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ORIGINAL ARTICLE

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Muscle strength and soft tissue composition as measured by dual energy x-ray absorptiometry in women aged 18–87 years

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Abstract Dual energy x-ray absorptiometry (DEXA) offers the possibility of assessing regional soft tissue composition, i.e. lean mass (LM) and fat mass : LM may be considered a measure of muscle mass. We examined age-related differences in LM, percentage fat (%fat) and muscle strength in 100 healthy non-athletic women aged 18–87 years. Relationships between muscle strength and leg LM in 20 elite female weight lifters and in 18 inactive women with previous hip fractures were also studied. The LM and %fat of the whole body, trunk, arms and legs were derived from a whole body DEXA scan. Isokinetic knee extensor strength (KES) and flexor strength (KFS) at $30° \cdot s^{-1}$ were assessed using an isokinetic dynamometer. The women aged 71–87 years had 35% lower KES and KFS than the women aged 18–40 years ($P < 0.0001$). Differences in LM were less pronounced. The LM of the legs, for instance, was 15% lower in the old than in the young women ($P < 0.0001$). In a multiple regression analysis with age, body mass, height and leg LM or KES as independent variables and KES or leg LM as the dependent variable, age was the most important predictor of KES ($r_{partial} = -0.74$, $P < 0.0001$). The same applied to KFS. Body mass, not age, was the most important predictor of leg LM ($r_{partial} = 0.65$, $P < 0.0001$) and of LM at all other measurement sites. The LM measured at different regions decreased equally with increasing age. The KES:leg LM ratio was negatively correlated with age ($r = -0.70$, $P < 0.0001$). The weight lifters had significantly higher KES:leg LM ratios than age-matched controls (+12%, $P < 0.0001$) and vice versa for the women with previous hip fractures (–36%, $P < 0.0001$). In conclusion, from our study it would seem that in healthy nonathletic women, age is a more important determinant of muscle strength than is LM as measured by DEXA. Muscle strengthening exercises and inactivity seem to have a considerably stronger influence on muscle strength than on LM.

Key words Aging · Dual energy x-ray absorptiometry · Isokinetics · Lean mass · Muscle strength

Introduction

The age-related loss of muscle strength has been well established and appears to affect all parts of the muscular apparatus (e.g. Borges 1989; Rice et al. 1989b; Harries and Bassey 1990; Era et al. 1992; Madsen et al. 1993). It has been suggested that loss of muscle strength is predominantly caused by loss of muscle mass (Frontera et al. 1991) while others have suggested that age itself independently of muscle mass may have greater importance (e.g. McLennan et al. 1980). In those studies different methods of assessing muscle mass or size have been used making general conclusions difficult. Furthermore, previous studies have examined only nonathletic healthy individuals. No data exist on the influence of physical activity on the association between strength and muscle mass.

Lean mass (LM) has been used frequently as a measure of muscle mass (e.g. Hassager and Christiansen 1989; Frontera et al. 1991; Fuller et al. 1992). The present study is the first to examine relationships between age, muscle strength and LM as measured by dual energy x-ray absorptiometry (DEXA). Recently, DEXA has become available for assessing whole body and regional LM and fat mass (FM). This method has been reported to be valid, reliable and easy to use (Mazess et al. 1990; Haarbo et al. 1991a; van Loan and Mayclin 1992). DEXA has mainly been used in studies of bone mineral density but studies on soft tissue composition have also been performed (e.g. Bevier et al. 1989; Lindsay et al. 1992; Madsen et al. in press, a). The DEXA machines are widespread and may have the potential of becoming an important tool in studies on regional LM and FM. We have examined the associations

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of isokinetic knee extensor and flexor strength with respect to LM measured by DEXA, age, height and body mass in a cross-sectional study of 100 healthy non-athletic women aged 18–87 years. Relationships between strength and LM were also studied in 20 young female weight lifters and in 18 inactive women with previous hip fractures.

Methods

Subjects

The subjects comprised three groups of women:

1. A group of 100 healthy white women between the ages of 18 and 87 years volunteered for the study in response to posters distributed in the local community. None of the women reported a history of musculoskeletal disease or use of steroids. All were physically active to a moderate degree, none were or had been athletes. None were using sticks or other walking aids and all were functionally independent in daily life. The women were divided into five age groups (groups I–V) (Table 1).
2. A group of 18 women who had been rehabilitated between 1 and 2 years earlier at the Copenhagen Municipal Hospital following a hip fracture volunteered to participate. The women had no symptomatic heart, pulmonary, liver, joint or muscle disease, or signs of dementia. All the women were able to walk without assistance. The handicap of the women was graded according to the Northwick Park activity index for patients with a previous fracture of the hip (Wand et al. 1992). This index consists of questions regarding mobility, activity and functional dependency. The maximal possible score is 100%. The mean score was 46% (SD 19%) indicating a low level of activity and a high degree of dependency.
3. A group of 20 female elite weight lifters were recruited from All-Denmark Teams. These women took part in a larger study of the relationship between muscle strength and bone mineral density in athletes (Madsen et al. in press,b). None of the athletes were known to have taken steroids. The mean time spent in weight lifting was 6 h (range 5–12 h) a week. Each woman signed an informed consent in accordance with the Helsinki II Declaration. The study was approved by the local Ethics Committee.

Muscle strength

Isokinetic strength of the knee extensors (KES) and flexors (KFS) of the dominant leg was estimated at $30° \cdot s^{-1}$ by a Cybex 6000 dynamometer (Cybex, Division of Lumex, Inc., Ronkonkoma, N.Y., USA) as previously described (Madsen 1996). The dominant leg was measured in the 100 healthy women and in the weight lifters. The nonfractured leg was measured in the women with previous hip fractures. All procedures were standardized and measurements were performed by the same experienced examiner (O.R. Madsen). Strength was recorded in Newton-metres (N · m) and was calculated as the highest peak torque obtained from three trials preceeded by three warm-up repetitions. The short-term inter-session reproducibility of the measurements in women, expressed as the coefficient of variation (CV) as a percentage, is approximately 8% in our laboratory (Madsen and Lauridsen 1995; Madsen 1996).

Soft tissue

The LM and FM of the whole body, trunk, abdomen, arms and legs were derived from a total body scan using DEXA (Norland XR26, USA) (Fig. 1).

According to Gotfredsen et al. (1986) the LM measurements by DEXA represents the sum of all chemically fat-free soft tissue elements in the body, and FM represents the sum of the fatty elements of all soft tissues. In this study, LM refers to nonfat tissue excluding bone mineral. Percentage fat (%fat) was calculated as FM divided by total soft tissue mass (FM + LM) in each anatomical region.

Table 1 Age, body mass, height, body mass index (*BMI*), lean mass, percentage body fat and muscle strength of five age groups in 100 women

Age group Age range (years)	I 18–40		II 41–50		III 51–60		IV 61–70		V 71–87	
n	36		11		14		20		19	
	mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Age (years)	24.0	4.7	46.3	3.6	56.3	2.6	65.7	3.5	75.5	4.5
Body mass (kg)	62.4	9.1	64.5	10.8	65.1	10.2	64.3	7.9	62.6	10.0
Height (cm)	171	5.0	165	7.2	163	4.4	162	6.0	159	6.9
BMI ($kg \cdot M^{-2}$)	21.2	2.6	23.6	3.4	24.6	4.2	24.6	2.3	24.6	3.4
Lean mass (kg)										
body	37.7	5.1	36.2	4.6	36.3	4.2	35.4	4.8	34.9	3.4
arms	3.3	0.6	3.3	0.6	3.2	0.6	2.9	0.6	2.9	0.5
trunk	17.4	2.4	17.1	2.3	17.7	2.2	17.3	2.5	17.3	1.8
abdomen	8.3	1.1	7.8	0.9	8.2	0.8	7.9	1.3	7.7	1.4
legs	13.7	2.1	12.6	1.9	12.3	1.5	11.9	1.7	11.6	1.4
Fat (%)										
body	36.1	5.4	40.7	7.4	40.9	6.9	42.3	6.0	41.3	5.0
arms	42.9	7.2	46.7	9.7	48.1	8.8	50.3	7.4	50.5	6.9
trunk	35.0	6.8	40.5	8.0	41.1	8.0	43.4	6.7	41.6	6.7
abdomen	34.1	8.2	40.3	8.3	40.0	9.1	42.8	7.1	40.7	8.6
legs	38.7	4.8	41.3	7.4	42.4	6.6	42.6	7.0	43.9	7.4
Strength (N · m)										
extensor	166	28	148	18	129	20	109	17	103	20
flexor	79	14	71	14	62	12	56	12	50	14

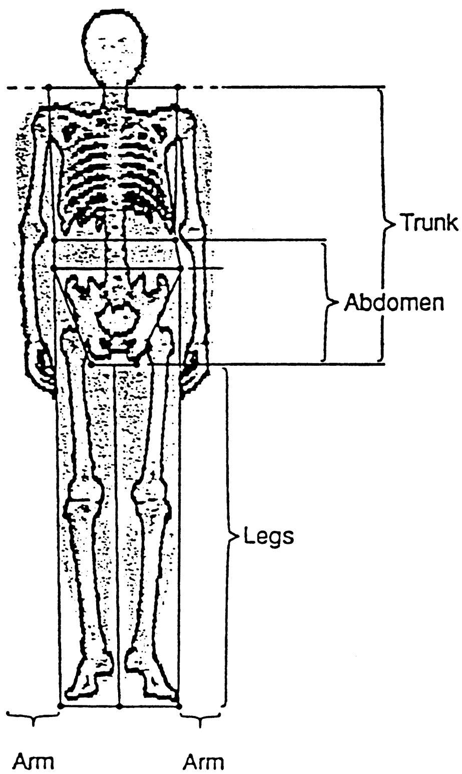

Fig. 1 Body regions in which soft tissue composition was assessed using total body dual energy x-ray absorptiometry

The CV of duplicate measurements after repositioning has been shown to range from 1.3% to 4.5% depending on the anatomical region and on whether LM or FM was measured (Madsen et al. in press b).

Statistical methods

Statistical analyses were performed using the software package SPSS/PC$^+$ Statistics V4. 01. Although data of all variables except age had approximately normal distributions, we preferred to calculate ranked correlations (Spearman's rank correlation coefficient, r) to measure the strength of association between paired variables (Altman 1991). Multiple regression analyses with stepwise selection was used to assess the dependency of a variable on several explanatory variables, not just one. In all regression analyses, the residuals had a normal distribution. Multiple and partial ranked correlation coefficients ($r_{multiple}$ and $r_{partial}$, respectively) were derived from the analyses. Standard errors of estimation (SEE) are presented.

Comparisons of paired or unpaired observations were performed using ANOVA. Statistical significance was accepted at an α level of less than 0.05.

Results

Age, body mass, height, and the results of the soft tissue and muscle strength measurements of the 100 healthy nonathletic women divided into five age groups are given in Table 1. The KES and KFS decreased consistently with increasing age. Comparing the women aged 18–40 years (group I) with those aged 71–87 years (group V), muscle strength was reduced by approximately 35% ($P < 0.0001$). Differences in LM were less pronounced. The LM of the legs, for instance, was 15% lower in group I than in group V ($P < 0.0001$). The ratio KES:KFS did not change significantly with increasing age.

Table 2 Correlation coefficients among age, height, body mass, body mass index (*BMI*), lean mass and muscle strength in 100 women

	Age	Height	Body mass	BMI
Age	–	–0.65***	0.07	0.46***
Lean Mass				
body	−0.22*	0.40***	0.67***	0.38***
arm	−0.28*	0.34**	0.46***	0.20*
trunk	−0.06	0.24*	0.68***	0.50***
abdomen	−0.06	0.38***	0.47***	0.19
leg	−0.41***	0.51***	0.56***	0.22*
Muscle strength				
extensor	−0.78***	0.65***	0.21*	−0.19
flexor	−0.67***	0.60***	0.21*	−0.16

$^{*}P < 0.05$, $^{**}P < 0.001$, $^{***}P < 0.0001$

The analyses of age-related changes in muscle strength and LM were complicated by the significant intercorrelations between age, height, body mass, muscle strength and LM (Table 2). To examine the dependency of a variable on several explanatory variables, not just one, multiple regression analyses were performed. When KES and KFS were related to age, body mass, height and leg LM in multiple regression analyses, age was the most important predictor of KES and KFS. The LM contributed significantly to the equations, while no independent effect was found for body mass or height. The following regression equations were obtained from the analyses:

$$KES = -0.97 \times age + 7.68 \times \text{leg } LM + 86.0 \text{ (SEE = 17.2)}.$$

$r_{multiple} = 0.86$ ($P < 0.0001$),
$r_{partial,\ age} = -0.74$ ($P < 0.0001$),
$r_{partial,\ leg\ LM} = 0.56$ ($P < 0.0001$).

$$KFS = -0.42 \times age + 3.58 \times \text{leg } LM + 33.8 \text{ (SEE = 11.2)}.$$

$r_{multiple} = 0.75$ ($P < 0.0001$),
$r_{partial,\ age} = -0.46$ ($P < 0.0001$),
$r_{partial,\ leg\ LM} = 0.35$ ($P < 0.0001$).

In multiple regression analyses with whole body LM, trunk LM, abdominal LM, arm LM or leg LM as the dependent variables, and age, height and body mass as the independent variables, body mass, not age, was the most important predictor of LM measured at any site ($r_{partial}$ ranging from 0.42 to 0.68, $P < 0.0001$). Height and/or age added significantly to some of the equations. The following equation was obtained for leg LM:

$$\text{Leg } LM = 0.14 \times body\ mass - 0.04 \times age + 6.03 \text{ (SEE = 1.28)}.$$

$r_{multiple} = 0.72$ ($P < 0.0001$),
$r_{partial,\ body\ mass} = 0.65$ ($P < 0.0001$),
$r_{partial,\ age} = -0.55$ ($P < 0.0001$)

To examine whether muscle strength and leg LM decreased differently with age, muscle strength was expressed as KES or KFS per kilogram leg LM (KES/leg LM and KFS/leg LM, respectively). Highly significant negative correlations were found between KES:leg LM ratios and age ($r = -0.70$, $P < 0.0001$) (Fig. 2) and between KFS:leg LM ratios and age ($r = -0.53$, $P < 0.0001$). When studying only the women aged 50 years and younger ($n = 47$), no significant correlations between age and the KES:leg LM or KFS:leg LM ratios were found. In the women older than 50 years ($n = 53$), however, the correlations between age and KES:leg LM or KFS:leg LM were highly significant ($r = -0.44$ and $r = -0.53$, respectively, $P < 0.0001$).

To examine whether arm and leg LM decreased equally with age, arm LM was expressed as a percentage of leg LM in each individual. No significant correlation was found between age and the ratio of arm to leg LM. The ratio of arm, leg, trunk or abdominal LM to whole body LM also remained constant with increasing age.

Significant correlations were found between %fat in any region and age (r ranging from 0.27 to 0.39, $P < 0.01$–0.001). The ratio of abdomen %fat to limb %fat increased significantly with age ($r = 0.20$, $P < 0.05$). The same applied to the ratio of arm %fat to leg %fat ($r = 0.24$, $P < 0.05$).

Women in age groups I and V, and women with previous hip fractures and weight lifters were studied to examine differences in strength to LM ratios not only between young and old women but also between nonathletic active women, inactive women, and athletic women engaged in muscle strengthening exercises. The 18 women with hip fractures did not differ statistically from the women in group V regarding age [mean 76.8 (SD 4.8) years], height [mean 155.7 (SD 5.6) cm], body mass [mean 61.7 (SD 13.4) kg] and body mass index (BMI) [mean 25.3 (SD 4.8) $kg \cdot M^{-2}$]. Lean mass values (kg) and %fat of the body, arms, trunk, abdomen and legs were not significantly different from those found in group V, although a trend toward a lower %fat was found for each anatomical region (data not shown). The ratio of arm LM to leg LM was not significantly different between the two groups ($P = 0.8$). Values of KES and KFS were 75 (SD 25) N·m and 32 (SD 12) N·m, respectively, which were approximately 25% lower than those in group V ($P < 0.0001$).

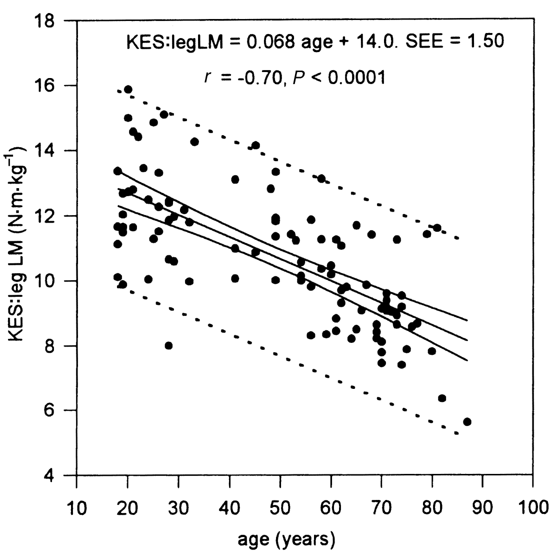

Fig. 2 Relationship between the ratio of knee extensor strength (*KES*) to leg lean mass (*LM*) and age in 100 healthy women. The 95% confidence interval (*solid lines*) and the 95% prediction interval (*dotted lines*) are shown

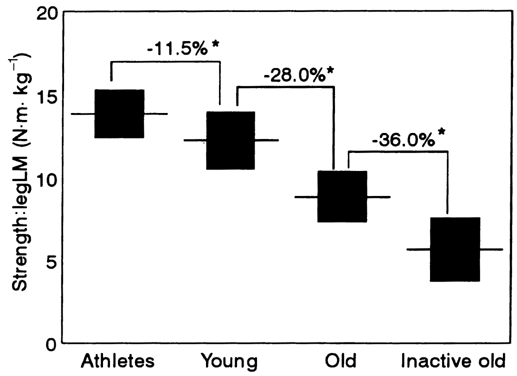

Fig. 3 Ratio of knee extensor strength to leg lean mass (*LM*) in young female weight lifters ($n = 20$), young nonathletic women (age group I, $n = 36$), elderly healthy women (age group V, $n = 19$) and elderly inactive patients with a previous hip fracture ($n = 18$). Mean and SD. Percentage differences between the means are shown. $^*P < 0.0001$

The 20 weight lifters did not differ statistically from the women in age group I regarding age [mean 26.3 (SD 4.0) years] and height [mean 170.3 (SD 5.5) cm], but were heavier [mean 71.7 (SD 8.3) kg, $P < 0.0001$] and had higher BMI [mean 24.7 (SD 2.2) $kg \cdot M^{-2}$, $P < 0.0001$]. In each region measured, lean mass was significantly higher and %fat was significantly lower than in group I. A detailed description of the body composition in the weight lifters has been given in a previous study (Madsen et al. in press b). Mean values of KES and KFS were 240 (SD 35) N·m and 119 (SD 22)N·m, respectively, which were approximately 45% higher than those in group I ($P < 0.0001$).

To correct for between-group differences in LM, strength was expressed as KES per kilogram leg LM (Fig. 3). The weight lifters had significantly higher KES: leg LM ratios than the women in group I ($P < 0.0001$). These in turn had higher ratios than the women in group V ($P < 0.0001$). The women with previous hip fractures had the lowest ratios ($P < 0.0001$). The difference in mean KES:leg LM ratios between the weight lifters and the women with previous hip fractures was 75%. Similar results were found for KFS:leg LM ratios. In the 100 healthy women, no correlation was found between the KES:leg LM ratio and leg LM.

Discussion

The considerable loss of strength with age found in the present study is in accordance with the results of previous cross-sectional studies of age-related changes in muscle strength (Sperling 1980; Young et al. 1984; Frontera et al. 1991).

The results obtained from the scans are in agreement with those reported in previous DEXA studies, e.g. the fact that whole body LM was only weakly associated with age (Compston et al. 1992; Lindsay et al. 1992). Whole body %fat increased with increasing age and abdominal FM expressed as a percentage of fat mass in the limbs was positively correlated with age suggesting a more central fat distribution in the older age groups. These findings are also consistent with previous works on DEXA reporting greater %fat in postmenopausal than in premenopausal women (Lindsay et al. 1992) and increase in abdominal %fat during and after menopause (Haarbo et al. 1991b; Svendsen et al. 1995). Furthermore, the fact that the weight lifters were leaner and the women with previously fractured hips tended to be leaner than age-matched controls are in keeping with previous observations based on measurements by photon absorption (Hassager and Christiansen 1989; Karlsson et al. 1993).

Data in the literature on the association between the loss of muscle mass and function with age are contradicting. Using simple anthropometric indices, Pearson et al. (1985) found significant differences in strength per unit muscle area between young and old individuals. A striking fall in grip strength with age but only a minimal change in fat free mass calculated on the basis of anthropometric measurements was demonstrated by Maclennan et al. (1980). Similarly strength of the adductor pollicis muscle per unit muscle area has been shown to be lower in elderly than in young subjects (Bruce et al. 1989). Stålberg et al. (1989) found that changes in muscle mean fibre area and body size explained less than half of the age-related changes in strength. In contrast to these findings, Young et al. (1984), found an equal reduction (30%) of quadriceps strength and cross-sectional quadriceps muscle area assessed by compound ultrasound imaging in old compared to young women. Rice et al. (1989a) using computed tomography found that the cross-sectional area of elderly muscles was smaller (28%–36%) than that of young muscles with greater amounts of nonmuscle tissue located within a muscle.

Using DEXA, we were able to assess not only total soft body composition but also regional soft tissue composition of the legs. Multiple regression analyses showed that age, not LM, was the most important determinant of muscle strength. The influence of age on the strength: LM ratio may, however, be more important in older than in younger age-groups. When studying women aged below 50 years and women aged 50 years and above, separately, the KES:LM and the KFS:LM ratio were only correlated with age in the older group. Our results are not in agreement with those of Frontera et al. (1991) comparing age-related changes in muscle strength and fat free mass assessed by hydrostatic weighing. Age-related differences in muscle strength in an older age group were reported to be considerably reduced or eliminated when correcting for total fat free mass.

The fact that DEXA does not discriminate between skeletal muscle and the other components of bone free LM may explain in part the unequal loss of LM and strength found in the present study. Furthermore, as stated by Stålberg et al. (1989), changes other than those related to muscle size and morphology may be responsible for the majority of the strength loss with age. Changes in muscle contractility (Campbell et al. 1973), enzyme activity (Borges and Essén-Gustavsson 1989) and degenerative changes in central or peripheral neural structures (Gutmann and Hanzlikova 1972) must also be taken into consideration.

The study indicated that not only age but also muscle strengthening exercises and inactivity may have a greater influence on muscle strength than on LM. Inactive women with previous hip fractures had significantly lower KES:leg LM ratios than age-matched controls and vice versa for weight lifters. As discussed above, multiple factors related to muscles may explain these findings. The fact that weight lifters had higher KES:leg LM ratios was probably not a result of the higher leg LM in itself. The ratio of strength to leg LM was not associated with strength in the 100 healthy women. Whether the age-related changes in strength: LM ratios were a result of a reduced level of a physical activity in the older groups cannot be excluded as the 100 healthy women were not graded regarding physical activity but were merely categorized as healthy, functionally independent and active to a moderate degree.

Frontera et al. (1991) reported that muscle strength of the arms declines more rapidly with age than strength of the legs. In contrast, Rice et al. (1989b) found similar rates of strength loss with age in arms and legs. When comparing young and elderly men by computed tomography Rice et al. (1989a) demonstrated similar reductions in muscle area corrected for nonmuscle tissue of arms and legs. In the present study, the age-related loss of LM was equal in arms and legs but %fat increased more rapidly in the arms than in legs. Using DEXA, we were not able to support the hypothesis of a decreasing use of arm compared with leg muscles in elderly healthy women (Frontera et al. 1991) or in inactive women compared to healthy controls.

Although age was the most important predictor of KES and KFS, LM contributed significantly to the regession equations reflecting that muscle mass also is important for strength. The SEE for KES values estimated on the basis of age and leg LM in a multiple regression analysis was approximately 17 N·m corresponding to a 95% prediction interval of ±34 N·m - or expressed as a percentage of the mean value of KES in the whole study sample $\pm 34/136 \times 100\% = \pm 25\%$. A much tighter prediction interval may be needed for such a relationship to have any clinical value in an individual. The between-group differences discussed above further complicate the use of LM as a predictor of muscle strength.

The results discussed above were obtained by examining isokinetic KES and KFS at a low velocity in women. Whether the findings can be generalized to other muscle groups, to isokinetic strength measured at higher velocities, and to men remains to be investigated. Previous studies have shown that strength in elderly women is more reduced at high test velocities than at low velocities (Harries and Bassey 1990). Consequently, the difference between the age-related loss of strength and LM would possibly have been even more pronounced if strength had been measured at a high velocity.

The study suggests that

1. Age-related differences in strength seem to be more qualitative than quantitative in nature, especially in older age-groups and
2. Muscle strengthening exercises and inactivity have considerably greater influence on muscle strength than on LM as assessed by DEXA.

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