 ± 0.33	
18 weeks	85.3 ± 21.0	1.29 ± 0.19	2.16 ± 0.45

After the first 9 weeks of training (IV), the endurance-trained women increased KE torque (interaction p=0.109, contrast p=0.037) and KE torque/body mass (interaction p=0.065, contrast p=0.021) compared to the controls. When only the baseline and 18-week measurements were considered, both the strength and endurance training regimens tended to increase KE torque/body mass when compared to the change observed in the controls (interaction p=0.095, contrasts p=0.060 and p=0.054, respectively). No change was observed in the torque related to lean CSA of the quadriceps. When comparing the baseline, 9-week and 18-week measurements within the groups separately, both the endurance- and strength-training groups increased KE torque (p=0.042 and p=0.048), and KE torque/body mass (p=0.017 and p=0.038).

In the baseline measurements, knee extension force correlated with type IIa fiber CSA (r=0.432, p=0.040). The correlation between knee extension force and type I fiber CSA was somewhat lower (r=0.377, p=0.076).

No significant interaction of group by time or within-group changes were observed for KF force, KF torque, KF torque/body mass or KF torque/CSA (Table 3 in article IV).

No significant correlation was observed between muscle force and muscle compartment CSA in either of the muscles studied.

6 DISCUSSION

6.1 Female athletes and controls

In this study, the elderly female athletes had larger US- and CT- measured quadriceps muscle CSA and greater voluntary isometric knee extension strength compared to the untrained women. No difference was observed between the study groups in the CSA of the knee flexor compartment. The muscle force of the knee flexors was, unfortunately, not measured. The mean difference of 11-15% in quadriceps CSA between the study groups is well in accordance with the study by Klitgaard et al. (1990), showing 14% higher quadriceps CSA in elderly strength-trained male athletes when compared to untrained controls. The difference in the present study between the female athletes and controls in maximal isometric knee extension torque was, however, clearly smaller than between Klitgaard's strength-trained athletes and untrained men (24% vs. 72%, respectively). The athletes in the present study were heterogeneous with respect to their training history and sports practised. However, despite their sporting differences the female athletes were equally distributed with respect to quadriceps CSA and isometric knee extension force. One reason for this might be that the physical training of elderly female athletes is not highly sport-specific. In addition, the power athletes were mainly throwers using the muscles of the upper-body, whereas the cross-country skiing and bicycling performed by many of the endurance athletes probably stress the muscles of the lower extremities. On the other hand, Alway et al. (1988) have shown in younger men that not only strength athletes but also highly trained marathon runners have greater muscle torque and larger type I and II fiber CSA of the gastrocnemius when compared to untrained age-peers. A few studies have also shown that long-term endurance training (running, orienteering and cross-country skiing) may preserve maximal knee extension strength in elderly men (Klitgaard et al. 1990, Sipilä et al. 1991).

To overcome the difficulties related to the assessment of muscle mass in elderly people (Baumgartner et al. 1992, Borkan et al. 1983, Fiatarone et al. 1990, Sipilä & Suominen 1991), the tissue composition of the quadriceps compartment was evaluated according to the echogenicity pattern of the US scans. The low intramuscular echo intensity and increased echo intensity reflected from the connective tissue structures and femur observed in the athletes indicate the presence of less infiltrated fat in the muscle in the athletes when compared to that in the untrained women. This is supported by the CT scanning which showed a significantly lower absolute and relative proportion of fat inside the quadriceps compartment in the athletes when compared to the untrained controls. The athletes also had a lower relative proportion of CT-measured fat in the knee flexor compartment than the controls. It seems that although the training performed by the athletes may not preserve knee flexor muscle mass, as it preserves muscle mass in the knee extensors, long-term training counteracts the age-related infiltration of fat into the knee flexor compartment as well as into the quadriceps muscle.

The differences between the athletes and controls should be interpreted with caution because of the cross-sectional nature of the study. The athletes comprised a selected group of elderly people who were generally healthier than the control women. However, selection with respect to health status was also true for the controls with the consequence that those in poorer health were under-represented. Thus neither should the differences observed between the athletes and controls be underestimated.

6.2 Exercise intervention

Strength training for 18 weeks induced a significant 5-6% enlargement in quadriceps muscle CSA as measured by CT. The strength-trained women also showed an increase in both the mean CSA and proportion of larger, slow contracting type I fibers. At the level of group mean values, strength training resulted in an average increase of 14-16% in isometric knee extension strength. It is possible, therefore, that the hypertrophy of type I fibers contributes to the increase in muscle mass and strength observed after a strength-training program which included a resistance of 60-75% of the 1 RM with 8-10 repetitions irrespective of the speed of contraction. In the study reported by Pyka et al. (1994), type I fiber hypertrophy was also observed together with an increase in the 1 RM for the leg press after 15 weeks of strength training in 61-78-year-old people. After a further 15 weeks of training, both type I and II fiber areas were increased with only a small additional increase the in 1 RM.

Results somewhat different from those found in the present study have also been observed after strength training experiments in elderly people. A few months of strength training in older men (Grimby et al. 1992) produced only a small increase in quadriceps CSA together with no change in the CSA of the major fiber types, although the strength gains were similar (10-19%) to those observed in the present study. Also in young women (mean age 21 years), hypertrophy of the major fiber types of the vastus lateralis muscle was not observed after 8 weeks of heavy-resistance training, despite a significant increase in muscle strength measured using the 1 RM (Staron et al. 1994). After 20 weeks of resistance training, a significant enlargement of type I, IIa and combined IIab and IIb fibers was, however, observed (Staron et al. 1989). Somewhat surprisingly, some studies in elderly subjects have suggested hypertrophy of both type I and II fibers (Brown et al. 1990, Frontera et al. 1988) and selective hypertrophy of type II fibers (Roman et al. 1993, Charette et al. 1991) in concert with strength gains after only 12 weeks of strength training.

Although a specific knee flexion exercise was included in the present strength-training program, no change was observed after training in the CSA of the knee flexor compartment or hamstrings, or in isometric knee flexion force. The different adaptation to strength training observed in the knee extensors when compared to the flexors may be due to differences in the actual training stimulus. The knee extensors were trained using a combination of two different exercises (leg press and leg extension curl), whereas the knee flexors were trained using only the knee flexion curl. On the other hand, earlier studies (Brown et al. 1990, Fiatarone et al. 1990) have shown significant hypertrophy of the knee flexor compartment even after strength-training programs not specifically directed at the knee flexors. Knee flexor strength was not, however, evaluated in those studies.

After 18 weeks of strength training, US-measured MGS_{VL} decreased and MGS_F increased by about 10%, reflecting decreased intramuscular and increased bone echo intensity. CT scanning also showed a significant decrease in the relative proportion of fat inside the quadriceps compartment. The decrease, which was mainly due to the increase in lean tissue CSA, was significant when compared to the endurance group. Within the strength-training group, the relative proportion of fat in the knee flexor compartment decreased and there was also a tendency toward a smaller proportion of fat in the hamstrings. In the study by Grimby et al. (1992), no significant change was observed in adipose tissue concentration after 2-3 months of strength training in elderly men.

After endurance training, no change was observed in CT-measured quadriceps CSA. Although the frequency histograms for the fiber areas suggested a shift towards mid-size type I and type IIa fibers, no sign of hypertrophy was observed when the mean values were taken into account. Five of the endurance-trained women even showed a decrease in type IIa fiber CSA. However, it is possible that the relatively high tempo used during the walking and step aerobics sessions recruited some of the type IIa fibers. Although muscle hypertrophy was not observed after endurance training, mean isometric muscle torque increased by 24% after the first 9 weeks of training. After that, no additional strength gains were observed. In the light of the results, it seems that changes in neural factors account for the changes in muscle torque after endurance training. This is supported by the small increase in specific tension observed in the endurance group. Era (1988) has also shown strength gains after 8 weeks of traditional gymnastics, including weight-bearing, flexibility, and rhythmic exercises in elderly men, although Agre et al. (1988) failed to show improvements in isokinetic knee extension torque in women after a similar training procedure. Significant hypertrophy of both type I and IIa fibers in the gastrocnemius muscle has also been shown after 9-12 months of intensive walking/jogging in 60-70-year-old men and women (Coggan et al. 1992). Unfortunately muscle strength was not measured in that study.

Both the US scanning and frequency histograms for type I and IIa fiber CSA suggested decreased quadriceps muscle mass in the control group after the 18-week period. Individual changes in muscle fiber CSA also show that the type I fiber area decreased in 4 and the type IIa area in 5 out of 7 control women during the experiment (Figure 6). An almost 200% increase in type IIa fiber CSA in one control woman reflects the imprecision of needle muscle biopsy measurements. Altogether, no significant change was observed in CT- measured CSA or mean type I or IIa fiber CSA. In addition, virtually no change was observed in knee extension torque. It seems unlikely that the atrophy of the knee extensors in 76- to 78-year-old women could proceed that fast, especially when the physical activity diary revealed that the weekly walking performed by the controls ranged from 10 to 16 km (III) and did not change during the trial. A small increase in the lean CSA of the hamstrings in the control women was a confusing finding. The increase was, however, close to the precision of the measurement and was not significant when compared to the other study groups. In addition, no change was observed in knee flexion torque after the 18-week period.

Although a large CSA of the muscle fibers was associated with high isometric force in the baseline measurements of the 18-week trial, the changes observed in muscle or muscle fiber CSA were not related to the changes observed in muscle strength. The lack of correlation between muscle hypertrophy and strength gains has also been reported earlier in elderly people (Charette et al. 1990, Fiatarone et al 1990, Frontera et al. 1988, Grimby et al. 1992, Pyka et al. 1994). According to Roman et al. (1993), the change observed in muscle mass by measuring muscle CSA is greater than the change in muscle volume, which they regard as a more accurate method for muscle mass assessment. In addition, CSA of the muscle is not necessarily obtained perpendicular to the muscle fibers because of the pennate fiber arrangement observed in several muscles. Earlier studies have also shown that the change observed in muscle strength, especially when measured using the 1 RM, is several times greater than that observed in muscle mass. This is probably because of the influence of a strong neurological component on strength gains, especially in the early phase of training. Although it is likely that an association exists between muscle hypertrophy and strength gains, there seem to be problems related to the measurement of the respective variables.

The major strength of the present experimental study was the utilization of a randomized and controlled design. Compliance with the protocol was very high in those women who completed the study. The high variability observed in several measurements and the relatively small number of subjects, however, somewhat limited the statistical power of the design when studying the differences in changes between the groups.

6.3 Quantitative ultrasonography

When comparing the two imaging techniques in both the female athletes and controls and in the experimental study, US scanning yielded, on average, a 31% smaller quadriceps muscle CSA than CT scanning. The correlation between muscle CSA measured by US and CT was, however, highly significant. In addition, the change observed in CT CSA after strength training tended to correlate with that in US CSA. The difference between the methods was partly due to the thick connective tissue fasciae around the quadriceps muscle group which were excluded from the CSA measurement when using US scanning. Because the fasciae were not discernible in the CT scans, they had to be included in the CSA. In addition, Engstrom et al. (1991) and Hudash et al. (1985) have shown that CT measurement tends to overestimate muscle area by 10-20% compared to anatomical CSA.

A somewhat puzzling finding was the difference between US and CT in the change observed in quadriceps CSA after 18-weeks of training. US-measured CSA decreased significantly in the endurance and control groups, while CT-measured CSA remained unchanged. We were, however, unable to find any systematic error in our US measurements. It is possible that an increased muscle echo intensity in elderly people in concert with a decrease in bone echo hindered muscle mass assessment. Difficulties in muscle mass assessment using US have been observed in elderly subjects (Sipilä & Suominen 1991) and in patients with muscular dystrophy (Heckmatt et al. 1988).

The muscle composition measured using US scanning was evaluated in two different ways. When comparing the elderly female athletes and controls, the echogenicity pattern of the whole scan was evaluated by two blind observers. In the experimental training study, a more quantitative analysis using an image analysis program for micro computers was applied. The results obtained from the US measurements were then compared with the fat area and relative proportion of fat within the muscle compartment obtained from the CT measurements.

The results obtained from both cross-sectional and experimental studies suggest that the echo intensity reflected from the femur is sensitive to the relative proportion of fat inside the muscle compartment. The less the amount of infiltrated fat, the better the discernibility of the femur and the higher the MGS_F. The reason for this association might be that in the case of fat infiltration, muscle echogenicity is increased because fat and muscle tissue differ with respect to their acoustical impedance properties. As a result, the sound wave is attenuated and the intensity of the echo reflected from the bone is decreased. The results obtained in the present study support this theory since the MGS_F increased and MGS_{VL} decreased in the strength training group along with a decreased relative proportion of fat. In the study by Heckmatt et al. (1989), patients suffering from muscular dystrophy had significantly higher muscle echogenicity and decreased bone echo intensity when compared to healthy subjects. However, in their study, muscle echogenicity was more discriminating than bone echo and correlated with the proportion of fat tissue measured from the muscle biopsy. This is probably because a severe pathological process in the muscle tissue effects muscle echogenicity, not only because of the fat but also because of the connective tissue infiltration, thus making the measurement of bone echo difficult (Heckmatt et al. 1988).

Keeping in mind the earlier mentioned difficulties related to muscle mass and composition analysis, US scanning employed in this study offers a less expensive and non-invasive choice when compared to CT or muscle biopsy techniques in studying skeletal muscle in elderly people.

7 MAIN FINDINGS AND CONCLUSIONS

The main findings and conclusions of the present study can be summarized as follows:

1) Elderly female athletes, specializing in various sports, had higher quadriceps muscle mass and less fat in the thigh muscles than untrained controls of the same age. No difference, however, was observed between the study groups in the muscle mass of the knee flexors.

2) Voluntary isometric knee extension strength was greater in the elderly female athletes compared to their untrained age-peers.

3) Strength training for 18 weeks resulted in the enlargement of total quadriceps CSA and larger type I fiber CSA in the vastus lateralis muscle. However, considerable individual variation in muscle fiber CSA was observed within the biopsy samples and within the study groups. The composition of the thigh muscles was affected by strength training, suggesting a decrease in the relative proportion of fat. No change was observed in the muscle mass of the knee flexors. The effects of endurance training on thigh muscle mass, composition and muscle fibers were negligible.

4) Eighteen weeks of physical training, whether of the strength or endurance type, increased voluntary isometric knee extension strength. Knee flexion strength remained unchanged.

5) US imaging is a potentially useful tool in the study of skeletal muscle mass and composition in elderly women. Echo intensity reflected from the bone seems to be sensitive to the amount of fat infiltrated into the muscle. The changes in the grey scale histograms also reflect short-term training effects in the muscle.

The results suggest that female athletes preserve superior muscle mass and performance up to old age and that physical training, started in old age, also improves the properties of skeletal muscle. The results also point to the usefulness of quantitative US imaging in studying skeletal muscle composition in elderly women.

8 TIIVISTELMÄ

Tutkimuksen tarkoituksena oli selvittää fyysisen harjoittelun ja reisilihasten massan, koostumuksen, lihassolujen ominaisuuksien ja voiman välisiä yhteyksiä ikääntyvillä naisilla. Tutkimuksessa verrattiin fyysisesti aktiivisia ja liikuntaa harrastamattomia naisia sekä selvitettiin 18 viikkoa kestävän voima- ja kestävyysharjoittelun vaikutuksia aikaisemmin harjoittelemattomilla iäkkäillä naisilla. Tarkoituksena oli myös arvioida ultraäänikuvauksen käyttökelpoisuutta ikääntyvien ihmisten lihasten tutkimusmenetelmänä.

Eri urheiluliittojen jäsenluetteloista valittiin 60 aktiivista 66-85-vuotiasta liikunnan harrastajaa (yleisurheilijoita, hiihtäjiä ja naisvoimistelijoita). Tutkittavat olivat harrastaneet liikuntaa säännöllisesti keskimäärin 50 vuoden ajan. Tutkimusta edeltäneen vuoden aikana he olivat harjoitelleet keskimäärin 7 tuntia viikossa. Vertailuryhmäksi valittiin systemaattisella satunnaisotannalla 71 70-81-vuotiasta naista Jyväskylän maalaiskunnan väestörekisteristä. Lihastutkimuksiin valittiin 21 kilpaurheilua harrastavaa sekä 15 vertailuryhmän naista.

Kokeellista tutkimusta varten valittiin satunnaisotannalla 240 76-78-vuotiasta naista Jyväskylän kaupungin väestörekisteristä. Alkukyselyn, lääkärintarkastuksen ja kliinisen kuormituskokeen jälkeen tutkimukseen valittiin 42 naista, joilla ei todettu vasta-aiheita intensiiviseen fyysiseen harjoitteluun. Koehenkilöt satunnaistettiin voima- (n=16), kestävyys- (n=15) ja kontrolliryhmään (n=11). Molemmat koeryhmät harjoittelivat ohjatusti kolme kertaa viikossa tunnin kerrallaan. Voimaharjoittelu koostui kuntosalityöskentelystä paineilmalaitteilla ja sen tavoitteena oli lisätä alaraajojen lihasten voimaa lihasten hypertrofian kautta. Harjoitusvastukset määritettiin yksilöllisesti maksimivoimatestin perusteella kahden viikon välein. Vastusta lisättiin tutkimuksen kuluessa 60 %:sta 75 %:iin maksimista. Kestävyysryhmän harjoittelu koostui ratakävelystä ja step aerobic-voimistelusta. Harjoitussyke määritettiin yksilöllisesti alkumittausten yhteydessä tehdyn kliinisen kuormituskokeen perusteella. Harjoituksen intensiteettiä lisättiin tutkimuksen aikana 50 %:sta 80 %:iin maksimaalisesta sykereservistä.

Quadriceps femoris -lihasryhmän poikkipinta-ala määritettiin ultraäänikuvauksen ja tietokonetomografian avulla. Polven koukistajalihasryhmän

poikkipinta-ala sekä quadriceps -lihasryhmän ja polven koukistajien rasvattoman kudoksen pinta-ala ja rasvakudoksen suhteellinen osuus mitattiin tietokonetomografian avulla. Ultraäänikuvista analysoitiin quadriceps -lihasryhmän koostumusta arvioimalla lihasryhmää ja yksittäisiä lihaksia ympäröivien sidekudosrakenteiden ja reisiluun erottuvuus sekä lihasksen sisäinen kaikupitoisuus neliluokkaisen asteikon avulla. Kokeellisessa tutkimuksessa ultraäänikuvien analysointia kehitettiin edelleen. Ultraäänikuvat siirrettiin mikrotietokoneelle, jonka avulla analysoitiin sekä vastus lateralis -lihaksen että reisiluun kaiun harmaasävyhistogrammit ja niiden painotettu keskiarvoinen harmaasävy. Kokeellisessa tutkimuksessa analysoitiin lisäksi eri lihassolutyyppien suhteelliset osuudet ja poikkipinta-alat vastus lateralis -lihaksesta otetusta lihassolunäytteestä. Polven maksimaalinen isometrinen ojennusvoima ja kokeellisessa tutkimuksessa myös koukistusvoima mitattiin dynamometrillä. Voimista laskettiin edelleen vääntömomentit sekä kehon painoon ja lihaksen poikkipinta-alaan suhteutetut voimat.

Urheilijoiden quadriceps -lihasryhmän ja rasvattoman kudoksen pinta-ala oli suurempi ja lihasryhmän sisäisen rasvakudoksen suhteellinen osuus pienempi kuin vertailuryhmän naisilla. Lihaksia ympäröivät sidekudosrakenteet sekä reisiluu erottuivat selvemmin urheilijoiden ultraäänikuvissa, mutta lihaksen sisäinen kaikupitoisuus oli pienempi kuin vertailuryhmän naisilla.

Kokeellisessa tutkimuksessa havaittiin, että voimaharjoittelun seurauksena tietokonetomografialla mitattu quadriceps -lihasryhmän poikkipinta-ala ja rasvattoman kudoksen pinta-ala kasvoivat. Muutos koko lihasryhmän poikkipinta-alassa oli tilastollisesti merkitsevä verrattuna vertailuryhmässä havaittuun muutokseen ja rasvattoman kudoksen pinta-alassa verrattuna sekä kestävyys- että vertailuryhmissä havaittuihin muutoksiin. Quadriceps -lihasryhmän sisäisen rasvakudoksen suhteellinen osuus puolestaan väheni voimaharjoittelun seurauksena kun muutosta verrattiin kestävyysryhmässä havaittuun muutokseen. Vastus lateralis -lihaksen keskiarvoinen harmaasävyarvo oli pienempi ja reisiluun kaiun harmaasävyarvo suurempi voimaharjoittelun jälkeen. Harmaasävyarvojen muutokset eivät olleet kuitenkaan merkitseviä verrattuina muissa ryhmissä tapahtuneisiin muutoksiin.

Ultraäänikuvissa havaittu reisiluun hyvä erottuvuus ja korkea keskiarvoinen harmaasävyarvo olivat yhteydessä tietokonetomografialla mitattuun alhaiseen quadriceps -lihasryhmän rasvakudoksen suhteelliseen osuuteen.

Polven koukistajalihasten poikkipinta-alassa ei havaittu eroa urheilijoiden ja vertailuryhmän naisten välillä. Koukistajalihasten rasvakudoksen suhteellinen osuus oli kuitenkin urheilijoilla pienempi kuin vertailuryhmän naisilla. Lihasryhmän poikkipinta-alassa ei havaittu muutosta myöskään 18-viikon voima- tai kestävyysharjoittelun jälkeen, mutta rasvakudoksen suhteellinen osuus väheni voimaharjoittelun jälkeen.

Kokeellisessa tutkimuksessa havaittiin lisäksi, että tutkittujen naisten vastus lateralis -lihas koostui yli 90 prosenttisesti I- ja IIa-tyypin soluista ja että molempia lihassolutyyppejä oli suunnilleen yhtä paljon. Lihassolukoostumus ei muuttunut koeryhmissä harjoittelun seurauksena. I-tyypin solujen poikkipinta-ala ja suurien solujen suhteellinen osuus oli suurempi voimaharjoittelun jälkeen kuin ennen harjoittelua. Kestävyysharjoittelun jälkeen puolestaan pienten IIa solujen suhteellinen osuus oli pienempi ja keskikokoisten I-tyypin solujen osuus suurempi kuin ennen harjoittelua. Pienikokoisten I- ja IIa-tyypin solujen osuus lisääntyi vertailuryhmän naisilla 18-viikon seurantajakson jälkeen verrattuna lähtötilanteeseen. Molempien solutyyppien poikkipinta-alojen muutoksille oli tyypillistä huomattava yksilöllinen vaihtelu.

Urheilijoiden polven ojennuksen ja kehon painoon suhteutetun ojennuksen vääntömomentit olivat keskimäärin suuremmat kuin vertailuryhmän naisten. Ryhmät eivät eronneet toisistaan lihaksen poikkipinta-alaan suhteutetun voiman suhteen. Kokeellisessa tutkimuksessa polven ojennuksen vääntömomentti lisääntyi merkitsevästi yhdeksän viikon kestävyysharjoittelun jälkeen verrattuna kontrolliryhmässä havaittuun muutokseen. 18-viikon harjoittelun jälkeen kehon painoon suhteutettu polven ojennuksen vääntömomentti lisääntyi sekä voima- että kestävyysryhmissä kontrolliryhmään nähden. Lihaksen poikkipinta-alaan suhteutettu polven ojennuksen vääntömomentti ei muuttunut merkitsevästi 18-viikon kokeen aikana missään tutkimusryhmässä. Polven koukistajien absoluuttiset ja suhteelliset voimat eivät muuttuneet tilastollisesti merkitsevästi missään ryhmässä kokeellisen tutkimuksen aikana. Voimakkuutta kuvaavien muuttujien yksilökohtaisissa muutoksissa havaittiin huomattavia eroja kaikissa tutkimusryhmissä.

Tutkimuksen tulokset viittaavat siihen, että fyysisesti aktiiviset naiset säilyttävät ikääntyessään suuremman lihasmassan ja paremman lihasten suorituskyvyn kuin liikuntaa harrastamattomat naiset. Myös iäkkäänä aloitettu voimaharjoittelu lisää lihaksen massaa. Lihasten suorituskyky paranee sekä voima- että kestävyysharjoittelun seurauksena. Tulokset osoittavat lisäksi, että ultraäänikuvaus on käyttökelpoinen tutkimusmenetelmä, jolla voidaan selvittää ikääntyvien ihmisten lihasten kokoa ja koostumusta.

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