STUDIES IN SPORT, PHYSICAL EDUCATION AND HEALTH
123

Janne Sallinen

# Dietary Intake and Strength Training Adaptation in 50–70 -Year Old Men and Women

## With Special Reference to Muscle Mass, Strength, Serum Anabolic Hormone Concentrations, Blood Pressure, Blood Lipids and Lipoproteins and Glycemic Control

JYVÄSKYLÄN YLIOPISTO

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# ABSTRACT

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Frailty has been defined as an age-related decrease of the physiologic systems that results in weakness, weight loss and decreased functional performance, thus increasing the risk of disability. The physical characteristics of frailty are affected by the amount of muscle mass and strength. Strength training (ST) can alleviate age-related declines in muscle mass, strength and physical function. However, there is controversy regarding whether dietary intake can improve the effects of ST. The present thesis assessed the effects of dietary intake (DI) on muscular, hormonal and metabolic adaptations to ST in healthy 50-70 year old people. In cross-sectional study I, maximal strength of the leg extensors and muscle thickness of the vastus lateralis (measured using ultrasound) were compared between male strength athletes (MA52: n=9 & MA72: n=8) and control males (M52: n=11 & M71: n=10). The strength athletes had greater maximal strength than the controls, but no group effect was recorded for muscle thickness. In studies II-IV, the effects of nutritional counseling (NC) aimed at providing appropriate energy and protein intake and recommended fat intake were studied during 21 weeks of progressive ST (40-80% of 1RM loads) in women (ST+NC: n=25 & ST: n=26) and men (ST+NC: n=22 & ST: n=23). In study V the effects of continued reduced strength training (CRST) for another 21 weeks were assessed between the ST group and the male control group (C: n=21). The measurements included muscle cross-sectional area of the quadriceps femoris (CSA of QF) (by MRI), maximal strength of the leg extensors, serum anabolic hormone concentrations, resting blood pressure (BP) and fasting concentrations of blood lipids and lipoproteins, and blood glucose. The NC reduced the saturated fat intake in both men and women. After the NC, an increased protein intake was observed in women and increased carbohydrate and fiber intake in men. The muscle CSA of QF increased more (10% vs. 7%) in the NC group of women compared to the group with no dietary advice. In older men the increases in muscle CSA of QF (5-6%) did not differ between the groups. Gains in muscle strength also showed no differences between the groups in women (24-29%) or in men (16-20%). The CRST maintained increased muscle strength in older men. No group differences were observed in serum anabolic hormone concentrations during ST. The average serum testosterone per sex hormone-binding globulin –ratios correlated positively with the average body weight-normalized intake of energy, protein and fat in older men. The BP decreased mildly in both genders after ST. The NC enhanced the decreases in serum LDL -cholesterol concentration and serum total cholesterol per HDL cholesterol –ratio in older women. No changes were observed in serum lipids and lipoproteins in older men. Blood glucose levels did not differ between the experimental groups during the ST period. The CRST resulted in sustained fasting blood glucose levels in strength-trained men compared to an increase in the C. The present data showed that progressive ST reduced the risk of frailty by increasing muscle mass and strength, and improving metabolic risk profiles in older men and women. Furthermore, a recommended moderate fat diet with a suitable energy and protein intake reinforced the ST-induced muscle hypertrophy and caused favorable changes in metabolic health indicators in older women.

Key words: Older adults, nutrition, strength training, muscle mass, strength, metabolic health

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*Dedicated to my lovely family*
*Maare, Rasmus and Ronja*

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Jyväskylä, July 2007

Janne Sallinen

## ABBREVIATIONS

| | |
|---|---|
| 1RM | one repetition maximum load |
| ANCOVA | analysis of covariance |
| ANOVA | analysis of variance |
| BIA | bioimpedance analyses |
| BMI | body mass index |
| CI | confidence interval |
| CSA | cross-sectional area |
| CT | computed tomography |
| DHEAS | dehydroepiandrosterone sulphate |
| DI | dietary intake |
| DXA | dual-energy X-ray absorptiometry |
| E% | percent of energy |
| FT | free testosterone |
| GH | growth hormone |
| HDL-C | HDL –cholesterol |
| LDL-C | LDL –cholesterol |
| MJ | megajoule |
| MM | muscle mass |
| MRI | magnetic resonance imaging |
| MUFA | monounsaturated fatty acids |
| NC | nutritional counseling |
| P/S -ratio | ratio of polyunsaturated and saturated fatty acids |
| PUFA | polyunsaturated fatty acids |
| QF | quadriceps femoris |
| RCT | randomized controlled trial |
| RDA | recommended dietary allowances |
| SAFA | saturated fatty acids |
| SD | standard deviation |
| SE | standard error |
| SH | sex hormone |
| SHBG | sex hormone-binding globulin |
| SMMI | skeletal muscle mass index |
| ST | strength training |
| T | total testosterone |
| TAG | triacylglycerols |
| TC | total cholesterol |

## LIST OF ORIGINAL PUBLICATIONS

The present thesis based on following articles, which will be referred to by their Roman numerals I-V.

I Sallinen J, Ojanen T, Karavirta L, Ahtiainen JP, Häkkinen K. Muscle mass and strength, body composition and dietary intake in master strength athletes vs. untrained men of different ages. (submitted for publication)

II Sallinen J, Pakarinen A, Fogelholm M, Sillanpää E, Alen M, Volek JS, Kraemer WJ, Häkkinen K. Serum basal hormone concentrations and muscle mass in aging women: effects of strength training and diet. *International Journal of Sport Nutrition and Exercise Metabolism* 2006; *16: 316-331.*

III Sallinen J, Pakarinen A, Fogelholm M, Alen M, Volek JS, Kraemer WJ, Häkkinen K. Dietary intake, serum hormones, muscle mass and strength during strength training in 49-73-year old men. *International Journal of Sports Medicine* 2007 (in press)

IV Sallinen J, Fogelholm M, Pakarinen A, Juvonen T, Volek JS, Kraemer WJ, Alen M, Häkkinen K. Effects of strength training and nutritional counseling on metabolic health indicators in aging women. *Canadian Journal of Applied Physiology* 2005; *30: 690-707.*

V Sallinen J, Fogelholm M, Volek JS, Kraemer WJ, Alen M, Häkkinen K. Effects of strength training and reduced training on functional performance and metabolic health indicators in middle-aged men. *International Journal of Sports Medicine* 2007 (in press)

## CONTENTS

# 1 INTRODUCTION

The number of older people (aged 65+) is increasing all around the world, and these people are living longer than ever. In many nations such as Japan, Great Britain, USA and Nordic countries including Finland, the percentage of the total population made up of people aged 65 years and over is approaching, or already exceeds, 15% (Crews and Zavotka 2006, Parkkinen 2002). Although the older adults are healthier with a lower prevalence of disability than previous cohorts at the same age, the number of disabled older people has increased simply due to their increasing longevity in the present day (Crews and Zavotka 2006).

The largest age cohorts in Finland were born in the years 1945-1956 compared to the years 1960-1974 in the other European countries. This indicates that the age structure of Finland is about fifteen years ahead of the rest of Europe. As a result, Finland will have the highest ratio of pensioners per working population in Europe when these people reach the age of retirement during the 2010's and 2020's. The "greying" population will pose a significant challenge to the health and social services. For example, in 2000, Finnish comprehensive school-aged children used public and private nursing services representing an average value of 1 000 euros per year compared to as much as 23 000 euros by people over the age of 90 (Parkkinen 2002).

Because older people have varying health levels, this heterogeneity is often described using a continuum ranging from good physical fitness to physical frailty (Rockwood et al. 2004). Frailty has been defined as an age-related cumulative decrease of multiple physiologic systems that results in vulnerability to adverse outcomes such as weakness, weight loss, and decreased balance, functional performance and physical activity contributing to the risk of disability (Fried et al. 2001). Although no consensus is available regarding the definition of frailty, it is recommended that operational criteria should be based on mobility, balance, muscle strength, motor processing, cognition, nutritional state or weight change, endurance, and physical activity (Ferrucci et al. 2004).

As well as the underweight, obese older people are also more vulnerable to frailty and disability than their normal-weight peers due to their reduced muscle mass and strength relative to body weight (Villareal et al. 2004, Baumgartner et al. 2004, Woods et al. 2005). Obesity can decrease physical function via reduced physical activity and medical complications such as metabolic disorders (e.g. metabolic syndrome), arthritis (e.g. knee osteoarthritis) and pulmonary abnormalities (e.g. obesity-hypoventilation syndrome) (Villareal et al. 2005).

The prevalence of frailty increases from 4-7% in those aged 65-74 years, to 25-37% in those aged 85 years and older (Fried et al. 2001, Rockwood et al. 2004). Women have a higher risk of frailty than men, apparently due to their smaller lean body mass and strength levels, making them more vulnerable to reach the physical impairment threshold in old age (Fried et al. 2001, Puts et al. 2005). Older people with some risk factors for frailty (i.e. exhaustion, weight loss, low level of physical activity, slow walking speed or weak grip strength) have more than twice the probability of becoming frail relative to people with no frailty characteristics (Fried et al. 2001). Therefore, it is not a surprise that the discovery of effective interventions to prevent and delay frailty and disability of old people is a public health priority (Ferrucci et al. 2004).

The etiology of frailty is associated with four causative elements: 1) genetic factors, 2) disease and injuries, 3) lifestyle (nutritional problems and inactivity) and 4) aging (Bortz et al. 2002). Regardless of factors contributing to frailty and disability, interventions have proved strength training as an effective prevention action to reduce age-related loss of muscle mass, strength and physical function in previously sedentary older adults (Janssen and Ross 2005). However, some controversy exists whether dietary intake can improve the effects of strength training in older people. The following thesis will assess the effects of dietary intake on muscular, hormonal and metabolic adaptation to strength training in healthy older adults.

# 2 REVIEW OF THE LITERATURE

## 2.1 Age related loss of skeletal muscle mass "sarcopenia"

It is well known that skeletal muscle mass reaches its peak level in early adulthood and declines gradually, beginning at about 45 years of age even in the healthy older adults (Janssen et al. 2004). Typically, muscle mass decreases at a minimum of 0.5% per year beyond the age of 50 (Deschenes 2004).

Old age muscle atrophy is commonly referred to as "*sarcopenia*". This word was first used by Irwin H. Rosenberg in 1988, referring to the age-related decline in lean body mass that impairs functional performance in older people. Rosenberg coined sarcopenia from the Greek words *sarx* meaning flesh and *penia* meaning loss (Iannuzzi-Sucich et al. 2002). In other words, sarcopenia is used to define age-related changes in skeletal muscle size originating from changes in the central and peripheral nervous system, hormone status, inflammatory cytokines, and energy and protein intake (Doherty 2003).

Sarcopenia has a central role in a hypothesized cycle of frailty as described in figure 1. It seems likely that frailty can be caused by two different pathways or their combinations: 1) as a result of age-related physiological changes in the absence of disease or 2) due to severe disease or comorbidity (such as cardiovascular diseases and diabetes) (Fried et al 2001). In the Cardiovascular Health Study of 5317 older adults (aged ≥65 years), 46% of those who were frail had comorbid disease. Conversely, only 27% of those who were frail had neither disability in activities of daily living nor comorbidity (Fried et al. 2001). In any case, a loss of muscle mass has a central role in the etiology of frailty, emphasizing the significance of the neuromuscular system for physical fitness and health in the older adults. Furthermore, changes in the composition of skeletal muscle, particularly an increase in intramuscular lipid content, can contribute to metabolic disorders (such as insulin resistance) and decreased muscle strength in old people (Janssen and Ross 2005).

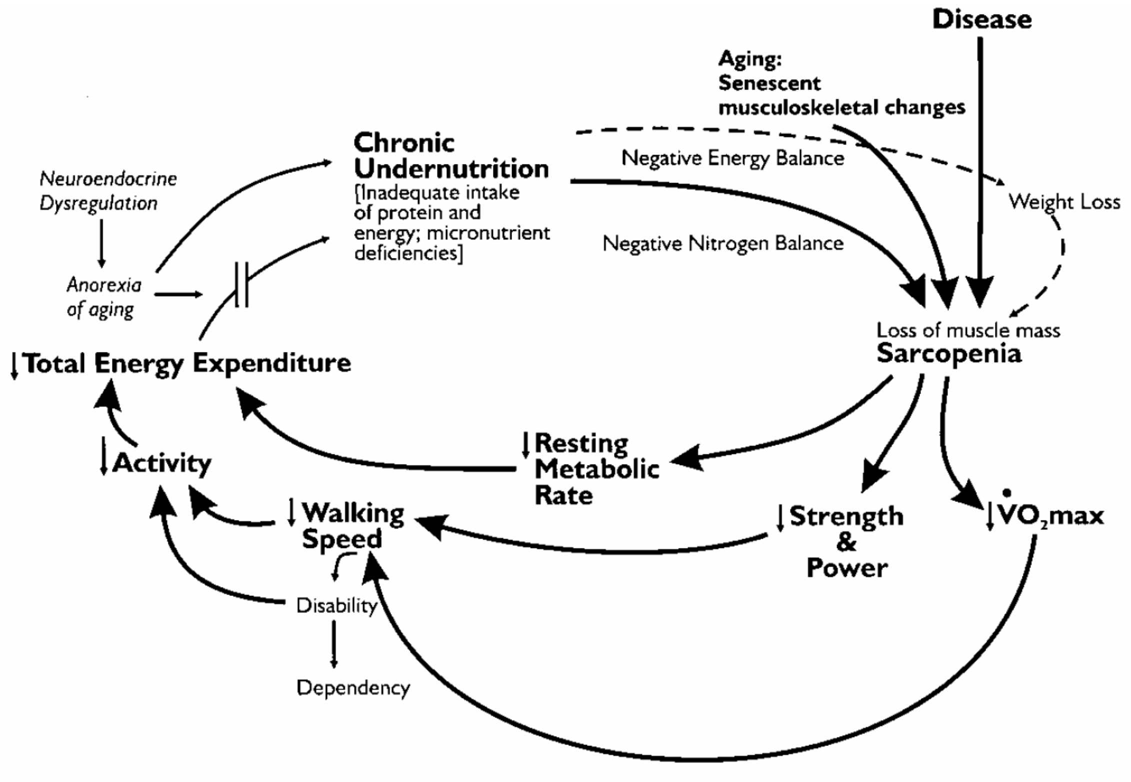



FIGURE 1 Hypothesized cycle of frailty (Fried et al. 2001). Copyright © The Gerontological Society of America. Reproduced by permission of the publisher.

Because our population is getting older, there is a clear need for effective lifestyle prevention against sarcopenia to maintain independence in senescence. This review will examine sarcopenia by describing its prevalence, consequences, etiology and non-pharmacological prevention.

## 2.2 Prevalence of sarcopenia

Sarcopenia is normally defined statistically as a skeletal muscle mass index (SMMI: appendicular [i.e. arms and legs] lean soft-tissue mass [kg] /height squared [$m^2$]) more than two standard deviations below the sex-specific young-normal mean value of skeletal muscle mass (Baumgartner et al. 1998, Iannuzzi-Sucich et al 2002, Tanko et al. 2002, Castillo et al. 2003, Gilette-Guyonnet et al. 2003, Kenny et al. 2003, Lau et al. 2005). Newman et al. (2003) classified participants as sarcopenic if their lean mass fell into the sex-specific lowest 20%. However, the cut-off points used by Newman and co-workers (2003) were similar to those reported previously in older persons compared to healthy young adults (Baumgartner et al. 1998). Based on the SMMI, the prevalence of sarcopenia ranges from 10% to as high as 50% among community-dwelling over 60-year old men and women (table 1).

TABLE 1 Prevalence of sarcopenia (skeletal muscle mass over 2 SD below young controls) in community-dwelling older adults*

| Reference | Participants | Prevalence of sarcopenia |
|---|---|---|
| Baumgartner et al. 1998 | 383 women and 426 men:<br>74±6 yrs<br>(45-48% Hispanic, 52-55% non-Hispanic Caucasian) | Women:<br>Hispanic <75 yrs: 30%<br>Caucasian <75 yrs: 28%<br>Hispanic ≥75 yrs: 48%<br>Caucasian ≥75 yrs: 40%<br>Men:<br>Hispanic <75 yrs: 18%<br>Caucasian <75 yrs: 17%<br>Hispanic ≥75 yrs: 47%<br>Caucasian ≥75 yrs: 40% |
| Tanko et al. 2002 | 152 women: 60-85 yrs<br>(Caucasian) | 11 % |
| Iannuzzi-Sucich et al. 2002 | 195 women: 64-93 yrs<br>142 men: 64-92 yrs<br>(Caucasian) | Women: 23%<br>Men: 27% |
| Gillette-Guyonnet et al. 2003 | 7518 women: 76-95 yrs<br>(Caucasian) | 76-80 yrs: 9%<br>86-95 yrs: 11% |
| Kenny et al. 2003 | 189 women: 59-78 yrs<br>(Caucasian) | 24 % |
| Newman et al. 2003 | 1549 women and 1435 men:<br>70-79 yrs<br>(Caucasian 59%, Black 41%) | Women:<br>BMI<25: 52%<br>25<BMI<30: 7%<br>BMI>30: 0 %<br>Men:<br>BMI<25: 50%<br>25<BMI<30: 9%<br>BMI>30: 0 % |
| Rolland et al. 2003 | 1458 women: ≥70 yrs<br>(Caucasian) | 10 % |
| Lau et al. 2005 | 265 women: 76.9±3.7 yrs<br>262 men: 73.8±2.8 yrs<br>(Chinese) | Women:<br>70-74 yrs: 10%<br>75-59 yrs: 6%<br>≥80 yrs: 6%<br>Men:<br>70-74 yrs: 10%<br>75-79 yrs: 15% |

*Published 1997-2007, participants >50 yrs, >100 person per group and muscle mass measured with dual-energy X-ray absorptiometry

Large variations in the reported prevalence of sarcopenia are related to differences in the sampling protocol (i.e. characteristics of the participants) and methodology. The prevalence of sarcopenia has been reported to be higher in random sampled population studies (30-50%) (Baumgartner et al. 1998, Newman et al. 2003) compared to the selection of volunteers (10-25%) (Tanko et al. 2002, Iannuzzi-Sucich et al. 2002, Gillette-Guyonnet et al. 2003, Kenny et al. 2003, Rolland et al. 2003, Lau et al. 2005) among non-obese older people (BMI<30 $kg/m^2$). Therefore, the nonrandomized sampling protocol (i.e. convenience sample) seems to underestimate the true prevalence of sarcopenia due to the exclusion of individuals with more severe impairment and morbidity.

Quantification of whole-body skeletal muscle mass is affected by the methodology used (Lee et al. 2001). Computed tomography (CT) and magnetic resonance imaging (MRI) are the most valid techniques for estimating skeletal muscle mass. However, these measurements are very expensive and only available at medical centers. Dual-energy X-ray absorptiometry (DXA) is considered as a valid tool for estimation of skeletal muscle mass with a strong correlation with imaging techniques. DXA is limited by the indirect quantification of skeletal muscle mass relying on several assumptions. However, the DXA device and its operation are much less costly than CT or MRI, and DXA soft tissue estimates are equally valid in young and old people. Although anthropometry and bioimpedance analysis (BIA) serve as rapid, safe and inexpensive field measurements for epidemiological and field studies, they are too inaccurate for the assessment of skeletal muscle mass (Lee et al. 2001). Based on BIA analysis, the prevalence of sarcopenia has been found to be small in older women (6-10%) and men (6-7%), apparently underestimating the real prevalence of the problem (Janssen et al. 2002, Castillo et al. 2003).

Classification of sarcopenia by the SMMI method is limited by the fact that it does not take into account the body size (fat mass) of the person. Therefore, the SMMI may not classify obese older people as sarcopenic, even though their muscle mass may be inadequate for their body size (Newman et al. 2003). Reported differences in the prevalence of sarcopenia between the original SMMI method and the fat mass adjusted SMMI method were 7% vs. 22% and 9% vs. 15% in overweight (25<BMI<30) older women and men, respectively. Corresponding values in obese (BMI>30) older women and men were 0% vs. 14% and 0% vs. 12%, respectively (Newman et al. 2003). These findings suggest that body fat should be considered when estimating the prevalence of sarcopenia in older people.

## 2.3 Consequences of sarcopenia

It has been estimated that sarcopenia is a major contributor to age-related decreases in muscle strength, accounting for a large proportion of the variability in strength (Frontera et al. 2000). Decreased muscle strength is associated with loss of neuromuscular function, leading to weakness and reduced functional performance in the older adults (figure 1, page 14). The relationship between loss of muscle strength and physical disability is not linear in older adults and the largest increase in disability occurs when muscle strength declines from a moderate to a low level (Jansen et al. 2004). Disability occurs when muscle mass decreases enough to impair the ability to perform normal activities of daily living (Villareal et al. 2004). The age-related substitution of muscle mass with fat (and connective) tissue may also increase the risk of metabolic disorders such as insulin resistance (Deschenes 2004, Janssen and Ross 2005).

### 2.3.1 Loss of muscle strength

Muscle strength is rather well maintained until the 6th decade of life, but thereafter an accelerated loss of strength is evident (Deschenes 2004). Strength of (weight bearing) knee extensor muscles is lost at a rate of 15-40% per decade according to longitudinal studies (table 2). Meanwhile, cross-sectional studies indicate a loss of strength of only 10-20% per decade, apparently underestimating the real changes in muscle strength. Older participants in their seventh and eighth decades have 20-40% less knee extension strength compared to their younger counterparts. Relative strength loss is even greater, at least 50%, in very old compared to young adults (Vandervoort 2002, Doherty 2003).

TABLE 2 Decrease in maximal strength of the knee extensors in community-dwelling older adults*

| Reference | Participants | Design | Decrease in maximal strength per 10 years |
|---|---|---|---|
| Samson et al. 2000 | 74 women & 81 men: 20-90 yrs | Cross-sectional | 55-80 yrs:<br>Women: 16%[a]<br>Men: 9%[a] |
| Goodpaster et al. 2001 | 2627 adults: 70-79 yrs | Cross-sectional | 21%[b] |
| Hughes et al. 2001 | 68 women & 52 men: 46-78 yrs | 10 yrs follow-up | Women: 12%[b]<br>Men: 15%[b] |
| Goodpaster et al. 2006 | 951 women and 929 men: 70-79 yrs | 3 yrs follow-up | Men: 34-41%[b]<br>Women: 27-30%[b] |

*Published 1997-2007, participants >45 yrs and ≥40 person per group, [a]isometric strength, [b]isokinetic strength (60°/s)

The assessment of muscle strength is methodologically challenging. Muscle strength is influenced by the mode of contraction i.e. isometric (static), eccentric (lengthening) or concentric (shortening), and by the speed of movement. When assessing muscle strength, the muscle groups and mode of contraction need to represent a muscle action relevant to the task of interest. For example, walking may be best represented by a peak torque generated by action of the knee extensors and plantar flexors during dynamic contractions (Chandler et al. 1997).

Although relative strength loss appears to be similar in men and women, the absolute loss of strength is greater in men due to their greater baseline strength values (Vandervoort 2002, Doherty 2003). Age-related declines in leg strength can be much greater than the loss of leg muscle mass, suggesting the potential for a significant decline in muscle quality (leg strength normalized to leg muscle mass) in senescence (Goodpaster et al. 2006). Therefore, besides the muscle quantity, muscle quality may be an important determinant of decreased muscle strength with aging (Goodpaster et al. 2006).

### 2.3.2 Decline in functional performance

Performance-based physiological function of the lower limbs, especially walking speed, is considered a good measure for predicting the incidence of functional impairments in older people (Shinkai et al. 2000, Newman et al. 2006). Maximal as well as normal walking speed declines comparably in both genders during aging (table 3). Walking speed seems to decline substantially after 65 years of age (Shumway-Cook et al. 2007).

TABLE 3 Walking speed (mean and SD) according to age and gender (Shumway-Cook et al. 2007)

| Age | Women (n=674) | | Men (n=554) | |
|---|---|---|---|---|
| | Walking speed (m/s) | | Walking speed (m/s) | |
| | Usual | Maximal | Usual | Maximal |
| <65 yrs | 1.30±0.19 | 1.70±0.24 | 1.36±0.19 | 1.90±0.28 |
| 65-74 yrs | 1.09±0.22 | 1.39±0.26 | 1.21±0.24 | 1.66±0.32 |
| 75-84 yrs | 0.89±0.23 | 1.15±0.29 | 1.06±0.23 | 1.42±0.33 |
| ≥85 yrs | 0.71±0.29 | 0.92±0.36 | 0.81±0.29 | 1.18±0.36 |

Longitudinal data about age-related changes in walking speed are very limited. In the Evergreen study, the maximal walking speed decreased comparably by 33% and 23% in 295 initially 75-year old Finnish women and men during a 10-year follow-up (Rautio et al. 2005). The estimates of prevalence of severe walking disability in women are: 2.0% for ages 65-74, 3.4% for ages 75-84, and 9.1% for ages 85 and older (Rantanen et al. 1999).

Age-related declines in walking performance depend mainly on lower limb strength, but balance is also important (Rantanen et al. 1999, Rantanen et al. 2001, Lord et al. 2002, Purser et al. 2003, Tiedemann et al. 2005). Severe sarcopenia and decreased performance of the lower extremities can increase the disability risk by at least threefold in older individuals compared to people with normal muscle mass and physical performance (Rantanen et al. 2001, Janssen et al. 2004). Furthermore, older people with poor lower extremity performance have a 1.8 times higher risk of hospitalization compared to people with good performance (Penninx et al. 2000).

### 2.3.3 Frailty

Medical practitioners often use the term "frailty" to describe the weakest and most vulnerable older individuals (Walston et al. 2006). Frail older people have a lower resistance to stressors (such as illness or operation) due to a cumulative decline in multiple physiologic systems, thus increasing their vulnerability to adverse outcomes (e.g. institutionalization, hospitalization and mortality) (Fried et al. 2001). Although standard criteria for frailty are not recognized, most of the studies in this area have focused on: 1) mobility (lower-extremity performance and gait abnormalities, 2) muscle weakness, 3) poor exercise tolerance, 4) unstable balance, and 5) body composition related factors (weight loss, malnutrition and sarcopenia) (Ferrucci et al. 2004). Therefore, multiple interrelated factors should be clinically present to constitute frailty (Fried et al. 2001). Practically all of these physical characteristics of frailty are more or less affected by the amount of skeletal muscle mass and strength (Cycle of frailty, page 14). However, social, psychological and medical factors associated with aging should also be considered in the estimation of risk of frailty (Hays and Roberts 2006).

Frailty is commonly screened according to the criteria of the Cardiovascular Health study (Fried et al. 2001) or its' modification, such as those used in the Women's Health and Aging Studies (Blaum et al. 2005) (table 4). However, a number of screening tests for frailty have also been developed, including one-leg standing balance and the "Timed Up and Go" test, performed with and without carrying a glass of water (Morley et al. 2002). The prevalence of frailty increases from 3-10% at 65-74 years to 15-35% in those aged 85 years and older (table 5). All studies presented in table 5 consisted of an age-stratified random sample of a predominantly caucasian population. Females are more prone to frailty than men (Fried et al. 2001, Puts et al. 2005, Rockwood et al. 2004) and the obese are more prone than normal weight older adults (Blaum et al. 2005, Woods et al. 2005). Furthermore, African-Americans are more vulnerable to frailty than Caucasians (Fried at al. 2001, Blaum et al. 2005, Boyd et al. 2005, Woods et al. 2005, Hirch et al. 2006). Therefore, it is not a surprise that the prevalence of frailty was greatest in the study with the highest proportion of African-American women (Boyd et al. 2005).

TABLE 4 Criteria for frailty in the Cardiovascular Health Study (Fried et al. 2001) and Women's Health and Aging Studies (Blaum et al. 2005)

| Characteristics | Cardiovascular Health Study | Women's Health and Aging Studies |
|---|---|---|
| Weight loss | Over 5 kg weight loss in last year | BMI < 18.5 or weight loss<br>≥ 10% relative to weight at age 60 |
| Exhaustion | Either of:<br>Felt that everything I did was an effort in last week<br>Could not get "going" in last week | Any of:<br>Low usual energy level<br>Felt unusually tired in last month<br>Felt unusually weak in last month |
| Slowness | Walking time (4.6 m):<br>≤ 7 s for height ≤159 cm<br>≤ 06 s for height >159 cm | Walking speed (4 m):<br>≤ 0.65 m/s for height ≤ 159 cm<br>≤ 0.76 m/s for height > 159 cm |
| Low activity level | < 270 kcal of physical expenditure on activity scale (18 items#) | < 90 kcal of physical expenditure on activity scale (6 items*) |
| Weakness | Grip strength of the dominant hand:<br>≤ 17 kg for BMI ≤ 23<br>≤ 17.3 kg for 23 < BMI < 26<br>≤ 18 kg for 26 < BMI < 29<br>≤ 21 kg for BMI > 29 | Grip strength of the dominant hand:<br>≤ 17 kg for BMI ≤ 23<br>≤ 17.3 kg for 23 < BMI < 26<br>≤ 18 kg for 26 < BMI < 29<br>≤ 21 kg for BMI > 29 |

BMI = body mass index; weight per square height ($kg/m^2$)

#walking for exercise, moderately strenuous household chores, mowing the lawn, raking the lawn, gardening, hiking, jogging, biking,, exercise cycle, dancing, aerobics, bowling, golf, singles tennis, doubles tennis, racquetball, calisthenics, swimming

*walking for exercise, moderately strenuous household chores, moderately strenuous outdoos chores, bowling, regular exercise, dancing

TABLE 5 Prevalence of frailty among the community-dwelling predominantly Caucasian older adults*

| Reference | Participants | Prevalence of frailty |
|---|---|---|
| Fried et al. 2001 | 2710 women and 2025 men: | Women: |
| | ≥65 yrs | 65-70 yrs: 3% |
| | (15% African-American) | 71-74 yrs: 7% |
| | | 75-79 yrs: 12% |
| | | 80-84 yrs: 16% |
| | | 85-89 yrs: 31% |
| | | Men: |
| | | 65-70 yrs: 2% |
| | | 71-74 yrs: 3% |
| | | 75-79 yrs: 6% |
| | | 80-84 yrs: 14% |
| | | 85-89 yrs: 16% |
| Blaum et al. | 599 women: 70-79 yrs | Overall: 8% |
| 2005 | (20% African-American) | 18.5<BMI<25: 8% |
| | | 25<BMI<30: 5% |
| | | BMI>30: 16% |
| Boyd et al. 2005 | 749 women: 78.0±7.9 yrs | Overall: 25% |
| | (28% African-American) | 65-74 yrs: 13% |
| | | 75-84 yrs: 30% |
| | | ≥85 yrs: 37% |
| Puts et al. 2005 | 1195 women: 72.4±8.5 yrs | Women: 18% |
| | 1062 men: 72.6±8.6 yrs | Men: 14% |
| Woods et al. 2005 | 4657 women: 65-79 yrs | Overall: 17% |
| | (18% from ethnic subgroups) | <18.5 BMI: 1% |
| | | 18.5<BMI<24.9: 22% |
| | | 25.0<BMI<29.9: 33% |
| | | ≥30 BMI: 44% |

*Published 2001-2007, participants >60 yrs, >100 person per group, criteria for frailty from Cardiovascular Health Study or Women's Health and Aging Studies or modification of them, BMI = body mass index; weight per square height ($kg/m^2$

## 2.4 Etiology of sarcopenia

It is generally accepted that sarcopenia results from multiple interrelated factors such as sedentary lifestyle, hormonal changes, inadequate diet and disease-related pathophysiology (figure 2). Furthermore, heredity may make some individuals more vulnerable to skeletal muscle atrophy (Roth et al. 2003, Schrager et al. 2004). It is also probable that when considering a specific age group, gender or pathological state, certain underlying mechanisms may be more applicable than others (Doherty 2003).

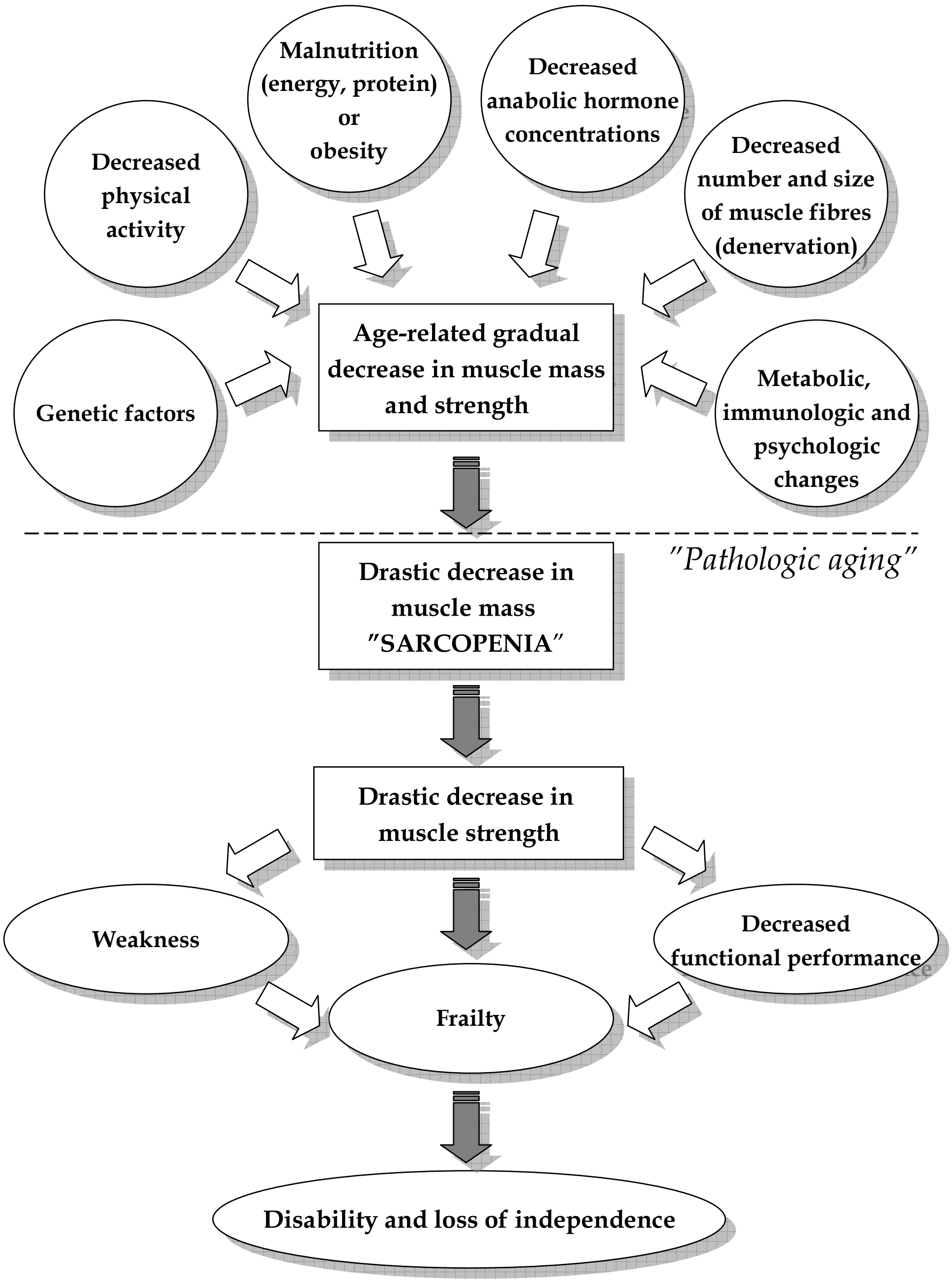



FIGURE 2 Sarcopenia in old age

### 2.4.1 Decreased physical activity

The prevalence of total and high intensity physical activity decreases in old age. The most prevalent exercise training modality among older adults is walking (Brach et al. 2004, van den Brink et al. 2005, Sulander et al. 2006). In Europe, the percentage of old people engaged in physical exercise is highest in the Northern and Central European countries (de Groot et al. 2004). The self-reported frequency of daily walking (at least 30 minutes per session) decreased from 45% to 39% between the ages of 65-69 and 80-84 among Finnish women in a group of 1863 older people aged 65-84 years (Sulander et al. 2006). The corresponding values for older Finnish men were 46% and 40%, respectively (Sulander et al. 2006).

In cross-sectional studies, physically active older people usually have greater muscle mass compared to their physically inactive counterparts, but the limited existing longitudinal data do not support these findings (table 6). Thus, there is no certainty: 1) whether decreased physical activity can independently contribute to loss of muscle mass or 2) whether the decreased activity is a consequence of age-related physical impairments, such as increased morbidity and body fat, contributing to a loss of muscle mass. Furthermore, no information is available about the effects of the intensity of physical activity on muscle mass in the older adults. Moreover, long-term studies are needed to show the effects of different types (endurance training, strength training etc.) and doses (frequency, intensity and volume) of physical activity on skeletal muscle mass in older individuals.

TABLE 6 Relationship between physical activity (PA) and muscle mass (MM) in community-dwelling older adults*

| Reference | Participants | Desing | Relationship between PA and MM |
|---|---|---|---|
| Baumgartner et al. 1999 | 180 women and 121 men: 65-97 yrs | Cross-sectional | PA[a] correlated positively with muscle mass in both genders |
| Kenny et al. 2003 | 189 women: 59-78 yrs | Cross-sectional | No correlation between PA[a] and SMMI |
| Aubertin-Leheudre et al. 2005 | 40 women: 55-65 years | Cross-sectional | High PA energy expenditure[b] was associated to higher LBM and SMMI than low PA energy expenditure |
| Di Francesco et al. 2005 | 85 men: 68-79 yrs | Cross-sectional | Total PA[a] and high-intensity PA (brist walking, cycling etc.)[a] correlated positively with SSMI |
| Hughes et al. 2002 | 78 women: 60.0±7.4 yrs<br>53 men: 61.1±8.1 yrs | 9 yrs follow-up | No correlation between PA energy expenditure[a] and LBM |
| Raguso et al. 2006 | 66 women and 74 men: >65 yrs | 3 yrs follow-up | PA energy expenditure[a] did not correlate with LBM and SMMI |

*Published 1997-2007, participants >50 yrs, ≥40 person per group and muscle mass measured with dual-energy X-ray absorptiometry, PA = physical activity, MM = muscle mass, SMMI = skeletal muscle mass index: appendicular lean mass (kg) / height squared ($m^2$), [a]questionnaire, [b]accelometry

Estimation of physical activity is methodologically difficult. Although the doubly labeled water (DLW) method is considered as the "gold standard" for the assessment of energy expenditure, it is limited by high costs and technical complexity. Therefore, standardized physical activity questionnaires and diaries, heart rate monitors and motion sensors (pedometers and accelerometers) are the most common tools used to record physical activity. Questionnaires are useful for assessing the patterns, frequency, type and context of physical activity. However, questionnaires and diaries are limited by memory, as well as being subject to misrepresentation and socially-desirable responses. Furthermore, questionnaires and diaries are inconsistent in terms of reliability and validity. Heart rate monitors only measure heart rate responses to an activity, but do not quantify activity itself. Furthermore, the relationship between energy expenditure and heart rate only becomes more secure with moderate to high-intensity activity. Pedometers are best suited to showing relative changes in physical activity or for ranking participants according to activity levels. Accelerometers may represent a valid assessment tool for intermittent activity of various intensities. However, pedometers and accelerometers are insensitive to non-locomotor type physical activity (cycling, strength training etc.) (Livingstone et al. 2003).

Very little information is available about the effects of a long-term history of physical activity (i.e. experience of different type and intensity of physical activity) on sarcopenia. It seems likely that moderate to high-intensity muscle loading exercises (strength training etc.) maintain muscle strength and mass better than low-intensity muscle loading exercises (walking etc.) in senescence (Fatouros et al. 2005). This statement is supported by the finding of greater knee extension strength in 54 elite master weightlifters aged 40-87 years compared to age-matched untrained control men (Pearson et al. 2002). Furthermore, greater knee extension strength and lean body mass were recorded in old strength athletes compared to old speed athletes, endurance athletes and control men when 67 athletes and 42 control men aged 70-89 years were compared (Sipilä et al. 1991). Klitgaard and co-workers (1990) reported that knee extension strength in 7 older recreationally strength trained men (68±0.8 years) were greater than in 8 age-matched sedentary controls and identical to 7 young sedentary controls (28±0.1 years). However, knee extension strength in 6 recreational older swimmers (69±1.9 years) and 5 older runners (70±0.7 years) did not differ from the age-matched controls (Klitgaard et al. 1990). A natural phenotypic selection (i.e. muscularity and body fatness) to a different type of sport cannot be ruled out, and greater muscle strength cannot be directly interpreted to mean better physical function (e.g. mobility).

### 2.4.2 Nutrition

#### *Malnutrition*

Factors such as impaired regulation of food intake and a monotonous diet are associated with smaller energy and nutrient intake in community-dwelling older people (Marshall et al. 2001, Schröder et al. 2004, Roberts et al. 2005). Food intake is impaired by age-related physiological changes (such as declined taste and smell sensitivity, reduced sensory-specific satiety, delayed gastric emptying, impairments in food-intake and digestion-related hormonal systems etc.) contributing to reduced perception of hunger, increased satiation and reduced dietary variety. Moreover, several non-physiological causes including social (poverty, isolation etc.), psychological (depression, dementia, fatigue etc.) and medical (chronic diseases, dysphagia, poor dentitation, restrictive therapeutic diet etc.) factors, and multiple medications (side effects e.g. change in the sense of taste and smell, nausea) can impair food intake in older individuals (Hays and Roberts 2006). As a consequence, older people have a reduced ability to regulate their food intake, which can contribute to the etiology of involuntary weight loss called "*anorexia of aging*" (Figure 3) (Hays and Roberts 2006).

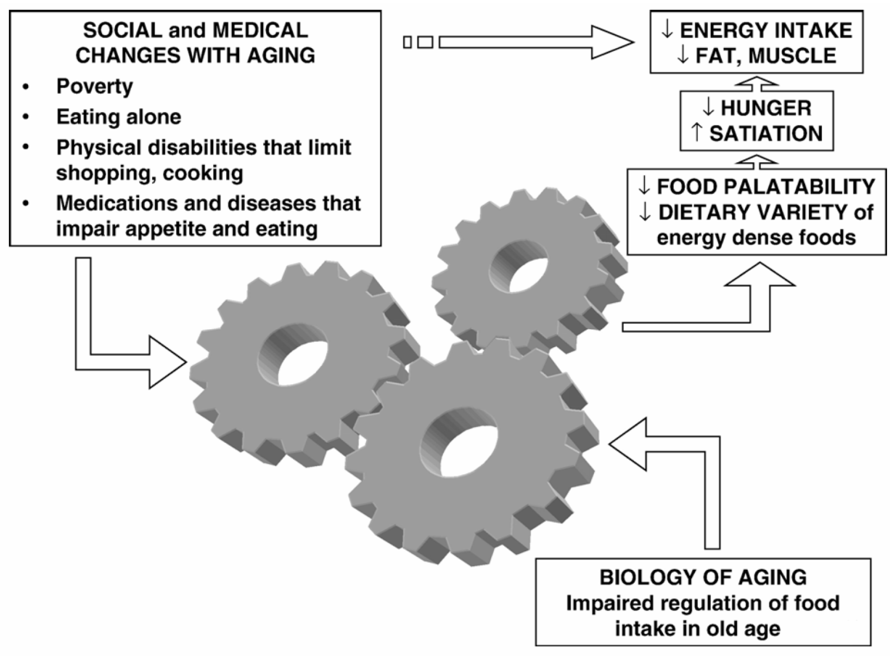



FIGURE 3 Mixed model for the anorexia of aging (Hays and Roberts 2006). Copyright © The International Behavioral Neuroscience Society. Reproduced by permission of the publisher.

Screening tools used to assess protein-energy malnutrition are based on four questions: 1) *What is the condition now?* Body mass index: 18.5-20 kg/m$^2$ for borderline underweight and <18.5 kg/m$^2$ for malnutrition, 2) *Is the condition stable?* Involuntary weight loss of more than 5% over 3 months, 3) *Will the* *condition become worse?* Decreased food intake, and 4) *Will the disuse process accelerate nutritional deterioration?* Decreased appetite and/or increased nutritional requirements due to the disease process (Kondrup et al. 2003). Variables 1-3 are essential for all nutritional screening tools, while variable 4 is mainly relevant to hospitals. Mini Nutritional Assessment (MNA) is an extensively tested and validated tool to detect the presence of malnutrition and the risk of malnutrition among the older adults (Kondrup et al. 2003). Laboratory assessment of protein-energy malnutrition is based on serum proteins (e.g. albumin), urine creatinine, immune function (e.g. total lymphocyte count) and serum cholesterol. However, biochemical indicators can be highly subjective and rely heavily on the knowledge and experience of the evaluator (Omran and Morley 2000).

Based on the MNA, a recent review reported the prevalence of malnutrition (MNA score <17 points from a maximum of 30 points) and risk of malnutrition (MNA 17-23.5 points) among older people aged 60 years or older (Guigoz 2006). The prevalence of malnutrition was about 2% in community-dwelling older adults (23 studies, 14149 participants), but the proportion of older persons at risk of malnutrition was much greater at 24%. Among the more frail older adults (25 studies, 3119 participants) 9% were malnourished and 45% were at risk of malnutrition. The prevalence and risk of malnutrition still increased notably when institutionalized (32 studies, 6821 participants; 21% & 51%) and hospitalized older people (36 studies, 8596 participants; 23% & 46%) were considered (Guigoz 2006), thus supporting the findings among Finnish nursing home residents (2114 participants, mean age 82 years; 29% malnourished and 60% at risk) (Suominen et al. 2005). These values demonstrate a real need for dietary guidance and interventions among the older adults.

Particularly small energy and protein intakes seem to contribute to a loss of muscle mass in older age (table 7). However, malnutrition as a whole (i.e. reduced intake of energy, protein and micronutrients) increases the risk of sarcopenia (Visser et al. 2005) and is independently associated with frailty in older people (Bartali et al. 2006, Semba et al. 2006). These findings indicate that both the quantity and quality of dietary nutrients affect the physical health of the older adults. Moreover, weight change alone may not be a sufficient criterion of dietary adequacy, and the assessment of dietary intake is a commendable part of the screening, diagnosis and treatment of frailty (Bartali et al. 2006).

TABLE 7 Relationship between dietary intake (DI) and muscle mass (MM) in community-dwelling older adults*

| Reference | Participants | Design | Relationship between DI and MM |
|---|---|---|---|
| Baumgartner et al. 1999 | 180 women & 121 men: 65-97 yrs | Cross-sectional | Energy intake correlated with MM in both gender |
| Starling et al. 1999 | 44 men: 49-85 yrs | Cross-sectional | Protein intake correlated with MM |
| Mitchell et al. 2003 | 1404 adults: ≥ 65 years | Cross-sectional | DI did not correlate with MM |
| Visser et al. 2005 | 1882 women and men: 70-79 yrs | 5 yrs follow-up | Lower serum albumin concentrations[a] were associated to a greater loss of MM |

*Published 1997-2007, participants ≥49 yrs, ≥40 person per group, dietary intake assessed with food records, questionaires or serum albumin, muscle mass measured with dual-energy X-ray absorptiometry, DI = dietary intake, MM = muscle mass, [a]marker of malnutrition

Several methodological points should be considered regarding the commonly used dietary assessment tools i.e. food diaries and questionnaires. The food diary method has a high level of specificity (type of food, food processing method, food preparation, portion sizes etc.) and does not rely on memory. However, it may not be representative of an individual's usual dietary intake and requires a large effort from clients and investigators. Furthermore, the process of keeping a food record may alter food intake manifested by underreporting of at least 20% in the older adults (Buzzard 1998). The food-frequency questionnaire method is suitable for long-term usual dietary intake assessment with little effort required from clients and investigators. However, the results of food-frequency questionnaires are limited by restrictions of a fixed list of foods, lapse of memory, perception of portion sizes and interpretation of questions (Willet and Lenart 1998).

### *Obesity*

The decrease in energy expenditure (physical activity) compared to energy intake (diet) is a major reason for body fat accumulation during aging, although other factors such as hormonal changes and genotype also contribute to body fatness (Villareal et al. 2005). The prevalence of obesity (BMI ≥ 30 $kg/m^2$) among the senior citizens (aged 65+) of the Western European countries is about the same as reported in Finland. Based on self-reported height and weight, 24% of Finnish women aged 65-74 years and 22% of those aged ≥75 years are classified as obese (Sulander et al. 2006). The corresponding values in older Finnish men are 17% and 13%, respectively (Sulander et al. 2006). When weight and height are measured, almost one third of women and about one fifth of men aged 65 years or over are classified as obese in Finland (Aromaa and Koskinen 2004). However, as much as 66% of older women and 40% of older men are classified as abdominally obese (waist circumference over 88 cm in women and over 102 cm in men) in Finland (Aromaa and Koskinen 2004). A smaller prevalence of BMI-predicted obesity in the older adults is related to the accelerated loss of skeletal muscle mass in senescence. Therefore, a large portion of the older population is classified as obese in Western Europe, and older women are more prone to obesity than older men (Sulander et al. 2006, Zamboni et al. 2005).

Obese older people are more vulnerable to functional impairments and disability than their normal weight peers due to their smaller muscle mass and strength (muscle quality) relative to body weight (Baumgartner et al. 2004, Villareal et al. 2004, Woods et al. 2005). This mismatch between muscle and fat mass is described as "*sarcopenic obesity*". Sarcopenic obese older people can be at an even greater risk of functional impairments and disability than the lean sarcopenic older persons (Baumgartner et al. 2004, Villareal et al. 2004). It seems that obesity-related reductions in physical activity and medical complications such as alterations in skeletal muscle tissue (e.g. impaired muscle energetics and substrate metabolism, reduction of type II fibers, and increase in connective tissue and intramuscular lipids), arthritis (knee osteoarthritis), elevated levels of inflammatory markers (e.g. C-reactive protein and interleukin -6), and pulmonary dysfunction (e.g. obesity-hypoventilation syndrome) contribute to accelerated declines in muscle mass and function in the obese older adults (Villareal et al. 2004 & 2005, Schrager et al. 2007). Therefore, the relation between muscle and body mass should be considered in the estimation of sarcopenia.

### 2.4.3 Decreased serum anabolic hormone concentrations

Serum concentrations of anabolic hormones such as testosterone, oestrogen, dehydroepiandrosterone and growth hormone, normally decline during aging (Leow and Loh 2006, Orwoll et al. 2006). Furthermore, the anabolic actions of insulin are diminished in old age due to insulin resistance and/or insulin secretory defects (Chang and Halter 2003).

#### *Sex hormones*

Testosterone, the most important gonadic androgen in men, is produced predominantly (95%) by the testicular Leydig cells in response to stimulation of pituitary gonadotropins (luteinizing hormone) (Janssens and Vanderschueren 2000). However, testosterone is also produced to some extent in women by the ovaries (25%), adrenal glands (25%) and by peripheral conversion of androgen precursor androstenedione in adipose tissue (50%) (Rosmond 2006).

In men, serum total and bio-available testosterone concentrations seem to decline at a constant rate during aging without a significant effect of obesity, illness, medications, smoking or alcohol intake (Harman et al. 2001). However, due to the fact that a health-conscious sample of men were involved in the aforementioned study (average BMI 25.6 kg/m$^2$, minor use of tobacco and alcohol) (Harman et al. 2001), it is possible that a very unhealthy lifestyle may reinforce age-related declines in serum testosterone levels. In women, the androgen to estrogen ratio increases after menopause due to a sharp decrease in estradiol levels and unchanged levels of total testosterone (Rosmond 2006). A dramatic loss in ovarian function and subsequent menopause is recorded around 50-years of age in women (Wu et al. 2005).

Serum total testosterone concentration typically declines by about 1% per year after 30 years of age in men. An even greater decline is recorded in serum bio-available testosterone concentration (~2% per year) due to an increase in serum sex hormone-binding globulin (SHBG) concentrations with aging (Tariq et al. 2005). The prevalence of hypogonadismic small bio-available testosterone levels have been reported to be 34%, 68% and 91% in men in their 60's, 70's and 80's, respectively (Harman et al. 2001). An age-related decline in serum testosterone concentrations is associated with dysfunctions: 1) at the testicular level (reduced response to luteinizing hormone due to the decrease in number of Leydig cells and their enzymes responsible for androgen production), and 2) at the hypothalamic-pituitary level (changes in the release of gonadotropin releasing hormone resulting in diminished secretion of luteinizing hormone) (Janssens and Vanderschueren 2000, Tariq et al. 2005). Decreases in serum bio-available testosterone concentrations have been shown to correlate with reduced muscle mass in older people in cross-sectional studies (table 8). However, cause-effect relations cannot be inferred from the cross-sectional design, so longitudinal studies are needed to prove the independent role of bio-available testosterone in the genesis of sarcopenia.

TABLE 8 Serum sex hormone (SH) concentrations and muscle mass (MM) in cross-sectional studies in community-dwelling older adults*

| Reference | Participants | SH and SHBG | Relationhips between SH and MM |
|---|---|---|---|
| Baumgartner et al. 1999 | 180 women & 121 men: 65-97 yrs | T, SHBG | Women: Not analyzed (distributions of the variables extremely skewed)<br>Men: T and FTI correlated positively with MM |
| Van den Beld et al. 2000 | 403 men: 73-94 yrs | T, FT, E1, E2, SHBG | FTI correlated positively with MM |
| Iannuzzi-Sucich et al. 2002 | 195 women: 64-93 yrs<br>142 men: 64-92 yrs | T, FT, E1, E2, SHBG | Women: E1 and E2 correlated positively with SMMI<br>Men: FT correlated positively with SMMI |
| Kenny et al. 2003 | 189 women: 59-78 yrs | T, E1, E2, SHBG | T correlated positively with SMMI |

*Published 1997-2007, participants >50 yrs, >100 person per group, sex hormones measured with radioimmunoassay and muscle mass with dual-energy X-ray absorptiometry, SH = sex hormones, SHBG = sex-hormone binding globulin, MM = muscle mass, T = testosterone, FTI = free testosterone index (T/SHBG), E1 = estrone, E2 = estradiol, SMMI = skeletal muscle mass index: appendicular lean mass (kg) /height squared (m$^2$)

*Dehydroepiandrosterone*

Dehydroepiandrosterone (DHEA) and its' sulphate (DHEAS) are the major adrenal cortex hormones released by stimulation of adrenocorticotropin (ACTH) from the anterior pituitary. DHEA and DHEAS act as a precursor to approximately 50% of androgens in men, and 75% and 100% of active estrogens in premenopausal and postmenopausal women, respectively (Leowattana 2004). Circulating concentrations of DHEA and DHEAS decrease significantly during aging by 3.1% and 2.2% per year after reaching a peak between the ages of 20 and 30 years (Janssens and Vanderschueren 2000, Labrie et al. 2005). Although serum DHEAS concentration can be positively associated with physical function in older people, research does not support the idea of DHEA supplementation as a 'fountain of youth' (Valenti et al. 2004, Leow and Loh 2006, O'Donnell et al. 2006).

*Growth hormone*

Growth hormone (GH) is a peptide hormone that stimulates fatty acid mobilization, amino acid uptake, and synthesis of DNA, RNA and proteins. Therefore, GH takes part in the regulation of cell division and tissue hypertrophy. Growth hormone is released in pulses from the pituitary gland with the majority of secretion occurring during sleep (Khan et al. 2002).

Serum GH levels decline at a rate of about 14% per decade after 30 years of age (Leow and Loh 2006) due to reduced GH responses to several stimuli such as hypoglycaemia, sleep and physical exercise (Khan et al. 2002, Weltman et al. 2006). Although the pulse frequency of GH secretion is not affected by age, the amplitude, duration and fraction of GH pulses gradually decline over the years (Leow and Loh 2006). Smaller amplitude pulses accompanied by increased tissue resistance to the action of GH are considered as contributing factors to old age muscle catabolism. Growth hormone deficiency and aging are associated with "symptoms" of the same kind, such as a decrease in lean body mass, increase in body fatness, and a decline in bone density and immune function (Khan et al. 2002).

### 2.4.4 Progressive denervation

Single muscle fibers atrophy during aging with a decrease in the number and size of the fibers. Fast type II muscle fibers are especially diminished, whereas slow type I muscle fibers are less affected. Age-related muscle fiber atrophy is largely caused by a progressive denervation (i.e. decrease in the number of motor units) in senescent muscles after the sixth decade of life. Moreover, decreased physical activity (i.e. amount and intensity) can augment the loss of type 2 fibers in senescence (Lexell 1993, Vandervoort 2002, Doherty 2003).

Denervation is observable not only within the spinal cord, but the peripheral nervous system also appears to be affected. For example, axonal withdrawal is evident in the neuromuscular junctions of the older adults but not in young adults. Furthermore, ciliary neurotophic factor, which is important for survival of motor neurons, is attenuated in aged peripheral nerves (Deschenes 2004). The reduction in motor units appears to be compensated by hypertrophy of smaller and slower motor units attempting to reinnervate faster fibers and transform them into slower fiber types (Marcell 2003). Therefore, each (slower) motor unit activates a greater number of muscle fibers in old people (Deschenes 2004).

### 2.4.5 Metabolic disorders and other physiological changes

Aging is associated with an increased frequency of cardiovascular and metabolic diseases, especially metabolic syndrome and diabetes (Bax et al. 2006, Maggi et al. 2006). For example, the annual incidence of cardiac heart failure increased from 2.5 per 1000 in middle-aged adults to 22.4 and 28.2 per 1000 in older women and men aged 80 years or older in the Croningen Longitudinal Aging Study of 5279 adults aged ≥ 57 years (van Jaarsveld et al. 2006). The emerging body of evidence suggests that age-related increases in body fat (especially truncal fat) and concomitant decreases in muscle mass, as well as intramuscular lipid infiltration, are associated with metabolic disorders such as impaired glucose tolerance and type 2 diabetes in old age (Zamboni et al. 2005, Janssen and Ross 2005, Alexandersen et al. 2006). However, even obese older people with a minor accumulation of visceral adipose tissue can show normal metabolic profiles (Brochu et al. 2001). Therefore, body mass index needs to be combined with waist circumference measurements to identify older people who are at a high risk of metabolic disorders.

The metabolic importance of skeletal muscle tissue is further supported by the positive association between muscle strength and insulin sensitivity in 500 women aged 68±12 years (Abbatecola et al. 2005), and the negative relation between muscle strength and metabolic syndrome incidence in 3233 men aged 20-80 years (Jurca et al. 2005). Moreover, there are many other age-related physiologic alterations that have been associated with a loss of muscle mass and strength in the older adults, such as changes in protein metabolism (Chevalier et al. 2003, Chevalier et al. 2006, Rasmussen et al. 2006), reduced serum vitamin D levels (Visser et al. 2003, Szulc et al. 2004), decline in mitochondrial function (Waters et al. 2003), and elevated levels of inflammatory cytokines (Visser et al. 2002, Payette et al. 2003, Cesari et al. 2005).

## 2.5 Prevention of sarcopenia and metabolic disorders

Prevention strategies, such as exercise, nutritional and pharmacological interventions, have been tried against sarcopenia. The most effective intervention in reversing age-related muscle atrophy has proven to be strength training (Doherty 2003). However, only limited information is available about whether dietary intake can contribute to strength training-induced gains in muscle mass and health in older people. This chapter will summarize the effects of 1) nutrition, 2) strength training and 3) nutrition and strength training on physical performance, serum anabolic hormones and metabolic health indicators (blood pressure, blood lipids and lipoproteins, and glycemic control) in healthy older adults.

### 2.5.1 Nutrition for older adults

Nutritional recommendations are provided in order to assist in planning a diet that satisfies the nutritional needs and promotes good health (Nordic Council of Ministers 2004). Aging is associated with a decline in daily energy needs, mainly due to the decrease in muscle mass and physical activity (Gaillard et al. 2007). Daily energy needs for older people are described in table 9 (Nordic Council of Ministers 2004). A recent review showed that resting energy expenditure (REE) measured by indirect calorimetry is about 20 kcal/kg /day in sick and healthy older people aged 55 years or older (Gaillard et al. 2007). Furthermore, total energy needs (ratio of total energy expenditure to weighted REE) of 1.36 x REE and 1.66 x REE were observed in sick and healthy older people, indicating that physical activity is reduced during disease. Resting energy expenditure increased to about 25 kcal/kg /day in malnourished older people (BMI≤21 kg/m$^2$), suggesting that their total energy needs range between 32 and 38 kcal/kg/day (Gaillard et al. 2007).

TABLE 9 Reference values for energy intake[a] in the older adults (Nordic Council of Ministers 2004)

| Sex and age | Body weight[b] | REE[c] | Sedentary (limited physical activity) (PAL[d] 1.6) | Active (regular physical activity[e]) (PAL[d] 1.8) |
|---|---|---|---|---|
| Women | | MJ/day | MJ/day | MJ/day |
| 61-74 yrs | 63 | 5.3 | 8.5 | 9.5 |
| ≥75 yrs | 62 | 5.1 | 8.2 | 9.3 |
| | | | | |
| Men | | | | |
| 61-74 yrs | 74 | 6.6 | 10.6 | 12.9 |
| ≥75 yrs | 73 | 6.0 | 9.6 | 10.8 |

[a]Results should be used only on group level due to large standard error in estimation of REE and PAL, [b]based on mean population weights in Denmark, Sweden and Finland, [c]resting energy expenditure, [d]physical activity level: total energy expenditure divided by basal metabolism, [e]corresponding to an energy expenditure of 60 minutes brisk walking daily

The recommendations for energy-providing macronutrients, dietary fiber, salt and alcohol are the same for the whole adult population including the older persons (table 10). The population goals in terms of food planning are based on recommended intakes of 30% fat, 55% carbohydrates and 15% protein relative to total energy intake. A protein intake of at least 1.0 g/kg/day is recommended for older people with a very small energy intake (<6.5 MJ/day). Furthermore, 1.0-1.2 litres of water from daily fluid consumption is recommended for healthy adults with a sedentary lifestyle in a temperate climate. However, water needs increase to 1.5 litres per day in older people who have a limited capacity to concentrate the urine and impaired thirst sensation (Nordic Council of Ministers 2004).

Although there is no specification available for the optimal eating pattern, most individuals in the Nordic countries eat 4-6 times per day including 2-3 main eating occasions. The daily food and energy intake could be distributed as 20-25% in the morning meal (breakfast), 25-35% at midday (lunch), 25-35% evening (dinner) and 5-30% in 1-3 intermediate meals of good nutritional quality (Nordic Council of Ministers 2004). The Finnish food-based dietary guidelines are described in the methods section (table 18, page 53) (Finnish Nutrition Recommendations 2005).

TABLE 10 Recommended intakes of fat, carbohydrates, protein, dietary fibre, salt and alcohol (Nordic Council of Ministers 2004)

| Nutrient | Nordic recommendation |
|---|---|
| Total fat | 25-35 E% |
| - saturated fat | <10 E% |
| - monounsaturated fat | 10-15 E% |
| - polyunsaturated fat | 5-10 E% |
| | |
| Carbohydrates | 50-60 E% |
| - refined sugars | max 10 E% |
| - dietary fiber | 25-35 g/day (~3 g/MJ) |
| | |
| Protein | 10-20 E% |
| | |
| Salt | Women: <6 g/day |
| | Men: <7 g/day |
| | |
| Alcohol | Women: max 10 g/day |
| | Men: max 20 g/day |

E% = percent of total energy intake

### *Muscle strength*

A recent meta-analysis (55 trials with 9187 participants >65 years of age) showed that protein-energy supplementation can improve nutritional status and seems to reduce mortality and complications in malnourished older people in hospital (Milne et al. 2006). Community-dwelling or well-nourished older people did not benefit from protein-energy supplementation, although a small but consistent weight gain was recorded in all participants after supplementation (Milne et al. 2006). This data is supported by the finding that protein-energy supplementation cannot increase muscle strength in the older adults without simultaneous muscle loading exercise (table 11). Therefore, both dietary and exercise interventions are needed to induce significant improvements in muscle strength and functional performance in frail older individuals. The effects of nutritional counseling (NC) are rarely documented in older people, although intensive counseling has been shown to induce long lasting changes in eating habits among middle-aged adults (Lindström et al. 2006).

TABLE 11 Effects of protein-energy supplementation on muscle strength in randomized controlled trials (RCT) in older people with no acute diseases*

| Reference | Participants | Design | Outcome variables | Changes in physical function |
|---|---|---|---|---|
| Lauque et al. 2000 | 88 adults: ≥65 yrs nursing-home residents | 60 days RCT:<br>1) Well-nourished, MNA ≥24 : no supplementation<br>2) Risk of malnutrition, MNA 17-23.5: no supplementation<br>3) Risk of malnutrition, MNA 17-23.5: protein-energy supplement (0.7-1.2 MJ energy)<br>4) Malnourished, MNA <17: protein-energy supplement (0.7-1.2 MJ energy) | Isometric handgrip strength | No group differences. |
| Wouters-Wesseling et al. 2003 | 68 adults: 82±7 yrs BMI≤25 | 6 months RCT:<br>1) Protein-energy supplement (1.1 MJ energy, 8.8 g protein)<br>2) Controls(placebo) | Isometric handgrip strength<br>Timed "up and go" test<br>NHP and ADL questionnaires | No group differences. |
| Edington et al. 2004 | 100 adults: 65-95 yrs malnourished | 24 weeks RCT:<br>1) Protein-energy supplement for first 8 wks to attain 0.5 kg gain in body weight per week<br>2) Controls | Isometric handgrip strength<br>EuroQol -questionnaire for quality of life | No group difference in strength. In EQ5D the intervention group has less mobility problems than controls, but there were no differences in other domains. |
| Rosendahl et al. 2006 | 100 adults: 65-100 yrs living in residential care facilities | 6 months RCT:<br>1) Protein-energy supplement (0.9 MJ energy, 15 g protein and 31 g carbohydrates) for 3 months<br>2) Controls (placebo) | Dynamic leg extension strength<br>Modified chair-stand test<br>Maximum walking speed | No group differences. |

*Published 1997-2007, participants ≥65 yrs community-dwelling or nursing-home residents, ≥2 months intervention and threatment compliance >80%, RCT = randomized controlled trial, MNA = Mini-Nutritional Assessment, BMI = body mass index; weight per square height (kg/m2) , NHP = Nottingham Health Profile, ADL = Activites of Daily Living

*Serum anabolic hormones*

Serum sex hormone (testosterone and oestrogen) concentrations can be affected by the amount of dietary fat in older women (table 12). In this regard, cross-sectional data have shown a weak negative relationship between dietary fat intake and serum SHBG concentration in men of various ages (age range from 20 to 88) (Nagata et al. 2000, Allen et al 2002). Furthermore, a randomized controlled trial (RCT) with 39 men aged 50-60 years reported decreased serum testosterone, free testosterone and SHBG concentrations after 16 weeks of a low fat diet (<15% fat, fiber 25-35 g/day) compared to a high fat diet (>30% fat, fiber <20 g/day) (Wang et al. 2005).

Although the mechanisms by which macronutrient composition of the diet modulates sex hormone metabolism are not clear, it has been speculated that with a low fat diet: 1) Greater fiber content may reduce reabsorption of steroid hormones excreted through the biliary tract by altering the activities of steroid hydrolysis enzymes or the qualitative microflora of the gut. As a result, serum hormone concentrations would decrease without changes in the production rate. 2) Reduced cholesterol in the body may provide less cholesterol to the inner mitochondrial membrane or decrease the mobilization of cholesterol for steroidogenesis. This may cause a slight decrease in sex hormone concentration, but may not be adequate to activate the negative feedback mechanism by releasing gonadotropins. 3) Alternatively, the hypothalamic axis may be influenced and may decrease gonadotropin secretion. 4) The amount and quality of dietary fat acids may alter steroid metabolism by changing enzyme activities and/or directly modifying steroid production by the testes and ovaries (Wang et al. 2005).

TABLE 12 Dietary intake (DI) and serum basal sex hormones (SH) in community-dwelling older women*

| Reference | Participants | Design | Outcome variables | Dietary intake and SH and SHBG |
|---|---|---|---|---|
| Holmes et al. 2000 | 381 women: 62.6±4.7 yrs | Cross-sectional | E1, E2, T, SHBG | Total fat intake was negatively associated with E2, polyunsaturated fat was negatively associated with T. |
| Nagata et al. 2005 | 324 women: 57.5±5.9 yrs | Cross-sectional | E1, E2, T | Percent energy from fat was positively associated with E1. |
| Berrino et al. 2001 | 104 women: 50-65 yrs | 18 weeks RCT: 1) Normal diet 2) Modified diet (lower in total and saturated fat, rich in low GI foods and phytoestrogens) | E2, T, SHBG | Modified diet increased SHBG and decreased T, but after adjustment for body weight changes group differences disappeared. |
| Rock et al. 2004 | 291 women: 55±8 yrs | 1 year RCT: 1) Normal diet (fat ≤30%, fiber 20 g/day) 2) Low fat diet (fat 15-20%, fiber 30 g/day) | E1, E2, T, SHBG | Low fat diet decreased bioavailable E2 (ratio of E2/SHBG). Further analyse showed that only increased fiber intake was independently related to total and bioavailable E2. |

*Published 1997-2007, participants ≥50 yrs, ≥50 participants per group and sex hormones measured with radioimmunoassay, DI = dietary intake, SH = sex hormone, SHBG = sex hormone-binding globulin, RCT = randomized controlled trial, E1 = estrone, E2 = estradiol, T = testosterone, GI = Glycemic Index

*Blood pressure*

Non-pharmacological management of elevated blood pressure based on weight reduction and moderation of sodium and alcohol intake is considered as a cornerstone in the prevention and treatment of hypertension (Korhonen et al. 2003). Blood pressure can be particularly decreased in middle-aged and older people by replacing dietary saturated fat with unsaturated fat (table 13). Similarly, blood pressure can be reduced by adopting a diet that is low in sodium but rich in fruits, vegetables and low-fat dairy products. However, it is important to note that since blood pressure is the sum of both genetic and lifestyle factors, a single nutrient is unlikely to determine the blood pressure level. Nonetheless, a combination of all lifestyle factors together is of remarkable importance (Korhonen et al. 2003). A whole diet approach consisting of a diet rich in fruits, vegetables, low-fat dairy products and reduced intake of saturated and total fat (Dietary Approaches to Stop Hypertension; DASH diet) has been shown to substantially reduce blood pressure in middle-aged people (Appel et al. 1997).

*Blood lipids and lipoproteins*

A diet rich in vegetables/fruits and mostly unsaturated fat can moderately decrease serum total cholesterol (TC) and low-density lipoprotein cholesterol (LDL-C) concentrations in middle-aged and older people (table 14). However, a high intake of (refined) carbohydrates may have disadvantages by reducing serum high-density lipoprotein cholesterol (HDL-C) and by modestly raising serum triacylglyserides (TAG) (Liu et al. 2001, Appel et al. 2005). Therefore, the partial replacement of saturated fat with unsaturated fat and/or low-fat protein foods rather than carbohydrates may be a reasonable alternative (Appel et al. 2005). There is substantial evidence to support the idea that diets including (nonhydrogenated) unsaturated fats as the main source of fat, adequate omega-3 fatty acids, whole grains as the main source of carbohydrates and an abundance of fruits and vegetables can significantly protect against coronary heart disease (Hu and Willet 2002).

*Glycemic control*

Decreased insulin sensitivity has a central role in the etiology of metabolic syndrome. Besides genetic predisposition, lifestyle factors such as diet and physical activity can also contribute to the development of insulin resistance and related metabolic disorders (Vessby et al. 2001). Regarding dietary factors, previous studies have shown that in particular, substitution of saturated fat with unsaturated fat can improve glycemic control in middle-aged and older people (table 15). Cross-sectional data indicate that a high intake of whole grain is favorably associated with markers of glycemic control in middle-aged and older individuals, apparently due to a delayed absorption rate of carbohydrates (i.e. decreased glycemic response) (McKeown et al. 2002, Fung et al. 2001, Sahyoun et al. 2006). The cross-sectional data are confirmed by a recent RCT, reporting improved insulin sensitivity after 12-weeks of a low-glycemic index diet compared to a high-glycemic-index diet in 72 40-70-year old adults with metabolic syndrome (Laaksonen et al. 2006). The main carbohydrate sources were rye bread, pasta and oats in the low-glycemic index diet group, and wheat bread and potato in the high-glycemic-index diet group (Laaksonen et al. 2006). Therefore, dietary recommendations regarding glucose metabolism and insulin resistance should focus more on the quality of carbohydrates and fat than quantity alone (Hu et al. 2001).

TABLE 13 Dietary intake and resting blood pressure in intervention studies in community-dwelling older adults*

| Reference | Participants | Design | Changes in blood pressure |
|---|---|---|---|
| Sacks et al. 2001 | 412 adults: 48±10 yrs | 12 weeks RCT:<br>1) Control diet<br>2) DASH -diet (diet rich in fruits, vegetables, and low-fat dairy products and with reduced saturated and total fat)<br>Sodium levels in both diets: low 50 mmol/d, mederate 100mmol/d or high 150 mmol/d | Reduction of sodium intake reduced blood pressure in step-wise manner (low>moderate>high) in both diet, but DASH-diet produced greater reduction in blood pressure than the control diet. |
| John et al. 2002 | 690 adults: 46±10 yrs | 6 months RCT:<br>1) Diet rich in fruits and vegetables<br>2) Controls | Blood pressure decreased in the intervention group compared to the control group. |
| Korhonen et al. 2003 | 715 adults: 54±10 yrs | 2 years RCT:<br>1) Controls<br>2) Modified diet (Total fat ≤30E%, saturated fat <10E%, salt intake <5 g/day and alcohol ≤2 portions /day) | Blood pressure decreased more in the modified diet group. |
| Appel et al. 2005 | 164 adults: 54±11 yrs | 6 weeks randomized crossover study:<br>1) Carbohydrate (58 E%) diet (DASH -diet slightly higher in carbohydrates and lower in protein)<br>2) Protein (25 E%) diet (DASH diet, where carbohydrates were replaced with protein)<br>3) Unsaturated fat (31 E%) diet (DASH -diet, where carbohydrates were replaced with unsaturated fat) | Blood pressure decreased during all study diets, but decrease was greater during the protein and unsaturated fat diets compared to the carbohydrate diet. |
| Rasmussen et al. 2006 | 162 adults: 30-65 yrs | 3 months RCT:<br>1) MUFA diet (fat 37 E%, safa 8 E%, mufa 23 E% and pufa 6 E%)<br>2) SAFA diet (fat 37 E%, safa 17 E%, mufa 14 E%, pufa 6 E%)<br>Both diet groups received fish oil supplement (3.6 g n-3 fatty acids) or placebo | Blood pressure decreased with the MUFA diet, but did not change with SAFA diet. Favorable effect of MUFA diet on diastolic blood pressure disappeared at a high total fat intake (> 37 E%). Fish oil did not influence on blood pressure. |
| Estruch et al. 2006 | 772 adults: 55-80 yrs | 3 months RCT:<br>1) Mediterranean diet with virgin olive oil (1 liter per week)<br>2) Mediterranean diet with nuts (30 g per day)<br>3) Control diet (AHA guidelines) | Both mediterranean diets reduced blood pressure compared tot the control diet. |
| Howard et al. 2006 | 48835 women: 50-79 yrs | 3 years RCT:<br>1) Controls<br>2) Modified diet designed to reduce fat intake to 20E% (safa 7E%), and to increase intakes of vegetables/fruits to 5 servings per day and grains to at least 6 servings per day | Diastolic blood pressure decreased more in the modified diet group compared to the control group. No group difference in systolic blood pressure. |

*Published 1997-2007, mean age of participants >45 yrs, ≥80 participants per group, ≥6 weeks long intervention, just whole diet intervention with no intentional weight-loss, and blood pressure measured with sphygmomanometer, RCT = Randomized Controlled Trial, DASH = Dietary Approaches to Stop Hypertension, E% = percent of total energy intake, SAFA = saturated fatty acids, MUFA = monounsaturated fatty acids, PUFA = polyunsaturated fatty acids, AHA = American Heart Association

TABLE 14 Dietary intake and fasting blood lipids and lipoproteins in intervention studies in community-dwelling older adults*

| Reference | Participants | Design | Changes in blood lipids and lipoproteins |
|---|---|---|---|
| Smith-Warner et al. 2000 | 201 adults: mean age 59 yrs | 1 year RCT:<br>1) Diet rich in fruits and vegetables<br>2) Controls | Serum TC and LDL-C decrased in the intervention group comprated to the control group. Serum HCL-C and TAG did not differ between groups. |
| Korhonen et al. 2003 | 715 adults: 54±10 yrs | 2 years RCT:<br>1) Controls<br>2) Modified diet (Total fat ≤30E%, saturated fat <10E%, salt intake <5 g/day and alcohol ≤2 portions /day) | Serum TC and LDL-C decreased more in the modified diet group. |
| Harsha et al. 2004 | 390 adults: 49±10 yrs. | 3 months follow-up:<br>1) Controls<br>2) DASH -diet (diet rich in fruits, vegetables, and low-fat dairy products and with reduced saturated and total fat) | DASH-diet lowered serum TC, LDL-C and HDL-C compared to the control diet. The ratio of TC/HDL-C and seum TAG did not differ between groups. |
| Appel et al. 2005 | 164 adults: 54±11 yrs. | 6 weeks randomized crossover study:<br>1) Carbohydrate (58 E%) diet (DASH -diet slightly higher in carbohydrates and lower in protein)<br>2) Protein (25 E%) diet (DASH diet, where carbohydrates were replaced with protein)<br>3) Unsaturated fat (31 E%) diet (DASH -diet, where carbohydrates were replaced with unsaturated fat) | Serum TC and LDL-C decreased with all study diets. Serum HDL-C decreased with carbohydrate and protein diet. Serum TAG decreased with protein and unsaturated fat diet. |
| Estruch et al. 2006 | 772 adults: 55-80 yrs | 3 months RCT:<br>1) Mediterranean diet with virgin olive oil (1 liter per week)<br>2) Mediterranean diet with nuts (30 g per day)<br>3) Control diet (AHA guidelines) | Both mediterranean diets increased serum HDL-C and decreased the ratio of TC/HDL-C compared to the control diet. Serum TC decreased in mediterranean diet with nuts compared to the control diet. |
| Howard et al. 2006 | 48835 women: 50-79 yrs | 3 years RCT:<br>1) Controls<br>2) Modified diet designed to reduce fat intake to 20E% (safa 7E%), and to increase intakes of vegetables/fruits to 5 servings per day and grains to at least 6 servings per day | Serum TC and LDL-C decreased more in the modified diet group comprared to the controls. No group differences in serum HDL-C, TAG and ratio of TC/HDL-C. |

*Published 1997-2007, mean age of participants >45 yrs, ≥80 participants per group, ≥6 weeks long intervention, just whole diet intervention with no intentional weight-loss, enzymatic assays for lipids and lipoproteins and low-density lipoprotein cholesterol by Friedewald equation, RCT = Randomized Controlled Trial, TC = total cholesterol, LDL-C = low-density lipoprotein cholesterol, HDL-C = high-density lipoprotein cholesterol, TAG = triacylglycerols, DASH = Dietary Approaches to Stop Hypertension, E% = percent of total energy intake, AHA = American Heart Association

TABLE 15 Dietary intake and markers of glycemic control in randomized controlled trials (RCT) in community-dwelling older adults*

| Reference | Participants | Design | Dietry intake and glycemic control |
|---|---|---|---|
| Smith-Warner et al. 2000 | 201 adults: mean age 59 yrs | 1 year RCT:<br>1) Diet rich in fruits and vegetables<br>2) Controls | No group difference in fasting blood glucose levels. No other markers of glycemic control measured. |
| Vessby et al. 2001 | 162 adults: 49±8 yrs | 3 months RCT:<br>1) MUFA diet (fat 37 E%, safa 8 E%, mufa 23 E% and pufa 6 E%)<br>2) SAFA diet (fat 37 E%, safa 17 E%, mufa 14 E%, pufa 6 E%) | Insulin sensitivity index[a] decreased during the SAFA diet, but did not change during the MUFa diet. Favorable effects of the MUFA diet on insulin sensitivity were only seen at fat intake below 37 E%. No group differences in fasting plasma glucose, insulin and first-phase insulin response to IVGTT. |
| Watanabe et al. 2003 | 173 men: 55±7 yrs | 1 year RCT:<br>1) Modified diet (optimized intake of whole-grain, vegetables, fruits and low-fat dairy products etc.)<br>2) Controls (normal diet) | Changes in fasting blood glucose levels did not differ between groups. Blood glucose levels 2 hours after OGTT decreased in the modified diet group comprated to control group. |
| Estruch et al. 2006 | 772 adults: 55-80 yrs | 3 months RCT:<br>1) Mediterranean diet with virgin olive oil (1 liter per week)<br>2) Mediterranean diet with nuts (30 g per day)<br>3) Control diet (AHA guidelines) | Fasting blood glucose, insulin and insulin resistance (HOMA index) decreased in both both mediterranean diet groups compared to the control group. |
| Howard et al. 2006 | 48835 women: 50-79 yrs | 3 years RCT:<br>1) Controls<br>2) Modified diet designed to reduce fat intake to 20E% (safa 7E%), and to increase intakes of vegetables/fruits to 5 servings per day and grains to at least 6 servings per day | No group differences in fasting blood glucose, insulin and insulin resistance (HOMA index). |

*Published 1997-2007, mean age of participants >45 yrs, ≥80 participants per group, ≥6 weeks long intervention, just whole diet intervention with no intentional weight-loss, blood glucose with glucose oxidase method, and serum insulin with radioimmunoassay, RCT = Randomized Controlled Trial, MUFA = monounsaturated fatty acids, SAFA = saturated fatty acids, E% = percent of total energy intake, [a]calculated with the Minmod program, IVGTT = Intravenous Glucose Tolerance Test, OGTT = Oral Glucose Tolerance Test, HOMA = Homeostasis Model Assessment method, AHA = American Heart Association

### 2.5.2 Strength training for older adults

Progressive strength training is considered to be an effective method to alleviate age-related loss of skeletal muscle tissue and strength (Latham et al. 2004). Strength training is thus a recommended component of any well-rounded contemporary fitness program for adults. According to recommendations, strength training should be performed 2-3 times per week consisting of 8-10 exercises targeting the major muscle groups. At least one set per exercise is recommended, although a multiple-set regimen may be more effective. Moderate training intensity consisting of 8-12 repetitions per exercise is recommended. For older and frailer people, an even lower intensity corresponding to 10-15 repetitions per exercise may be more appropriate (American College of Sports Medicine 1998).

Neuromuscular adaptation to strength training is characterized by both neural and muscle fiber adaptations (Kraemer et al. 1996, Deschenes and Kraemer 2002). Initial strength training induced gains in muscle strength are primarily mediated by neural changes (e.g. increased activation of agonist muscles and reduced co-activation of the antagonist muscles) in previously untrained people. After a few weeks of strength training, an increased synthesis and accretion of contractile proteins (muscle hypertrophy) primarily accounts for strength improvements in the loaded muscles. Continued long-term strength training results in fiber type conversion from type IIB to type IIA fibers. Type IIA fibers display the greatest potential for hypertrophy, followed by type IIB and type I fibers (Kraemer et al. 1996, Deschenes and Kraemer 2002). Several months of heavy-resistance training are needed to induce substantial muscle hypertrophy in older individuals compared to untrained controls (Sipilä and Suominen 1995, Godard et al. 2002, Häkkinen et al. 2002, Kalapotharakos et al. 2004). On the other hand, musculoskeletal benefits of strength training start to diminish rather soon after the cessation of training (Connelly and Vandervoort 1997, Häkkinen et al. 2000b, Fatouros et al. 2005). Obviously, continued reduced volume strength training is needed to maintain muscle size and strength in the older adults after an intensive strength training program (Trappe et al. 2002). The most accurate assessment tools for regional body composition analysis (such as muscle CSA) are imaging methods like magnetic resonance imaging (MRI) and computed tomography (CT) (Lee et al. 2001).

*Muscle Strength*

Strength training has received a lot of scientific attention as an effective prevention strategy against old age frailty and disability. Prolonged strength training three times per week with a moderate to high training intensity (50-85% of one repetition maximum load (1RM)) has usually induced 20-40% gains in maximal dynamic leg extension strength in previously untrained older people compared to controls (table 16). Support for the favorable effects of strength training in terms of mobility of the older adults is provided by a recent systematic review indicating improvements in leg extension strength, 6-minutes walk test and walking speed after several weeks of strength training in older people (62 trials with 3674 adults; mean age ≥60 years) (Latham et al 2004).

TABLE 16 Strength training and muscle strength of the lower extremities in randomized controlled trials (RCT) in community-dwelling older adults*

| Reference | Participants | Design | Outcome variables | Leg strength |
|---|---|---|---|---|
| Rhodes et al. 2000 | 44 women: 65-75 yrs | 1 year RCT:<br>1) Whole-body ST: 3 xwk, 3 sets of 7 exercises with 8 repetitions of 75% 1RM load in a circuit fashion<br>2) Controls | Dynamic strength (1RM) by leg press and leg curl. | 1RM leg press and leg curl strengths increased by 19% and 14% in the ST group with no changes in the control group. |
| Vincent et al. 2002 | 62 older adults: 60-83 yrs | 6 months RCT:<br>1) Whole-body ST: 3 x wk, 1 set of 12 exercises with 13 repetitions of 50% 1RM load<br>2) Whole-body ST: 3 x wk, 1 set of 12 exercises with 8 repetitions of 80% 1RM load<br>3) Controls | Dynamic strength (1RM) by leg press, leg curl and knee extension. | 1RM leg press strength increased by 16-28%, leg curl strength by 17-25% and knee extension strength by 11-15% in the ST groups with no changes in the control group. |
| Binder et al. 2005 | 91 older adults: 83±4 yrs | 3 months RCT:<br>1) Whole-body ST: 3 x wk, first mo: 1-2 sets of 6 exercises with 6-8 repetitions of 65% 1RM, thereafter: 3 sets of 6 exercises with 8-12 repetitions with 85-100% of initial 1RM load.<br>2) Controls | Isokinetic strength (60o/s) by knee extension and flexion. Dynamic (1RM) strengt by knee extension, flexion and leg press for ST group only. | Knee extension and flexion strengths increased by 7-8% in the ST group compared to the control group. 1RM knee extension, flexion and leg press strengths increased by 43%, 17% and 27% in the ST group. |
| Fatouros et al. 2005 | 52 older men: 71±4 yrs | 24 weeks RCT:<br>1) Whole-body ST: 3 x wk, 2-3 sets of 10 exercises with 14-16 repetitions of 50-55% 1RM load<br>2) Whole-body ST: 3 x wk, 2-3 sets of 10 exercises with 6-8 repetitions of 80-85% 1RM load<br>3) Controls | Dynamic strength (1RM) by leg press. | 1RM leg press strength increased by 43% and 63% in low-intensity (50-55% 1RM) and high-intensity (80-85% 1RM) ST groups compared to the control group. |

*Published 1997-2007, participants ≥60 yrs, ≥14 participants per group, ≥12 weeks long intervention, just strength training intervention and dynamic or isokinetic muscle strength measured, RCT = Randomized Controlled Trial, ST = strength training, 1RM = one repetition maximum load

### *Serum anabolic hormones*

Heavy-resistance exercise can acutely increase serum concentrations of GH and testosterone in the older adults (Copeland & Tremblay 2004, Häkkinen et al. 2000a, 2001, 2002, Kraemer et al. 1998a). Women have smaller acute hormone responses than men, and older people smaller responses than younger people (Häkkinen and Pakarinen 1995, Kraemer et al. 1998a, 1999). The proposed mechanisms of attenuated testosterone responses to muscular loading include failure of the hypothalamic-pituitary axis, changes in testicular function, increased SHBG levels and/or greater sensitivity of gonadotropin secretion to androgen negative feedback inhibition (Crewther et al. 2006). In terms of the attenuated GH response to exercise, the proposed mechanisms include decreased sensitivity of GH release to GH-releasing hormone, variations in the neurohormonal and neurotransmitter control of GH secretion and peripheral factors (e.g. gonadal hormones and adiposity) (Crewther et al. 2006).

Strength training does not usually induce changes in the magnitude of post-exercise acute serum anabolic hormone responses (i.e. absolute hormone concentrations and relative increases in hormone concentrations) when the post-training condition is compared to the baseline in older individuals (Häkkinen et al. 2000a, 2001, 2002). However, inter-individual variation in the acute hormone response to heavy-resistance exercise seems to decrease after strength training (Häkkinen et al. 2000a, 2001, 2002). Furthermore, no changes have been recorded in serum basal anabolic hormone concentrations during chronic strength training in middle-aged and older participants (Copeland & Tremblay 2004, Häkkinen et al. 2000, 2001a, 2002). However, serum basal concentrations of testosterone may correlate with strength training-induced increases in muscle mass and strength in older women (Häkkinen et al. 2000a, 2001, 2002). Therefore, circulating testosterone levels may be an important indicator of trainability in older women with a diminished anabolic environment.

***Blood pressure***

Two recent meta-analyses showed that a strength training program of at least 6-weeks can decrease both systolic and diastolic blood pressure by about 3 mmHg in adults aged 18 years or older (Kelley & Kelley 2000, Cornelissen & Fagard 2005). However, very few studies have reported changes in resting blood pressure during long-term (>20 weeks) strength training programs in over 50-year old healthy participants compared to controls (Martel et al. 1999, Delmonico et al. 2005). Martel et al. (1999) reported 5 mmHg and 4 mmHg decreases in systolic and diastolic blood pressure in 21 65-73-year old women and men after six months of progressive strength training 3 days per week. Similarly, Delmonico et al. (2005) recorded 4-5 mmHg and 3-5 mmHg decreases in systolic and diastolic blood pressure in 70 men and women aged 52-81 years after 23 weeks of high-intensity strength training 3 days per week. These older participants were classified as having high normal blood pressure (systolic blood pressure 120-139 mmHg or diastolic blood pressure 80-89 mmHg) at the baseline measurement (Martel et al. 1999, Delmonico et al. 2005). Therefore, prolonged strength training seems to induce a small decrease in blood pressure in middle-aged and older people with mildly elevated blood pressure.

***Blood lipids and lipoproteins***

No significant changes in blood lipid/lipoprotein profiles are typically reported during short-term 8-16 week strength training periods in healthy middle-aged or older participants (Hagerman et al. 2000, Banz et al. 2003, Elliot et al. 2002, Boardley et al. 2007). Similarly, 12 months of very low-intensity strength training has been shown to produce no change in blood lipid/lipoprotein profiles in 207 older participants aged 65-74 years (Thomas et al. 2005). However, there are no data about the effects of longer-term high-intensity strength training on blood lipids and lipoproteins in healthy over 50-year old men and women.

*Blood glucose and insulin*

Physical conditioning can increase insulin sensitivity directly as well as by reducing total and abdominal obesity (Ryan et al. 2001). Although the beneficial effects of endurance training on glucose metabolism are well established, recent studies have shown that strength training may also improve insulin-stimulated glucose uptake in the older adults (Ryan et al. 2001, Hurlbut et al. 2002, Ferrara et al. 2006). However, fasting blood glucose concentrations do not usually change in the older adults during strength training with no intentional weight loss (Ryan et al. 2001, Hurlbut et al. 2002, Ferrara et al. 2006). Therefore, besides strength training, a concomitant loss of body fat seems to be needed to significantly improve glycemic control in the overweight older persons with glucose intolerance (Castaneda et al. 2002, Dunstan et al. 2002).

### 2.5.3 Nutrition and strength training for older adults

Heavy-resistance exercise-induced mechanical loading of muscles evokes several physiological changes in the body, such as acute increases in circulating anabolic hormone concentrations, stimulating the synthesis of muscle proteins. Dietary intake can interact with heavy-resistance exercise-generated physiological alterations, possibly contributing to the development of muscle strength and mass during chronic strength training (Volek 2004). Furthermore, physical status (physical fitness, health, age, gender etc.) and genetic factors (metabolism, muscle fiber composition, psychology etc.) contribute to individual neuromuscular adaptations to strength training (Figure 4). All of the aforementioned factors are interrelated, and the body's adaptation to exercise includes interactions between exercise, components of dietary intake and genetic variation (Heck et al. 2004).

*Nutritional recommendations for exercising older adults*

Regular all-around physical activity for cardiovascular fitness, body composition, muscle strength and endurance, and flexibility is recommended for older people. Nutrition can impact upon athletic performance, highlighting the importance of appropriate choices and timing of food and fluid intake to optimal health and physical performance (Campbell and Geik 2004). Unfortunately, athletic nutrition recommendations have not considered the effects of chronological age on nutritional needs (American College of Sports Medicine et al. 2001). Nutritional recommendations for the exercising older persons are considered comparable to all older people (table 10, page 33), although body weight adjusted recommendations for intakes of carbohydrates (≥6 g/kg/day) and protein (1.2-1.4 g/kg/day) are provided (Campbell and

Geik 2005). Regular exercise increases the requirements for energy, carbohydrates, protein and fluid, which supports the need for sensible nutrient-dense food choices in athletic older people (Campbell and Geik 2004). Practical food-based guidelines for the older adults are summarized in table 18 on page 53.

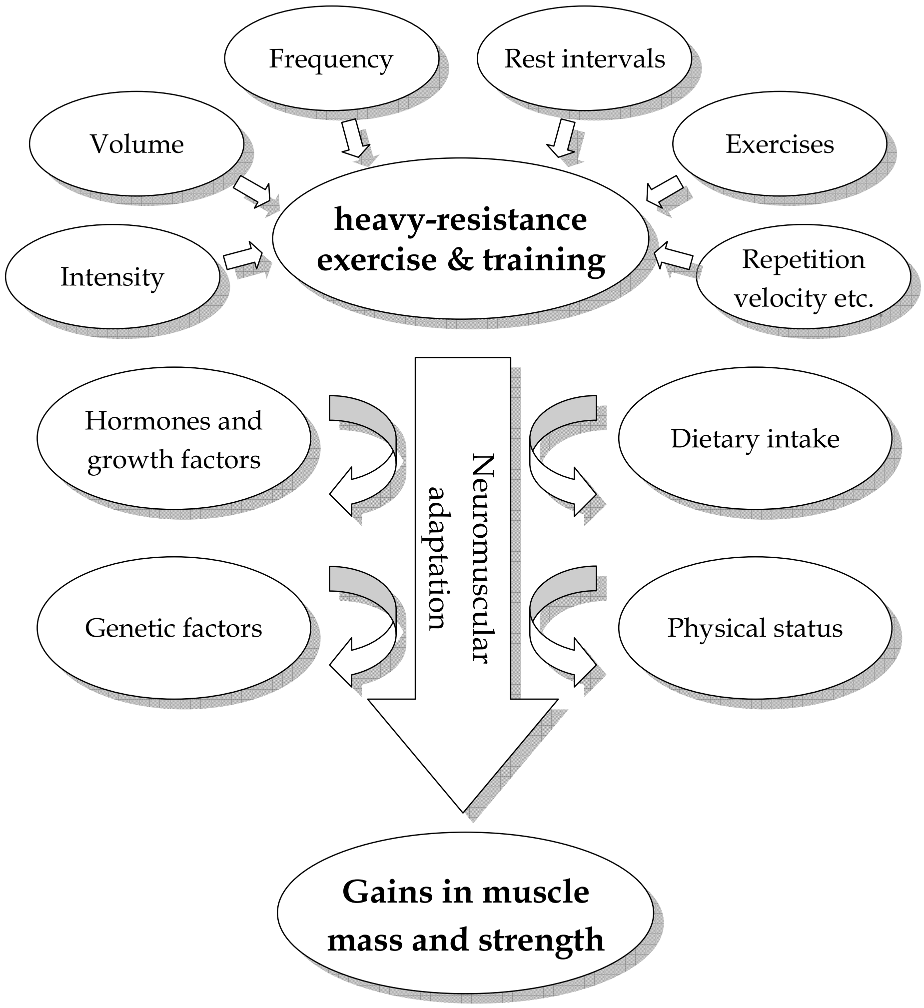



FIGURE 4 Neuromuscular adaptation to strength training

*Muscle mass and strength*

Although combined dietary and strength training interventions in the older adults are limited by the small sample sizes, they consistently indicate that training-induced gains in muscle strength are not affected by dietary intake in well-nourished community-dwelling older men (table 17). Furthermore, no significant effects of energy and/or protein intake on strength training-induced gains in muscle mass have been reported in community-dwelling older men recorded by hydrostatic weighing (Campbell et al. 1999), air-displacement plethysmography (Candow et al. 2006, Haub et al. 2002), dual-energy X-ray absorptiometry (Bunout et al. 2001, Carter et al. 2005) or computed tomography (Godard et al. 2002, Haub et al. 2002). Therefore, it seems that short-term neuromuscular adaptation to strength training is not limited by dietary intake in older men with an energy intake high enough to maintain stable body weight and a protein intake higher than the RDA recommendation of 0.8 g/kg/day (Recommended dietary allowances 1989). Longitudinal data regarding the effects of dietary intake on muscular adaptations to strength training in older women are very limited. Malnourished frail older people are most likely to benefit from "nutritional rehabilitation" during a strength training program (Bonnefoy et al. 2003).

TABLE 17 Dietary intake and leg extension strength during strength training in randomized controlled trials (RCT) in community-dwelling older adults*

| Reference | Participants | Design | Strength of the leg extensors |
|---|---|---|---|
| Campbell et al. 1999 | 19 older men: 51-69 yrs | 12 weeks RCT:<br>1) Strength training & normal diet (contain meat)<br>2) Strength training & meat-free diet | Strength increased by 25-37% in both group. |
| Bunout et al. 2001 | 108 older adults: ≥70 yrs | 18 months RCT:<br>1) Supplementation (1.7 MJ energy, 13 g protein, 62 g carbohydrates, 9 g fat)<br>2) Strength training & supplementation<br>3) Strength training<br>4) Controls | Strength increased by 53-64% in both strength trained group with no significant changes in the control and the supplementation group. |
| Haub et al. 2002 | 21 older men: 65±5 yrs | 12 weeks RCT:<br>1) Strength training & normal diet (contain meat)<br>2) Strength training & meat-free diet | Strength increased by 24-35% in both groups. |
| Godard et al. 2002 | 17 older men: 65-80 yrs | 12 weeks RCT:<br>1) Strength training and supplementation (1.4 MJ energy, 12 g protein, 72 g carbohydrates)<br>2) Strength training | Isometric strength increased by 21% and isokinetic torque by 11-24% with the various velocities in both group. |
| Carter et al. 2005 | 22 older men: 57±2 yrs | 16 weeks RCT:<br>1) Strength training and protein supplementation (35 g whey protein per day)<br>2) Strength training and placebo | Strength increased by 10-15% in both groups. |
| Candow et al. 2006 | 38 older men: 59-76 yrs | 12 weeks RCT:<br>1) Strength training & supplementation (0.3 g/kg/day protein) before training session<br>2) Strength training & supplementation (0.3 g/kg/day protein) after training session<br>3) Strength training | Strength increased by 23-28% in all study groups. |

*Published 1997-2007, mean age of participants >55 yrs, ≥8 participants per group and ≥12 weeks long intervention, RCT = Randomized Controlled Trial

### *Serum anabolic hormones*

No study has reported the effects of dietary intervention on serum anabolic hormone concentrations in the older adults during strength training. Presumably, serum basal sex hormone concentrations are lower with a low-fat diet (≤20% fat) compared to a higher fat diet (~30% fat) in both older women (table 12, page 35) and men (Wang et al. 2005) during strength training. Ingestion of protein and carbohydrates immediately before or after heavy-resistance exercise has been shown to decrease exercise-induced acute testosterone responses compared with a placebo in young men (Crewther et al. 2006). Although the mechanism behind the attenuated testosterone response is not clear, the unchanged luteinizing hormone (LH) levels suggest greater post-exercise testosterone clearance. In addition, an unchanged serum T/SHBG –ratio indicates stable bio-available testosterone levels, despite a reduced post-exercise testosterone response. The effects of pre- and post-exercise meals on GH responses to heavy-resistance exercise are inconsistent, apparently due to the timing and content of the meal, exercise regimen and training status of the participants (Crewther et al. 2006).

***Metabolic health indicators***

The effects of dietary intake on blood pressure, serum lipids and lipoproteins as well as glycemic control in older participants are well documented (see tables 13, 14 and 15). However, the strength training studies that are published about the changes in metabolic health indicators in the older adults are predominantly short-term studies (Miller et al. 1994, Joseph et al. 1999, Fahlman et al. 2002). Therefore, very little information is available about the effects of dietary modification on metabolic health indicators during prolonged strength training in the older people (Haub et al. 2005). Haub and co-workers (2005) compared the effects of a self-selected lacto-ovo-vegetarian diet with either 0.6 g/kg/day soy-based vegetable protein (VEG) or 0.6 g/kg/day beef-based animal protein (BEEF) on serum lipoprotein profiles during 12 weeks of strength training in 21 men aged 65±5 years. Group differences were recorded in the changes of serum HDL-C (VEG: -0.1±0.1 mmol/L & BEEF: 0.1±0.1 mmol/L, $P<0.01$) and serum TC/HDL-C –ratio (VEG: 0.4±0.6 & BEEF: -0.2±0.4, $P<0.05$) (Haub et al. 2005). The results of Haub et al. (2005) are limited by a small sample size and an uncontrolled study design. No information is available about whether reduced strength training can preserve the metabolic health effects of a progressive strength training program in the healthy older adults.

# 3 AIMS AND HYPOTHESES

Muscle weakness, weight loss, and decreased physical activity and functional performance contribute to the risk of frailty and disability in senescence. Therefore, effective interventions to prevent and delay frailty and disability in old age are considered as a public health priority. To date, the most effective intervention to alleviate age-related declines in muscle mass and strength has been strength training. However, only limited information is available about the effects of dietary intake on strength training adaptations in healthy older people. The general purpose of the present thesis was to study the effects of dietary intake on muscular, hormonal and metabolic adaptations to prolonged strength training in older men and women.

Although it seems likely that continuous strength training can maintain muscle strength and mass better than normal low-intensity physical activity (walking etc.), only limited information is available about the long-term effects of strength training on muscle mass and strength in the older adults. *Our first hypothesis was that chronically strength trained older athletes have more muscle mass and strength, as well as greater dietary intake of energy and protein compared to control men with no strength training experience.* Thus, our first aim was to compare muscle mass, strength and dietary intake between master strength athletes and untrained age-matched control men (I).

Age-related physiological changes (e.g. changes in taste and smell) and several non-physiological causes (e.g. social isolation and medications) can impair food intake in the older adults. Protein-energy malnutrition has been found to be associated with characteristics of frailty in senescence. Although increased protein and energy intake has not been shown to contribute to strength training-induced gains in muscle mass and strength in community-dwelling older men, the results of the corresponding interventions involving older women have not been published. Women have a higher risk of frailty than men due to their smaller muscle mass and strength levels, making them more vulnerable to reach the threshold in physical impairment in old age. *Our second hypothesis was that dietary intervention (based on appropriate energy and protein intake) could improve muscle mass development and thereby also strength gains* *during strength training in older women*. Thus, our second aim was to assess the effects of dietary intervention (aimed at providing appropriate energy and protein intake) on muscle mass and strength development during strength training in healthy older women (II).

Normal aging is associated with gradual decreases in serum anabolic hormone concentrations, possibly contributing to a loss of muscle mass and physical function. A single strength training session can induce acute increases in serum testosterone and GH concentrations, with no systematic changes in serum basal anabolic hormone levels. A low-fat diet has been found to decrease serum basal (bio-available) sex hormone concentrations in the older persons. However, the effects of a recommended moderate fat diet on serum anabolic hormones during strength training have not been reported in the older adults. *Our third hypothesis was that anabolic hormone concentrations would decrease with a recommended moderate fat diet compared to a normal higher fat diet during strength training in older people*. Therefore, we organized studies II and III to examine whether a recommended moderate fat diet would have an effect on serum anabolic hormone concentrations during strength training in healthy older men and women.

Aging is associated with an increased prevalence of cardiovascular and metabolic diseases contributing to loss of muscle mass and physical function in the older adults. Short-term strength training has been shown to induce a minor decrease in blood pressure with no changes in serum lipids and lipoprotein concentrations in adults. The long-term effects of strength training on metabolic risk factors are not well documented, and no information is available about whether continued reduced strength training can preserve strength training-induced changes in metabolic health in the older people. Furthermore, very limited information is available about the effects of dietary intake on metabolic health indicators during strength training in the older adults. Thus, *our fourth hypothesis was that a recommended moderate fat diet could augment favorable changes in metabolic health indicators during strength training*. Finally, *our fifth hypothesis was that continued reduced strength training could preserve strength training-induced improvements in muscle strength and metabolic health indicators in older people*. The aims of the final two studies were to assess the effects of a recommended moderate fat diet on metabolic health indicators in older women during strength training (IV), and to study whether continued reduced strength training could preserve strength training-induced changes in muscle strength and metabolic health indicators in healthy older men (V).

# 4 MATERIALS AND METHODS

## 4.1 Participants and design

A total of 51 women and 114 men participated in the present studies. The detailed study designs are described in the original articles (I-V). Suitability to participate in the present strength training studies (II-V) was assessed based on phone interview and physician's examination. The exclusion criteria were: 1) systemic or progressive disease (e.g. cancer, diabetes, rheumatoid arthritis etc.), 2) neuromuscular or musculoskeletal disorder and 3) hormonal or beta-blockade medication. The inclusion criteria were: 1) age: 50-80, 2) physical activity: no background of systematic strength training, and low-intensity recreational physical activity 1-3 times a week (walking, swimming etc.), 3) body mass index: 20-30 kg/m$^2$ and 4) high motivation.

### 4.1.1 Cross-sectional study in men (I)

Seventeen male master strength athletes and 31 untrained control men of various ages were compared. The master strength athletes (Finnish national level athletes in shot-put, discus or hammer throw) were a subgroup of volunteers who participated in a larger research project (Ojanen et al. 2007). Ojanen and co-workers (2007) recruited 75 elite Finnish master throwers for strength and power measurements, and 32 men aged 36-85 years volunteered and were physically able to participate (personal communication). The present subgroup of athletes had an average sport-specific and strength training experience of 22.8±14.9 years. The untrained control men were selected from previous studies based on their age and identical study measurements (isometric leg extension, vastus lateralis thickness, dietary intake and anthropometry).

### 4.1.2 Strength training study in women (II, IV)

Fifty-one healthy untrained women volunteered for the strength training and nutritional counseling study. Participants were randomly divided into the strength training & nutritional counseling group (ST+NC) or strength training (ST) only group for 23 weeks, including a 2-week control period with no interventions to study the physiological reproducibility of the measurements.

### 4.1.3 Strength training study in men (III, V)

Forty-five healthy untrained men participated in the strength training and nutritional counseling study (III). After a 2-week control period, participants were randomly assigned to the ST+NC group or the ST only group for 21 weeks.

Forty-three healthy untrained men performed the strength training and continued reduced training study (V). Participants were randomly allotted to the strength training group or control group for 21 weeks. Seventeen participants of the strength training group volunteered to continue a reduced training phase for another 21 weeks, and 17 participants agreed to continue in the control group.

## 4.2 Interventions

### 4.2.1 Strength training

The progressive strength training intervention was carried out in studies II-V. Supervised whole body strength training (with a special concentration on the legs) was performed twice a week for 21 weeks. The training program was progressive so that the loads increased from 40% to 80% of the maximum while the number of reps per set decreased from 10-15 to 8-10 and 5-8. Training loads were chosen individually so that the last reps of the training sets were difficult to perform. The number of sets per exercise also increased during the training (3-6 sets per exercise). The recovery periods between sets were about one minute for small muscle groups and about two minutes for large muscle groups.

Each training session included 6-8 different machine exercises for major muscle groups (bilateral leg press, bilateral/unilateral knee extension, bilateral/unilateral knee flexion, standing calf machine, machine bench press and pec dec machine, lateral pull down, elbow flexion and extension, abdominal crunch, trunk rotation and extension, leg adduction and abduction).

However, in each training session at least two exercises for the leg extensor muscles were performed. The training machines were sold as brand names "David" (Finndavid Oy, Espoo, Finland) and "Frapp" (UK-tekniikka Oy, Hammaslahti, Finland). Participants were instructed to take at least two days rest between the weekly strength training sessions, as well as to continue their normal recreational physical activities in the same manner as before (1-3 times a week) during the whole study period. The participants in the control group (V) were instructed to continue their normal low-intensity physical activity 1-3 times a week, and not to start any strength training regimen during the study period.

***Heavy-resistance exercise***

A heavy-resistance exercise (HRE) protocol was performed before (week 0) and after the 21-week strength training period in study III. The exercise consisted of five sets of 10 repetitions with the maximal load possible (10RM) in the bilateral horizontal dynamic leg press (David 210 machine). In the leg press, participants straightened their legs from a knee angle of 70 degrees to full extension at 180 degrees, ten times repeatedly. Two minutes of rest were allowed between the sets. The load of the first set was about 75% of the one repetition maximum (1RM). In the second and third sets the load was increased if the participant could perform ten repetitions without assistance. In the last two sets the load was reduced, and if necessary, manual assistance was given to obtain the required ten repetitions in each set.

### 4.2.2 Nutritional counseling

Nutritional counseling was given to half of the participants in studies II, III and IV at the beginning and in the middle of a 21-week strength training period. Counseling was carried out individually by an authorized nutritionist based on dietary intake (from dietary recordings) and personal interview. The purpose of the counseling was to obtain sufficient energy and protein intake and recommended intake of fat and fiber. The present Nordic recommendations for energy nutrients and fiber are: Carbohydrate 50-60 E% (percent of energy), protein 10-20 E%, fat 25-35 E% (saturated fat about 10 E%), and fiber 25-35 g per day (Nordic council of ministers 2004). The recommended healthy eating habits were based on Finnish food-based dietary guidelines (table 18) (Finnish Nutrition Recommendations 2005).

Besides verbal instructions, the participants also received written material: 1) a Finnish Bread Association's manual called "New Finnish Nutrition Guide" about healthy eating habits, 2) a handout about eating habits i.e. recommended meal frequency (breakfast, lunch, dinner and 1-3 snacks), food choices (e.g. low-fat dairy and meat products, vegetable fats and fish) and meal composition (e.g. low-fat dairy or meat product, grain product and vegetables or fruits in every meal), and 3) another handout containing recommendations for daily ingested portions of dairy and meat/fish products. A portion recommendation was provided to obtain about 1.0 g of good quality protein/kg/day. Participants were encouraged to follow the instructions to the end of the study period, and compliance was checked based on food diaries.

TABLE 18 Food-based dietary guidelines (Finnish Nutrition Recommendations 2005)

| Food | Finnish food-based dietary guidelines | |
|---|---|---|
| | Frequency | Quality |
| Fruits, berries and vegetables (not including potatoes) | • ≥ 5 portions per day<br>• At least 400 g per day | • Varied consumption<br>• Part of the vegetables as uncooked<br>• Berries and fruits preferably in the raw than as juice |
| Potatoes | • Daily | • Prepared without extra fat |
| Grain products | • Nearly every meal | • Wholegrain products (wholemeal bread, porridge etc.)<br>• Sparingly bakeries with high saturated fat content (cookies, cakes, pies etc.) |
| Dairy products | • Liquid milk products about half a liter per day<br>• 2-3 slices of cheese | • Non-fat or low-fat products (e.g. liquid products with ≤1% fat, cheeses with ≤20% fat and ≤0.7% salt)<br>• Sparingly high-fat products (full-fat cheeses, creams, ice creams, puddings etc.) |
| Fish | • At least twice a week | • Varied consumption<br>• Prepared without extra fat |
| Meat and poultry | • Daily | • Low-fat meat (≤4% fat) and low-fat cold cuts (≤12% fat and ≤1.5% salt)<br>• Sparingly fatty meat and meat pruducts as well as salty meat and fish products |
| Edible fats | • Daily | • Thin coat of vegetable margarine for slice of bread<br>• Little bit vegetable oil based dressing for salad<br>• Moderately vegetable oils or margarines for cooking and baking |
| Sugar and sugar-rich foods | • Infrequently | • Within meal |
| Salt | • Infrequently | • Low-salt foods<br>• Herbs, unsalted flavourings, fruit juices or mineral salt for spicing of foods<br>• Rarely high-salt foods (e.g. sliced sausages, cheeses, cold smoked products, pickled cucumber, mustard, ketchup) |

## 4.3 Measurements

All reported measurements were always carried out according to the same protocol at the same time of day. Body composition, resting blood pressure and blood sampling for determination of serum basal hormones and metabolic health indicators were measured in the morning between 8.00 AM and 9.00 AM after 10 h of fasting. Blood pressure and blood specimens were taken in the supine position after 15 minutes of rest. To improve the precision of body composition measurements, participants were asked not to perform any stressful physical exercise or to visit the sauna, but to drink normally during the day preceding the measurements and to empty their bladder before the measurements.

Before the strength testing and acute heavy resistance exercise, the participants performed a standardized warm-up (stationary biking and warm-up exercises for major muscle groups) to obtain optimal physical performance and to minimize the risk of muscle strains.

### 4.3.1 Dietary intake

Dietary intake was registered by food diaries for four days (3 workdays and 1 weekend day) in all studies I-V. Verbal and written instructions were given to the participants about how to record all food and drinks consumed including portion sizes by household measures, exact brand names and preparation techniques. The diaries were analyzed using the Finnish nutrient-analysis software Nutrica® (version 3.11, The Social Insurance Institution of Finland, Turku, Finland). If necessary, additional information was obtained from the food manufacturers' network homepage or from the network database 'Fineli' held by the National Public Health Institute of Finland. The reliability of food recordings has been shown to be high, with only a small non-significant difference in mean energy intake in adults (Toeller et al. 1997).

### 4.3.2 Muscle mass and body composition

In studies II and III the cross-sectional area (CSA) of the knee extensor muscles was assessed using magnetic resonance imaging (Philips Gyroscan ACS-NT Scanner, 1.5 T, Best, Netherlands). The length of the femur was measured in the coronal plane as the distance from the intercondular notch of the femur to the inferior corner of the femoral head. Subsequently, 15 axial scans were obtained along the length of the femur. The thickest portion of the CSA of quadriceps femoris (QF) (scan 9/15) was taken for the analyses (Häkkinen et al. 2001). In cross-sectional study I, leg muscle mass was estimated by measuring the thickness of the vastus lateralis at the middle of the thigh with an ultrasound scanner (Aloka SSD-280 LS, Tokyo, Japan).

Body composition was assessed based on standard anthropometry (weight, height, body mass index and waist circumference) and bioimpedance analysis (InBody 3.0, Biospace Co., Seoul, Korea & Bodystat 1500, Bodystat Ltd; Isle of Man, UK) in studies II-V. In cross-sectional study I, body composition was estimated using skin-fold measurements from four anatomical sites according to Durnin and Womersley (1974).

### 4.3.3 Muscle strength

Maximal concentric strength of the leg extensors was recorded using a bilateral horizontal leg press from a knee angle of 70 degrees to full extension at 180 degrees (David 210, David Fitness and Medical, Outokumpu, Finland) in studies II-V. The participants first performed a few warm-up/familiarization repetitions using loads of about 50% and then about 80% from the estimated maximum 1RM load (kg). Thereafter, maximal strength was determined by three to five separate attempts (accuracy of 2.5 kilograms) with rest periods of approximately one minute between attempts. Verbal encouragement was given to participants to encourage maximal force production. The physiological reproducibility (CV%) of 1RM testing was 6.2% for all the older women and 4.9% for all the older men based on measurements before and after the 2-week control period preceding the actual experimental period.

In cross-sectional study I, maximal isometric strength (N, Newton) of the leg extensors was measured with a calibrated leg dynamometer with a minimum of three attempts. Knee angle was set to 107 degrees. Before the actual testing, participants performed a few sub-maximal contractions to become familiar with the testing procedure.

### 4.3.4 Serum anabolic hormone concentrations

Serum basal hormone concentrations of total testosterone (T), free testosterone (FT), GH, dehydroepiandrosterone sulfate (DHEAS) and cortisol (C) as well as SHBG were determined in studies II and III. The participants were instructed to abstain from hard exercise on the day preceding the blood sampling, and to sleep at least eight hours during the previous night.

In study III, the HRE induced serum T, FT and GH responses were determined from blood samples taken before the exercise, and at 0, 15 and 30 minutes after the exercise. Furthermore, two control blood samples were taken within 30 minutes of each other at the same time of day as the HRE was performed.

Serum samples were kept frozen at -80 °C until assayed. Serum T concentrations were analyzed by an immunological chemiluminescence method with a Bayer ADVIA Centaur analyzer (Tarrytown, NY, USA), serum FT and

DHEAS concentrations using radioimmunoassay kits from Diagnostic Products Co. (Los Angeles, CA, USA), SHBG levels by the 1235 AutoDELFIA automatic immunoassay system using kits from Wallac Ltd. (Turku, Finland), serum GH concentrations by radioimmunoassay kits from Pharmacia Diagnostics (Uppsala, Sweden), and serum C concentrations by radioimmunoassays using kits from Farmos Diagnostica (Turku, Finland).

The sensitivities of the T, FT and GH assays were 0.6 nmol/l, 0.52 pmol/l and 0.2 μg/l, respectively, and the coefficients of intra-assay variation were 5.7 %, 3.8 % and 2.5-5.1 %. The sensitivities of the DHEAS, SHBG and C assays were 0.06 μmol/l, 0.5 nmol/l and 0.05 μmol/l, respectively, and the intra-assay variations were 4.5%, 4.4% and 4.0%. All samples for each test participant were analyzed in the same assay for each analyte. Physiological reproducibility (combined methodological and biological variability) (CV%) of 18.9% for T, 17.4% for FT, 24.3% for T/SHBG –ratio, 16.7% for DHEAS, 231.3% for GH, 25.3% for C and 9.8% for SHBG were recorded in the older men (III) during the 2-week control period measurements. During the same period, physiological reproducibility values of 15.5% for T, 32.1% for FT, 25.5% for T/SHBG –ratio, 19.4% for DHEAS, 25.5% for C and 11.2% for SHBG were recorded in the older women (II).

### 4.3.5 Metabolic health indicators

Metabolic health indicators of resting blood pressure, fasting serum lipids and lipoproteins and fasting blood glucose were recorded according to standardized laboratory practice in studies IV and V. Furthermore, fasting serum insulin concentrations were measured in the study involving older women (IV). Serum insulin concentrations were analyzed using radioimmunoassay kits from Pharmacia & Upjohn Diagnostics AB (Uppsala, Sweden).

Serum TC, HDL-C and TAG were determined using enzymatic assays (micro-flow spectrophotometer Shimadzu CL-720, Shimadzu corporation, Kyoto, Japan) and kits from Roche diagnostics GmbH (Mannheim, Germany). The sensitivity of the assays to serum TC and HDL-C is reported to be 0.08 mmol/L with an inter-assay variation of 1.7%. The sensitivity of the assays and the inter-assay variation for serum triacylglyserols are reportedly 0.05 mmol/L and 1.8%, respectively (Roche diagnostics GmbH, Mannheim, Germany). Serum LDL-C concentration (mmol/L) was estimated using the Friedewald's equation: LDL-C = TC - HDL-C - (TAG/2.2) (Friedewald et al. 1972). Blood glucose was recorded immediately using a quick-analyzer (B-Glucose photometer, Hemocue Ab Ängelholm, Sweden). The inter-assay variations for blood glucose measurements are reportedly 1.9-2.7% (Hemocue Ab Ängelholm, Sweden). The sensitivity of the assay to serum insulin assessment was below 2.5 mU/l, the intra-assay variation was 5.3 % and the inter-assay variation was 7.6 %.

Physiological reproducibility values of 8.2% and 7.6% for systolic and diastolic blood pressure, 8.8%, 13.1%, 12.5% and 43.6% for serum TC, HDL-C, LDL-C and TAG were recorded in the older women between the 2-week control period measurements. In the older men, physiological reproducibility values of 10.8% and 7.3% for systolic and diastolic blood pressure, 8.6%, 9.5%, 12.2% and 34.5% for serum TC, HDL-C, LDL-C and TAG were recorded during the 2-week control period.

## 4.4 Statistical methods

Standard statistics were used for descriptive variables: means, SD, SE and 95% CI. The criteria of normal distribution were checked with Shapiro-Wilk Tests and homogeneity of variances with the Levene Test. When necessary, the data were transformed logarithmically prior to analysis.

In the intervention studies II-V, the group differences were compared with analysis of covariance (ANCOVA) using the baseline values as the covariate. If necessary, additional within-group analyses were performed with paired samples t-tests. When similar changes were recorded in the experimental groups, the training effect was studied in the total group of participants using analysis of variance (ANOVA) with repeated measures. Correlation coefficients for continuous variables were calculated by the Pearson correlation method.

In cross-sectional study I, the group effect between study groups was examined with One-Way ANOVA, and a Tukey HSD Post Hoc was used for pair-wise group comparisons. Relationships between physical characteristics and macronutrient intake were determined by Spearman's Nonparametric Correlation Test.

The analyses were performed using SPSS statistical analysis software (SPSS, Chicago, IL, USA). The $P<0.05$ criterion was used for statistical significance.

## 4.5 Study approval

Studies were conducted according to the declaration of Helsinki and the study designs were approved by the Ethics Committee of the University of Jyväskylä, Finland. Full information about the risks and discomfort were given to the participants and they gave their written informed consent to participate.

# 5 RESULTS

## 5.1 Characteristics of the participants

### 5.1.1 Anthropometry

The age range of the older women (II, IV) was 49-74 years (table 19) and their average BMI was 25.4 $kg/m^2$ (19.3 to 36.0 $kg/m^2$), with a mean waist circumference of 88.6 cm (67.7 to 113.0 cm). The older men (including controls) (III,V) were aged 47-73 years and their average BMI was 24.8 $kg/m^2$ (18.3 to 30.5 $kg/m^2$), with a mean waist circumference of 93.9 cm (76.6 to 119.9 cm). The master strength athletes (I) were heavier than the age-matched control men (table 19).

### 5.1.2 Medication

Regular medications of the participants in health-related studies IV and V are shown in table 20. The number of participants using cholesterol-lowering margarine (i.e. margarine enriched with plant sterol or stanol esters) is stated in the original papers.

TABLE 19 Characteristics of the study groups (mean and SD)

| Participants | Gender | Age (years) | Height (cm) | Weight (kg) |
|---|---|---|---|---|
| Study I | | | | |
| • controls (n=10) | Men | 25.7 (3.4) | 181.9 (3.6) | 77.0 (5.2) |
| • master athletes (n=9) | Men | 52.1 (4.7) | 180.1 (3.3) | 94.1 (9.9) |
| • controls (n=11) | Men | 51.9 (3.1) | 176.7 (8.5) | 71.3 (9.7) |
| • master athletes (n=8) | Men | 71.8 (3.8) | 174.6 (6.5) | 86.3 (10.7) |
| • controls (n=10) | Men | 70.6 (3.3) | 170.0 (6.2) | 71.4 (6.4) |
| Study (II, IV) | | | | |
| • ST+NC (n=25) | Women | 58.8 (7.0) | 164.6 (5.1) | 69.4 (10.2) |
| • ST (n=26) | Women | 57.9 (6.8) | 162.0 (6.5) | 66.1 (8.7) |
| Study (III, V) | | | | |
| • ST+NC (n=22) | Men | 59.1 (6.1) | 178.5 (6.8) | 78.2 (9.4) |
| • ST (n=23) | Men | 58.5 (7.1) | 175.4 (5.6) | 75.2 (8.0) |
| • controls (n=21) | Men | 58.2 (6.1) | 176.3 (6.8) | 79.0 (10.8) |

ST = strength training, NC = nutritional counseling

## 5.2 Compliance to experimental training and drop outs

Compliance to the 21-week strength training program was high and 95% of the strength training sessions were performed in both the men's and women's training studies (II-V). In the reduced strength training study (V), 87% of the training sessions were completed during the second 21-week strength training phase.

Only one participant dropped out (home accident) during the studies in older women (II, IV). In the studies with older men (III, V), four participants dropped out (personal reasons, spare time accidents, knee pain) during the study periods.

TABLE 20 Number of participants using regular medication in health related studies IV and V.

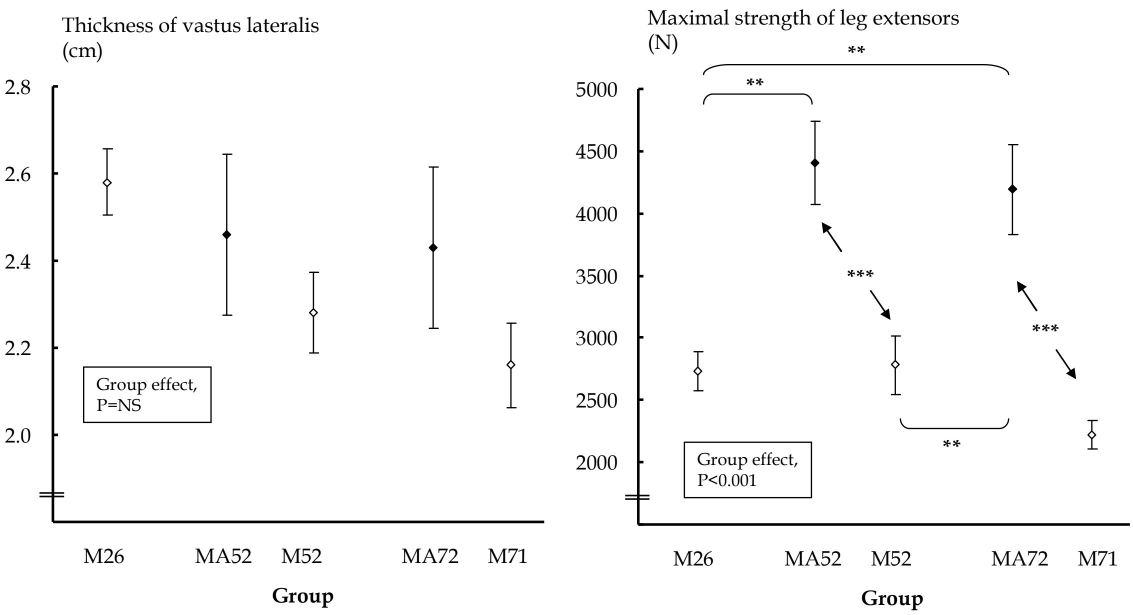
| Participants | HRT | Cholesterol | Blood pressure or heart | Other purposes |
|---|---|---|---|---|
| Older women (IV) | | | | |
| Week 0 | | | | |
| - ST+NC (n=25) | 15 | 2 | 4 | 3 |
| - ST (n=26) | 13 | 1 | 4 | 8 |
| Week 21 | | | | |
| - ST+NC (n=25) | 15 | 2 | 4 | 3 |
| - ST (n=25) | 13 | 2 | 5 | 11 |
| Older men (V) | | | | |
| Week 0 | | | | |
| ST (n=22) | | 1 | 3 | 3 |
| C (n=21) | | 1 | 3 | 5 |
| Week 21 | | | | |
| ST (n=20) | | 1 | 3 | 2 |
| C (n=19) | | 2 | 3 | 5 |
| Week 42 | | | | |
| ST (n=17) | | 1 | 3 | 1 |
| C (n=17) | | 2 | 3 | 5 |

ST = strength training, NC = nutritional counseling, C = control, HRT = hormone replacement therapy

## 5.3 Strength training background (I)

### *Muscle mass and strength*

Both master strength athlete groups had greater lean body mass (measured by skin folds) than the middle-aged and older men control groups, but no group effect was recorded in the thickness of the vastus lateralis (figure 5a). Absolute maximal strength of the leg extensors (figure 5b) as well as strength per vastus lateralis thickness were greater in the master strength athletes compared to all control groups (group effect, $P<0.001$). Body weight adjusted dietary intake did not differ between the groups. Dietary protein intake (g/day) correlated positively ($R=0.79$, $P<0.05$) with maximal leg extension strength (N) in the group of old master strength athletes (MA72), but further controlling of the correlation with body weight removed the correlation (Partial Correlation Test).




FIGURES 5a,b Muscle thickness of vastus lateralis (cm) and maximal isometric strength of leg extensors (N) (mean and SE). MA = master athletes, M = men and different age groups. **group difference, $P<0.01$, ***group difference, $P<0.001$.

## 5.4 Strength training interventions (II-V)

### 5.4.1 Dietary intake

*Baseline*

At baseline the only significant difference between the experimental groups of older women was a slightly lower relative intake of carbohydrates in the nutritional counseling group (II, IV). No group differences were recorded in dietary intake among the older men at baseline (III, V).

*Changes during the study period*

Group differences were particularly evident in the changes in quality of dietary fat among the older women (II, IV) (figure 6) and men (III, V) (figure 7) during the study. The changes in dietary fiber intake did not differ between the groups of older women. However, group effect was recorded in dietary fiber intake between the groups of older men during the study (P<0.001). Baseline adjusted changes in dietary fiber intake in the older men were (mean and SE): ST+NC: 5.2±1.2 g/day, ST: -3.1±1.5 g/day and C: 0.7±1.5 g/day. These group differences resulted mainly from dietary changes in the nutritional counseling group.

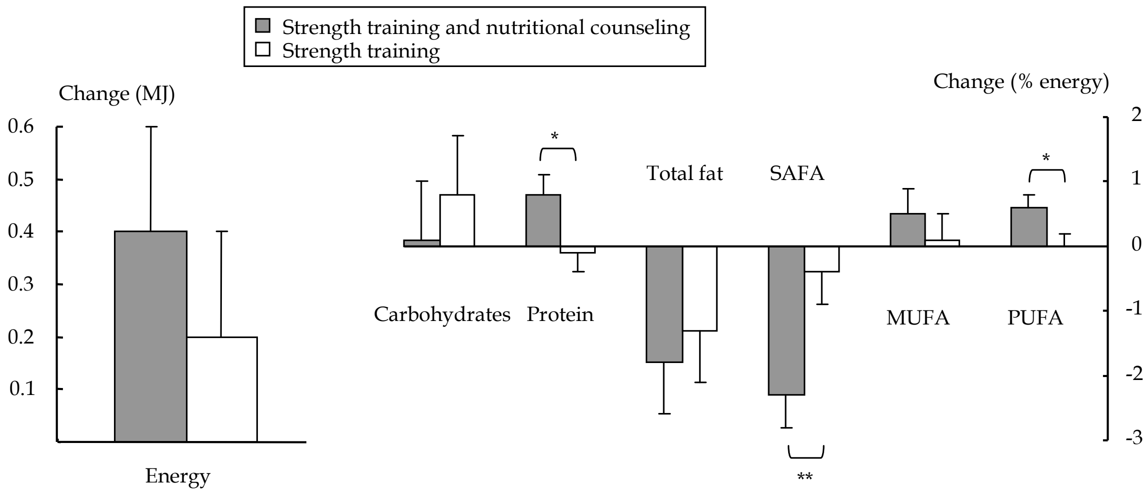



FIGURE 6 Baseline adjusted changes in dietary intake (mean and SE) in the experimental groups of older women during the 21-week study period. MJ = megajoule, SAFA = saturated fatty acids, MUFA = monounsaturated fatty acids, PUFA = polyunsaturated fatty acids, *group difference, P<0.05, **group difference, P<0.01.

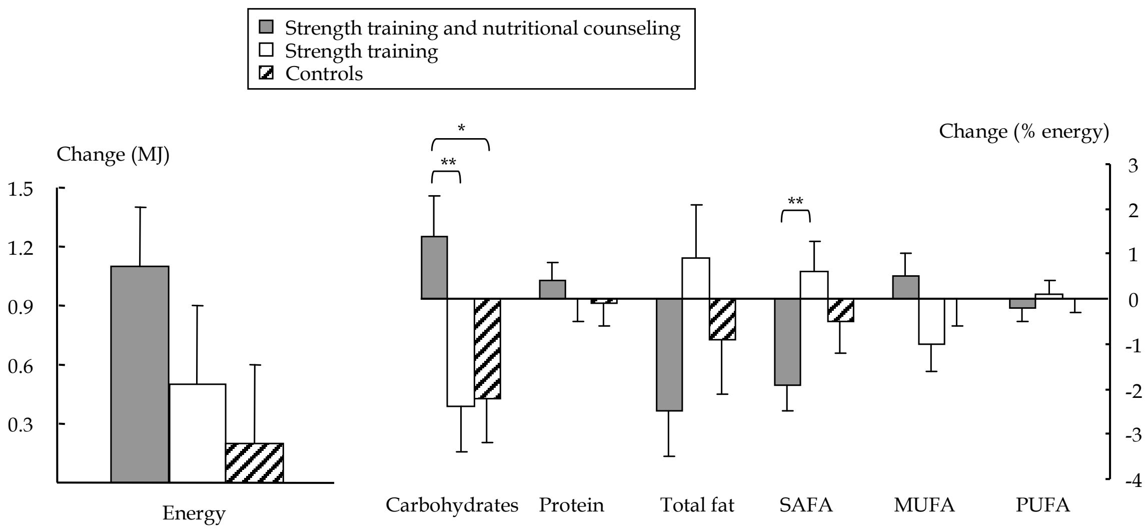



FIGURE 7 Baseline adjusted changes in dietary intake (mean and SE) in the experimental groups of older men during the 21-week study period. MJ = megajoule, SAFA = saturated fatty acids, MUFA = monounsaturated fatty acids, PUFA = polyunsaturated fatty acids, *group difference, P<0.05, **group difference, P<0.01.

### 5.4.2 Muscle mass and strength

*Baseline*

At baseline, two experimental groups of older women had similar muscle strength and muscle CSA of QF (II, IV). The groups of older men showed the same muscle mass and strength levels at baseline (III, V).

*Changes during the study period*

Maximal strength of the leg extensors already increased significantly after the first half of the 21-week strength training period in older women (II, IV) (figure 8) and men (III, V) (figure 9), but nutritional counseling did not contribute to strength development. Continued reduced strength training maintained strength gains for another 21 weeks compared to the controls (V) (figure 10).

Muscle cross-sectional area of the leg extensors increased more (10% vs. 7%) in older women who received nutritional counseling compared to the strength training only group during the study period (IV) (figure 8). In older men the increase in muscle CSA of QF (5-6%) did not differ between the groups after strength training (V) (figure 9).

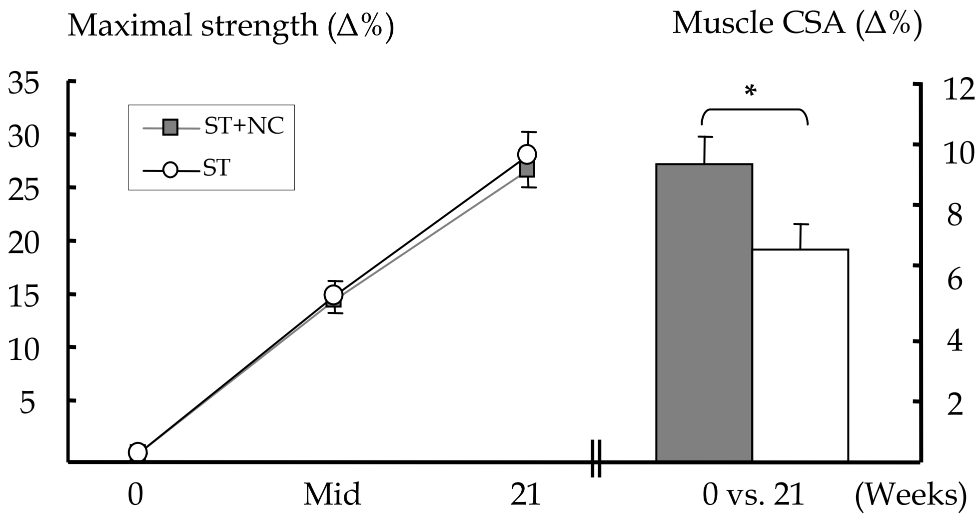



FIGURE 8 Baseline adjusted relative changes in maximal concentric strength of leg extensors and muscle CSA of quadriceps femoris (mean and SE) in the experimental groups of older women during the 21-week strength training period. ST = strength training, NC = nutritional counseling, *group difference, P<0.05.

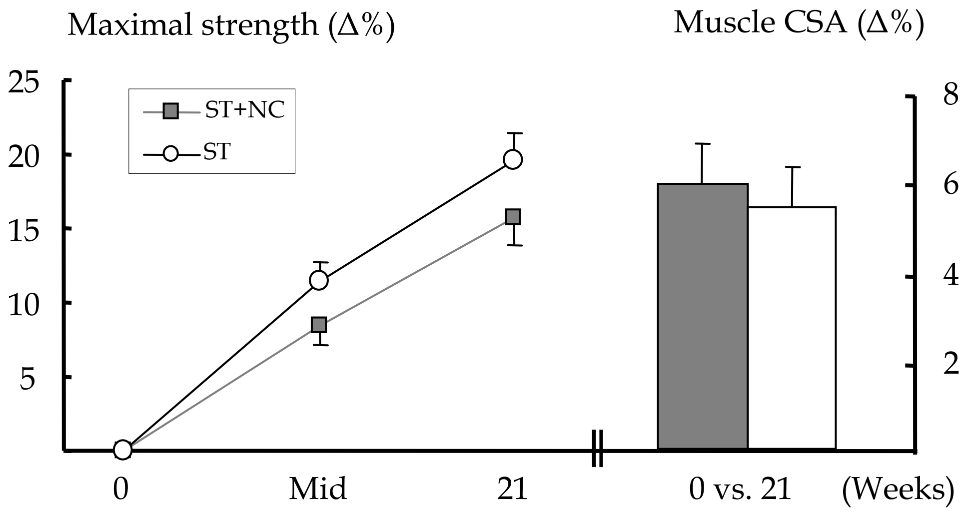



FIGURE 9 Baseline adjusted relative changes maximal concentric strength of leg extensors and muscle CSA of quadriceps femoris (mean and SE) in the experimental groups of older men during the 21-week strength training period. ST = strength training, NC = nutritional counseling.

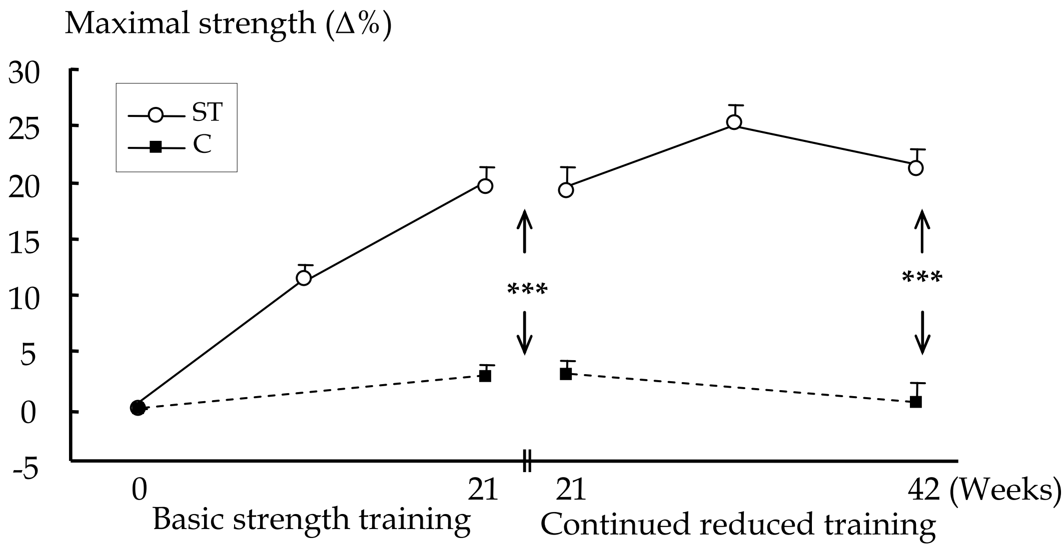



FIGURE 10 Baseline adjusted relative changes in maximal concentric strength of leg extensors (mean and SE) in the older men during the basic strength training and the continued reduced training periods. ST = strength training group, C = control group, *** group difference, $P<0.001$.

### 5.4.3 Serum anabolic hormone concentrations

***Baseline***

Serum basal anabolic hormone concentrations did not differ, either between the groups of older women (II) or between the groups of older men (III) at baseline.

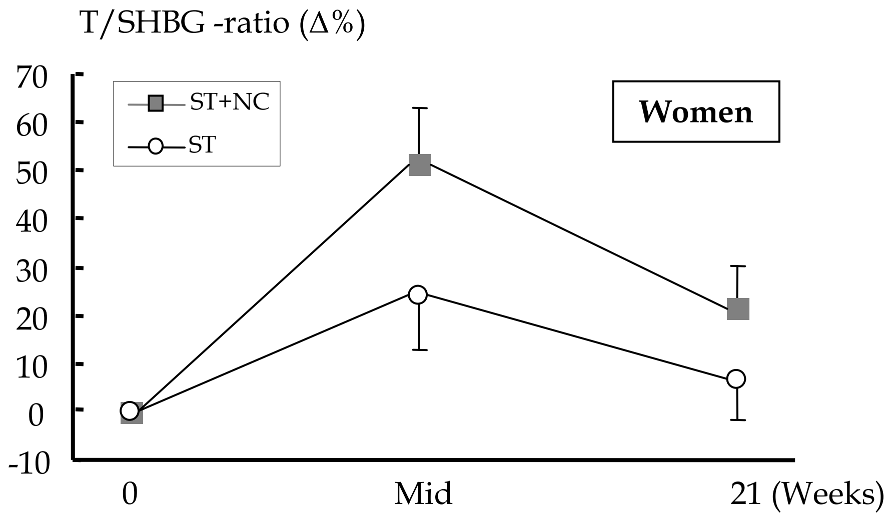
***Changes during the study period***

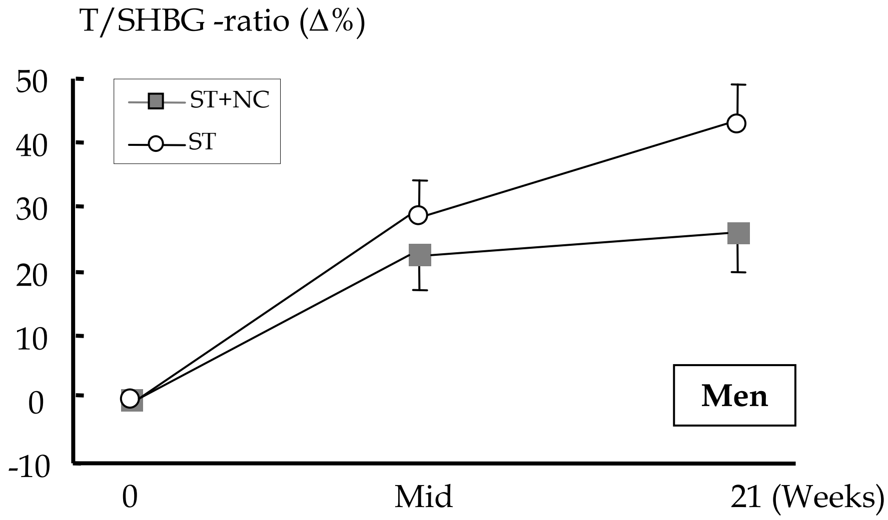
Serum basal anabolic hormones

Based on the changes in serum biologically active unbound T (i.e. serum T/SHBG -ratio), no group differences were recorded in serum basal anabolic hormones during 21 weeks of strength training either in older women (II) (figure 11a) or older men (III) (figure 11b). In older women the serum T/SHBG –ratio increased during the first part of the training, but returned to baseline at the end of the training period (II). In older men the serum T/SHBG –ratio was significantly higher after the strength training period compared to the baseline value (III). The individual average serum basal T/SHBG –ratios correlated positively with the average body weight normalized intake of energy (figure 12a), protein (figure 12b) and fat (figure 12c) in the total group of older men during the study period (III). Further controlling of the correlation with energy intake (kJ/kg) (Partial Correlation Test) removed the correlations between the serum T/SHBG –ratio and dietary protein and fat intake.

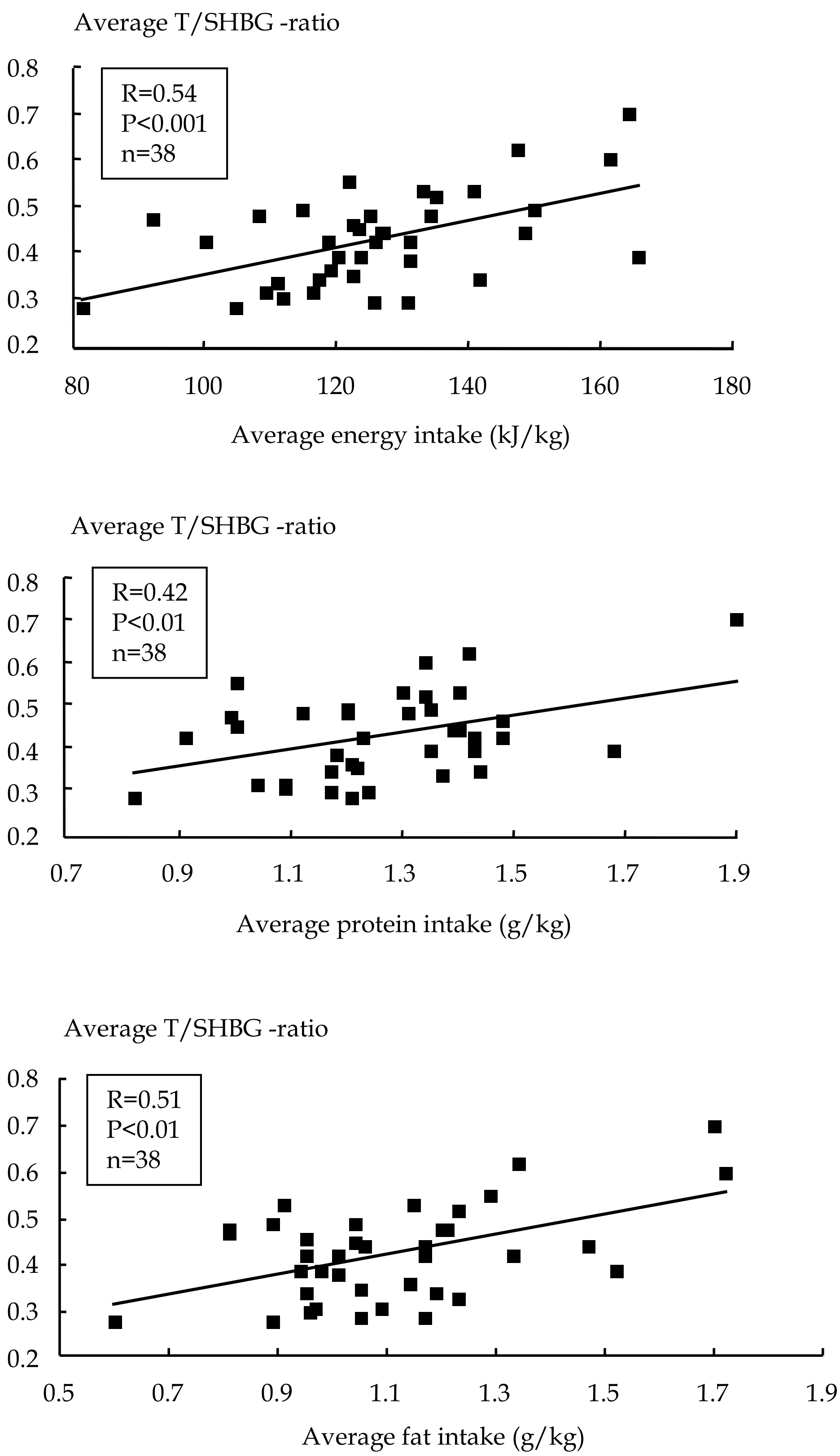
Acute hormone responses to heavy-resistance exercise

Heavy-resistance exercise induced significant ($P<0.001$) acute increases in serum concentrations of T and GH in older men (III). Before training, serum GH concentrations 15 and 30 minutes after HRE were significantly higher in the ST group compared to the ST+NC group. After training, the only significant group difference in the serum hormone concentration was a greater serum T concentration in the ST group compared to the ST+NC group immediately after HRE. Pre-exercise energy intake (eating within 6 hours before HRE) mildly attenuated post exercise T responses at 15 ($R=-0.38$, $P<0.05$) and 30 minutes ($R=-0.39$, $P<0.05$) after heavy-resistance exercise in the total group of older men after the 21-week strength training period.




FIGURES 11a,b Baseline adjusted relative changes in serum basal testosterone per sex hormone-binding globulin (T/SHBG) ratio (mean and SE) in older women and older men. ST = strength training, NC = nutritional counseling.




FIGURES 12a,b,c Relationships between the individual average serum basal testosterone per sex hormone-binding globulin (T/SHBG) –ratios and the average body weight normalized intake of energy, protein and fat in the total group of older men.

### 5.4.4 Metabolic health indicators

*Baseline*

Metabolic health indicators were comparable in the groups of older women at baseline (IV). In older men the only significant group difference in health indicators was a higher fasting blood glucose concentration in control men (V). Resting blood pressure was classified as high normal (systolic blood pressure 120-139 mmHg or diastolic blood pressure 80-89 mmHg) in both older women (135±17 mmHg & 81±9 mmHg) and men (131±13 mmHg & 83±6 mmHg) at baseline. Respectively, the fasting serum TC and LDL-C concentrations were higher than the optimal (TC: <5.0 mmol/L and LDL-C: <3.0 mmol/L) in both older women (5.7±0.9 mmol/L & 3.8±0.8 mmol/L) and men (5.4±0.9 mmol/L & 3.6±0.8 mmol/L) at baseline.

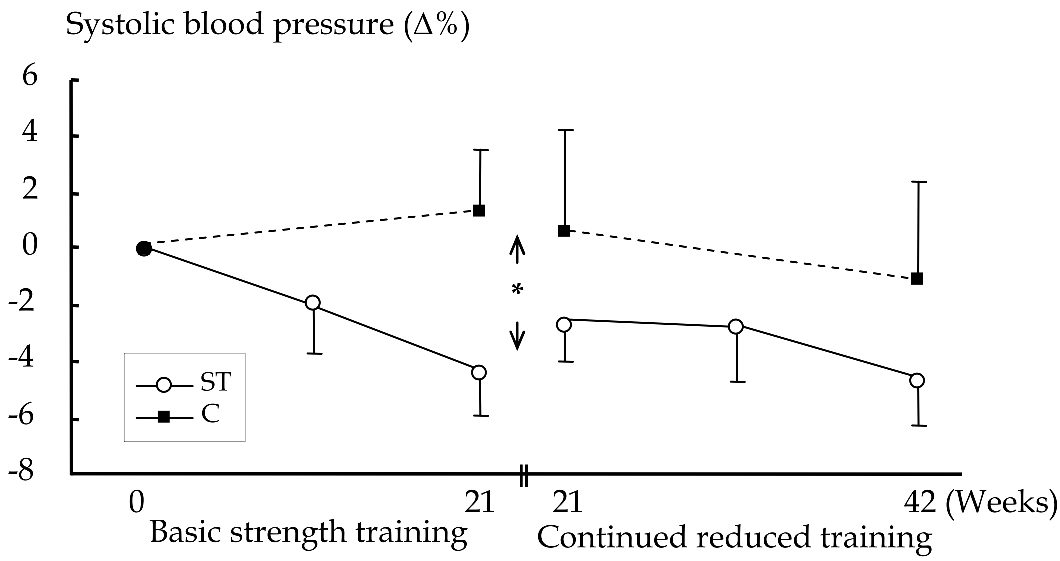
*Changes during the study period*

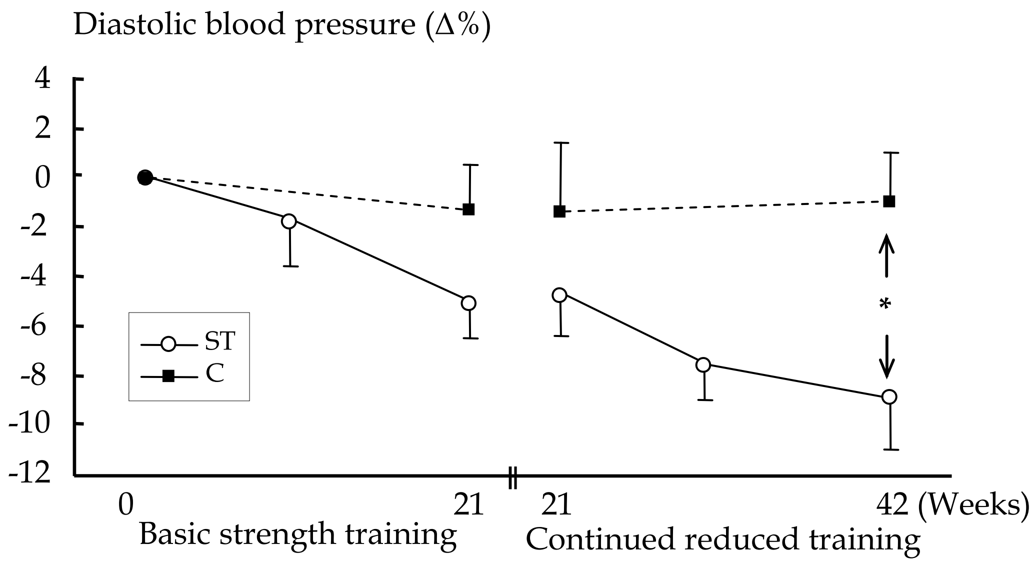
Blood pressure

After the 21-week strength training period, systolic blood pressure had decreased by 5.5-6.5% in older women without evidence of group differences (IV). In older men strength training resulted in a decrease in systolic blood pressure compared to the controls (figure 13a) (V). Continued reduced training caused a decrease in diastolic blood pressure (13b), but the group difference in systolic blood pressure disappeared (13a).

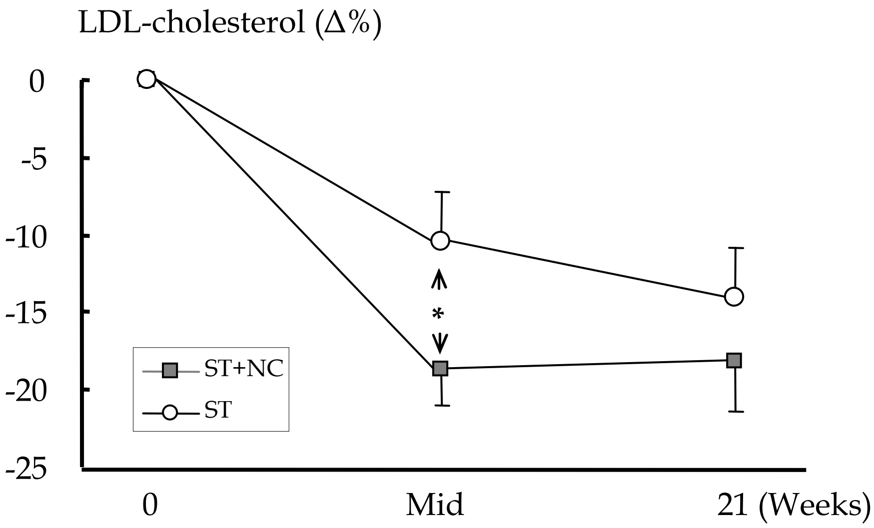
Serum lipids and lipoproteins

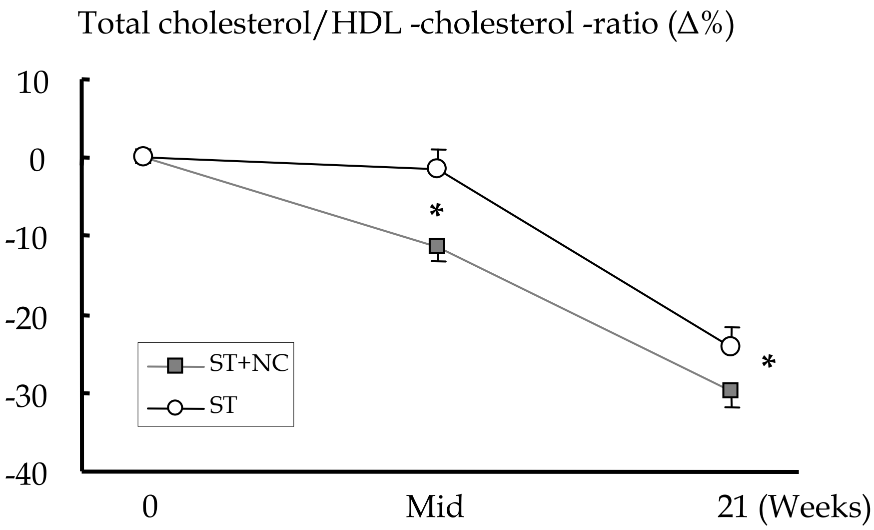
Nutritional counseling contributed to strength training-induced decreases in serum LDL-C concentration (Figure 14a) and the serum TC per HDL-C –ratio (Figure 14b) in older women (IV). Changes in serum TC, HDL-C and TAG concentrations did not differ between the groups. In the total group of older women, serum HDL-C increased significantly after the strength training period. In older men the only group difference in serum lipids and lipoproteins was a higher serum HDL-C concentration in the control group compared to the strength trained group (V).




FIGURES 13a,b Baseline adjusted relative changes in resting blood pressure (mean and SE) in older men during the basic strength training and the continued reduced training periods in older men. ST = strength training group, C = control group, *group difference, P<0.05.




FIGURES 14a,b Baseline adjusted relative changes in fasting serum LDL-cholesterol and total cholesterol per HDL cholesterol –ratio (mean and SE) in older women during the 21-week study period. ST = strength training, NC = nutritional counseling, * group difference, P<0.05.

Blood glucose and serum insulin

Fasting blood glucose and serum insulin concentrations did not differ between the groups of older women during the strength training period (IV). In the total group of older women, serum insulin concentration decreased below the baseline value after strength training (P<0.05). In older men no group differences were observed in blood glucose concentrations during the basic strength training period. However, continued reduced strength training resulted in sustained fasting blood glucose levels in strength-trained men compared to a significant increase in the control men (Figure 15) (V).

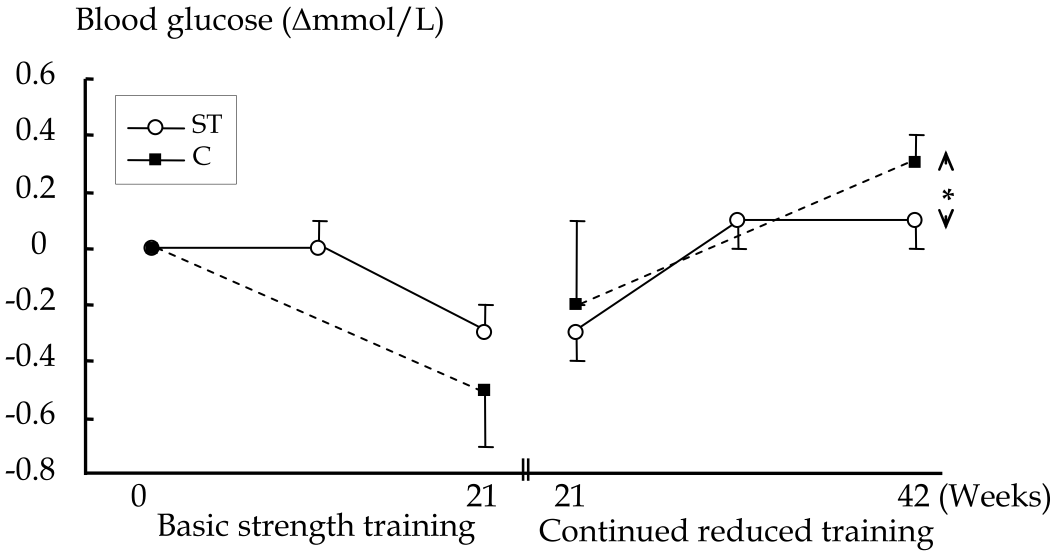



FIGURE 15 Baseline adjusted absolute changes in fasting blood glucose concentrations (mean and SE) in older men during the basic strength training and the continued reduced training periods. ST = strength training group, C = control group, *group difference, $P<0.05$.

# 6 DISCUSSION

The unique characteristic of this thesis was to study the effects of nutritional counseling-induced dietary changes on muscle mass, strength, serum anabolic hormones and metabolic health indicators in healthy older adults during prolonged strength training.

## 6.1 Strength training background (I)

Our cross-sectional data indicate that continuous strength training can minimize age-related declines in muscle mass and strength in older men compared to control men, confirming previous cross-sectional data (Klitgaard et al. 1990, Sipila et al. 1991, Pearson et al. 2002, Leong et al. 1999). Furthermore, higher leg extensor strength without significantly thicker vastus lateralis muscles in the present strength trained older men suggests a greater voluntary muscle activation level compared to the controls. Improved muscle activation capacity has been found to contribute to strength training-induced gains in muscle strength in previously untrained older persons in controlled studies (Reeves et al. 2003, 2004, 2006), and elite weightlifters have been shown to exhibit greater muscle activation than age-matched healthy controls (Pearson et al. 2002).

The present correlation between dietary protein intake and muscle strength in the group of 64-76-year old strength athletes originated from the high variation between those volunteers due to the wide range in their body weight (from 72.3 kg to 103.8 kg). Firstly, the correlations are dependent on the range and distribution of the variables, and thus on the method of sampling of the participants (Bland and Altman 2003). Secondly, the correlation ignores any systematic bias between the two variables. Thirdly, the correlation coefficient is vulnerable to consistent bias caused by methodological weaknesses (e.g. use of different methods or different experimenters) (Bland and Altman 2003). Absolute protein intake varied between 61 g/day and 148 g/day and body weight adjusted protein intake between 0.8 g/kg/day and 1.6 g/kg/day in the present group of eight older athletes. Respectively, a large variation between 2844 N and 5707 N was recorded in maximal leg extension strength among the present athletes. A recent review recommended a protein intake of 1.2-1.4 g/kg body weight /day for older athletes (Campbell and Geik 2004). However, cause-effect relationships can not be obtained from cross-sectional data.

## 6.2 Strength training interventions (II-V)

### 6.2.1 Dietary intake

Nutritional counseling induced a decrease of 2 E% in saturated fat intake in both older men and women. Furthermore, total fat intake decreased by over 2 E% in older men compared to the control group. In older women a comparable decrease was recorded in total fat intake in the nutritional counseling group and the control group.

A recent systematic review analyzed the effects of dietary advice on cardiovascular risk profiles among healthy adults (Brunner et al. 2005). Based on 11 RCTs with 4328 adults, Brunner and co-workers (2005) reported that the intake of total and saturated fat decreased by -6.2 E% (95% CI: -8.4 E% to -4.0 E%) and -3.3 E% (95% CI: -4.6 E% to -1.9 E%) with diary advice compared to the control group (Brunner et al. 2005). Therefore, the effectiveness of the present nutritional counseling is consistent with previous dietary interventions considering that only two nutritional counseling sessions were performed during the whole 21-week study period. High intensity dietary interventions with more than three personal meetings with participants have been shown to yield a net decrease of -7.9 E% (95% CI: -10.1 E% to -5.7 E%), and low intensity interventions a net decrease of -2.9 E% (95% CI: -4.4 E% to -1.3 E%), in total fat intake compared to the control groups (Brunner et al. 2005).

Nutritional counseling only induced minor changes in energy and protein intake in the present study. Body weight adjusted protein intakes of the older women (1.1. g/kg/day) and men (1.2 g/kg/day) at baseline were comparable with previous data in community-dwelling middle-aged and older Finnish people (Männistö et al. 2003, Virtanen et al. 2000). Therefore, it is not a surprise that dietary energy and protein intake did not increase substantially in our well-nourished participants after the nutritional counseling, which was aimed at providing a sufficient intake of energy with about 1.0 g of good quality protein /kg/day.

In summary, nutritional counseling induced improvements in dietary fat intake that were comparable to those recorded previously with low-intensity dietary interventions.

### 6.2.2 Muscle mass and strength

Very limited information is available about the effects of dietary intake on muscle mass during strength training in community-dwelling older women. In the present study, increased protein and energy intake contributed to gains in muscle CSA in older women during strength training. However, increased energy and/or protein intake has not been found to contribute to strength training-induced muscle hypertrophy in community-dwelling older men (Bunout et al. 2001, Godard et al. 2002, Carter et al. 2005, Candow et al. 2006), supporting the present data. Obviously, well-nourished older men (with a sufficient calorie intake and protein intake beyond the RDA-recommendation of 0.8 g protein /kg/day) (Recommended Dietary Allowances 1989) would receive most of the muscular benefits from strength training without dietary guidance or supplementation. However, the present data suggest that older women may receive muscular benefits from augmented protein and energy intake (as well as dietary variety) during progressive heavy-resistance training.

Our longitudinal data confirmed that strength training-induced substantial gains in muscle strength are not affected by dietary intake in well-nourished community-dwelling older men and women (table 17, page 46). Increased activation of the agonist muscles has been shown to make a significant contribution to strength development, especially during the initial weeks or months of strength training in previously untrained older persons compared to controls (Reeves et al. 2003, 2004, 2006). The present increases in maximal dynamic strength of 24-29% and 16-20% in older women and men compared with 7-10% and 5-6% gains in muscle cross-sectional area confirms the importance of neural factors for strength improvement in older people. However, older people retain the capacity for skeletal muscle hypertrophy during strength training with sufficient intensity, volume and frequency. The present data confirmed a 20-40% increase in maximal dynamic leg extension strength (table 16, page 42) and a 5-10 % increase in the muscle CSA of QF (Sipilä and Suominen 1995, Godard et al. 2002, Häkkinen et al. 2002, Kalapotharakos et al. 2004) after at least 12 weeks of moderate to heavy intensity (60-80% 1RM loads) strength training with 2-3 weekly training sessions in older individuals compared to controls.

In conclusion, muscle mass and strength are not affected by dietary intake in well-nourished community-dwelling older men during the first six months of moderate to heavy intensity strength training. However, strength training-induced muscle hypertrophy may be augmented by increased dietary protein and energy intake in older women.

### 6.2.3 Serum anabolic hormone concentrations

The longitudinal data showed that a recommended moderate fat diet (Nordic Council of Ministers 2004) did not change serum anabolic hormone concentrations in older men and women compared to controls (with no dietary advice) during strength training. In RCTs, sex hormone concentrations have been found to decrease with a low-fat high fiber diet (≤20% fat, ≥25 g fiber /day) compared to a normal diet (~30% fat and ≤20 g fiber /day) in middle-aged men and women (Rock et al. 2004, Wang et al. 2005). In older men the increase in serum basal T/SHBG –ratio observed after the 21-week strength training period was an unexpected finding. Previous studies have found no significant changes in serum basal hormone concentrations after prolonged strength training in older men (Häkkinen et al. 2000a, 2002). The present hormonal data are limited by the absence of a control group, and by the fact that only one blood specimen was collected. Due to the high physiological variation in serum basal hormone concentrations, a control group is necessary to separate normal physiological variation (such as diurnal variation) from true training effects.

The average serum basal biologically-active T concentrations (i.e. T/SHBG -ratio) correlated positively with average energy, protein and fat intake in the older men during the 21-week study period. The apparent positive effects of dietary fat intake on the T/SHBG -ratio are supported by a randomized controlled study reporting decreases of 12% and 8% in serum T and SHBG concentrations after 8 weeks of a low fat diet (<15% fat, 25-35 g fiber /day) compared to a high fat diet (>30% fat, <20 g fiber /day) in 39 healthy 50-60-year old men (Wang et al. 2005). In addition, decreases were recorded in plasma T and SHBG concentrations after 10 weeks of a low fat diet (<20% fat, P/S –ratio 1.2 and 4.6 g fiber /MJ) compared to a high fat diet (40% fat, P/S -ratio 0.6 and 2 g fiber /MJ) in a cross-over study with 43 healthy men aged 19-56 years (Dorgan et al. 1996). Although the mechanisms by which dietary fat modulates androgen metabolism are still under consideration, it has been suggested that a low-fat diet may contain less cholesterol or decrease mobilization of cholesterol for steroidogenesis, have an impact on the hypothalamic axis by decreasing secretion of gonadotropins, alter steroid metabolism by inhibiting enzyme activities or directly modify T production by the testes. Furthermore, the high dietary fiber content of a low fat diet may reduce reabsorption of steroid hormones by altering the activity of steroid hydrolysis enzymes or the microflora of the gut (Wang et al. 2006).

Positive effects of dietary energy and protein intake on the serum basal T/SHBG –ratio are supported by cross-sectional data. Longcope et al. (2000) reported a weak negative correlation between dietary protein intake and serum SHBG concentrations in 1552 men aged 40-70 years. Furthermore, a long-term low protein, low energy diet (8.3 MJ energy, 0.7 g protein /kg/day) has been found to be associated with a smaller serum T/SHBG –ratio and a greater serum SHBG concentration compared to a normal Western diet (9.8 MJ energy, 1.2 g protein /kg/day) in 26 men aged approximately 53 years (Fontana et al. 2006). However, cross-sectional data can not be used to state causal relations. The mechanisms by which dietary protein can affect serum SHBG concentrations are uncertain. One of the major controlling factors for SHBG metabolism is insulin. Because the intake of carbohydrates, the most potent dietary stimulus for insulin release, has not been found to correlate with serum SHBG, it is likely that the relationship of protein intake to SHBG involves more than just the effect of insulin (Longcope et al. 2000).

The present finding of an attenuation of heavy-resistance exercise-induced T responses with pre-exercise energy intake in older men confirmed previous findings obtained in young men (Chandler et al. 1994, Kraemer et al. 1998b, Bloomer et al. 2000). Although the mechanism behind the meal-induced attenuated T response to exercise is uncertain, it may derive at least partly from accelerated T clearance during recovery (Volek 2004, Crewther et al. 2006).

It can be concluded that dietary intake of energy in the form of protein and fat seems to be a major dietary factor contributing to circulating bio-available testosterone concentrations in older individuals during strength training. A recommended moderate fat diet with sufficient energy and protein appears to ensure a favorable anabolic environment for strength training in the older adults.

### 6.2.4 Metabolic health indicators

*Blood pressure*

Prolonged strength training decreased resting systolic blood pressure in older men and women, confirming the controlled data in older people with high normal blood pressure (systolic blood pressure 120-139 mmHg or diastolic blood pressure 80-89 mmHg) (Martel et al. 1999, Delmonico et al. 2005). Although resting diastolic blood pressure decreased concomitantly with systolic blood pressure in the older women after 21 weeks of strength training, the decrease in diastolic blood pressure did not manifest until the end of the continued reduced strength training period at week 42 in the older men. The decreased waist circumference after 21 weeks of strength training in the older women and after 42 weeks of strength training in the older men supports controlled data, suggesting that the training-induced loss of abdominal fatness (by MRI) was associated with decreased blood pressure in 55-75-year old men and women with mildly elevated blood pressure (Stewart et al. 2005a,b). Body composition improvements explained 7-8% and 15-17%, respectively, of the reductions in systolic and diastolic blood pressure in those older individuals (Stewart et al. 2005a,b). Martel et al. (1999) reported decreased systolic and diastolic blood pressure after six months of strength training in a total group of 21 older men and women aged 65-73 years. Training induced an increase in fat free mass in those older participants but no significant changes were recorded in fat mass (by DXA) (Martel et al. 1999). Delmonicio and co-workers (2005) showed comparable significant reductions in systolic and diastolic blood pressure after 23 weeks of strength training in 36 older women and 34 older men aged 52-81 years. Dual-energy X-ray absorptiometry data showed an increase in fat free mass in both genders after strength training, but only the men reduced their body fatness significantly (Delmonico et al. 2005).

In summary, each of the improvements in body composition and muscular fitness are associated with the mild strength training-induced reductions in blood pressure in older people with mildly elevated blood pressure. The mechanisms by which strength training can directly reduce blood pressure are not clear but suggestions include changes in the functional components of the arterial wall (Braith and Stewart 2006) and alterations in angiotensinogen action in the renin-angiotensin system (Delmonico et al. 2005).

***Serum lipids and lipoproteins***

A recommended moderate fat diet (with 30% of total fat and 10% of saturated fat) induced positive changes in serum lipids and lipoproteins in the older women during strength training. The present data is supported by previous controlled trials reporting that the substitution of saturated fat with unsaturated fat results in moderate decreases in serum TC and LDL-C concentrations in older adults (table 14, page 39). Saturated fatty acids increase serum TC and LDL-C concentrations by decreasing LDL catabolism mediated by the decreases in LDL receptor messenger RNA and membrane fluidity (Schaefer 2002). On the other hand, the reduced intake of saturated fat and cholesterol are associated with decreased concentrations of various lipoproteins including "bad" LDL-C and "good" HDL-C in plasma (Mooradian et al. 2006). However, the reduced dietary saturated fat-induced decrease in plasma LDL-C is much greater than the decline in HDL-C concentration (Schaefer 2002). The substitution of dietary saturated fat with unsaturated fat decreases LDL-C, but HDL-C changes only slightly (Hu and Willett 2002).

Unchanged serum lipids and lipoproteins in the present strength trained older men compared to the controls confirmed the findings of previous controlled studies whereby strength training alone did not lead to changes in blood lipids and lipoproteins in older men (Hagerman et al. 2000, Banz et al. 2003). Furthermore, RCTs with combined groups of older men and women have reported only minor non-significant changes in serum lipid and lipoprotein profiles after several months of strength training (Vincent et al. 2003, Boardley et al. 2007). However, the inclusion of an aerobic component to training has been shown to augment a significant increase in serum HDL-C in a combined group of older men and women compared to controls (Takeshima et al. 2004, Stewart et al. 2005a). Regarding the present older women, Fahlman et al. (2002) reported comparable decreases in serum LDL-C and TC/HDL-C – ratio, and increases in serum HDL-C in 30 women aged 70-87 years after 10 weeks of moderate intensity (70% of the 1RM loads) strength training. On the contrary, blood lipid and lipoprotein profiles did not change after 8-weeks of low-intensity (80% of the 10RM loads) strength training in 15 women aged 49-62 years compared to the controls (Elliot et al. 2002).

In conclusion, the substitution of dietary saturated fat with unsaturated fat can enhance the moderate to heavy intensity (60-80% of 1RM loads) strength training-induced decreases in serum LDL-C concentration and TC/HDL-C –ratio in older women. The inclusion of an aerobic component to training seems to be needed to augment positive changes in serum lipid and lipoprotein profiles in older men.

### *Glycemic control*

The importance of body fatness (especially truncal fat) as the regulator of glycemic control in older people (Chang and Halter 2003, Zamboni et al. 2005, Janssen and Ross 2005) was supported by the present data in 50-70-year old men and women. Fasting serum insulin concentrations decreased concomitantly with reductions in body fatness (measured by BIA) and waist circumferences in the older women after 21 weeks of strength training. In the older men, continued reduced strength training prevented an increase in fasting blood glucose observed in the control men, which occurred concurrently with the increase in waist circumference. Stewart et al. (2005a) reported that reductions in abdominal fatness (measured by MRI) were positively associated with improvements in insulin sensitivity after six months of combined strength and aerobic training in 115 older adults aged 55-75 years. Moreover, training-induced improvements in insulin sensitivity have been reported to be positively associated with reductions in visceral adipose tissue (measured by CT) in 16 obese older adults aged 63±1 years (O'Leary et al. 2006).

The positive direct effect of strength training on glucose disposal in older adults should not be underestimated. Hurlbut and co-workers (2002) reported improved insulin action in 12 older men aged 71±2 years after six months of strength training with no significant changes in older women aged 68±2 years. However, those older men had significantly higher fasting blood glucose concentrations and total glucose area under the curve (in OGTT) at baseline than the older women (Hurlbut et al. 2002). Regarding body composition, the same study reported that fat free mass (measured by DXA) increased after strength training with no significant changes in fat mass in the older individuals (Hurlbut et al. 2002). Ryan et al. (2001) reported non-significant 13% and 3% improvements in glucose utilization in 11 older men and 10 older women aged 65-74 years after six months of strength training with no significant changes in body composition (measured by DXA). However, training-induced improvements in glucose disposal were negatively related to the baseline glucose disposal in the total group of participants (Ryan et al. 2001). Finally, comparable improvements were recorded in glucose disposal in 39 obese men aged 50-79 years after 6 months of strength or aerobic training with no changes in total body fat mass (by DXA) or abdominal adipose tissue (by CT) (Ferrara et al. 2006).

It can be concluded that strength training can improve insulin stimulated glucose uptake in insulin-resistant (obese) older people, especially when combined with a significant loss of abdominal fatness. Previously proposed mechanisms to explain the improved insulin action after strength training include increases in muscle capillarization and glucose transporter proteins, and alterations in key enzyme activities regulating glucose uptake and storage (Ryan et al. 2001).

## 6.3 Methodological strengths and limitations

***Cross-sectional study (I)***

The strength of the present cross-sectional data was the comparison of top level master strength athletes, with several decades of strength training experience, with untrained control men of different ages. However, the data were limited by several factors including a cross-sectional design, a small sample of volunteers and the use of ultrasound for measuring femoral skeletal muscle mass. Cross-sectional designs can show differences between groups and the associations between variables, but cause and effect conclusions can not be obtained from cross-sectional data. The small sample size of volunteers decreases the reliability of the group comparisons and possible correlations. Convenience sampling (i.e. sampling of volunteers) increases the probability that those individuals who feel strongly about the issue in question become recruited to the study, thus favoring certain outcomes (Sousa et al. 2004). This represents a source of error in the convenience sample method, and its significance can be determined by comparing the collected data with previous data from a population in terms of average variability (Sousa et al. 2004). Unfortunately, we have no reliable population and athletic comparison data regarding maximal isometric strength of the leg extensors and thickness of the vastus lateralis from men in Finland. Ultrasound has been reported to exhibit high precision for the assessment of appendicular skeletal muscle thickness, but considerable practice is needed to obtain reliable results (Lee et al. 2001). In the present study, several investigators performed the muscle thickness and strength measurements and a couple of people analyzed the dietary recordings.

***Strength training interventions (II-V)***

The major strengths of the present strength training interventions were: 1) a long-term carefully structured supervised strength training program, 2) individualized nutritional counseling by an authorized nutritionist and 3) repeated assessment of muscle mass, strength, dietary intake, hormones and metabolic health indicators. Our main outcome variables, muscle mass and strength, were measured using the best measurement techniques available: MRI and 1RM strength testing. Imaging techniques like CT and MRI are the most valid techniques for skeletal muscle mass assessment (Lee et al. 2001). Normal dynamic muscle action (e.g. walking) is best predicted by dynamic strength assessment of the task-specific muscles (Chandler et al. 1997). The same preparatory instructions, same time of day, same investigator, same measuring technique and same calibrated measuring equipment were always used to study changes in the outcome variables. The dietary recordings were analyzed by the same person (authorized nutritionist). The control period was performed before the actual experimental design to minimize the possible learning effects on outcome variables and to record the physiological reproducibility of the measurements. Strict inclusion and exclusion criteria guaranteed that a homogenous group of healthy, active, non-obese, well-motivated, community-dwelling older individuals were recruited to the study. Thus, the present data can be generalized to healthy, non-obese older men and women. The suitability of analysis of covariance (ANCOVA) to the present intervention studies is supported by a recent review concluding that in randomized studies, both analysis of variance (ANOVA) and ANCOVA are unbiased, with ANCOVA yielding greater statistical power. If treatment assignment is based on the baseline status (i.e. pretest results), only ANCOVA is unbiased (van Breukelen 2006). A homogenous group of older individuals were selected for the present studies. After the control period measurements the participants were randomly divided into two comparable groups based on their age, size (weight and height) and maximal leg extension strength.

The main weakness of the present interventions (II-IV) was the absence of a control group with no treatment/intervention. One can calculate that at least 10 people are needed to establish group differences in 1RM strength (expected changes of 25% and 5% with SD of 10%) and muscle CSA (expected changes of 5% and 0% with SD of 3%) between the strength training and control groups with 90% statistical power ($\alpha$=0.05, $\beta$=0.1). However, because only minor differences could be expected between the strength training & nutritional counseling group and the strength training only group, the statistical power for demonstrating group differences in the outcome variables was weak. Furthermore, the absence of a control group limits the reliability of the time effects of strength training. Seasonal variations in metabolic health indicators (Bunout et al. 2003, Ockene et al. 2004) and human behaviour (e.g. physical activity and dietary intake) (Reilly and Peiser 2006, Ma et al. 2006) are well documented, indicating the necessity of a control group to separate seasonal variation from true training effects. In the continued reduced training study (V) a separate control group was measured one year after the actual strength training study. The present participants cannot be considered as a representative sample of Finnish older adults due to the non-randomized sampling protocol and the strict inclusion and exclusion criteria used (i.e. convenience sample). Unfortunately, we have no reliable population data to be compared with our data in terms of average variability of maximal concentric strength of leg extensors and muscle CSA of QF (by MRI) to determine the extent to which the data of the present sample can be generalized (Sousa et al. 2004). Finally, the present nutritional data are limited by the dietary assessment methodology (i.e. food records). Although feed records are among the most commonly used dietary assessment tools, the process of keeping food record may alter food intake augmenting remarkable underreporting of real dietary intake (Buzzard 1998).

## 6.4 Practical implications and suggestions for future research

The present data showed that supervised strength training combined with recommended healthy diet can minimize age-related loss of muscle mass and strength, and improve the metabolic risk profile in older persons. In practice, the present thesis supports the usefulness of "senior gym action", indicating the need to arrange suitable exercise facilities and competent exercise guidance for older people in the municipalities. The municipalities are also encouraged to arrange competent dietary counseling for older people with a high risk of frailty due to nutritional problems and/or metabolic risk factors/diseases. Finally, education about a healthy lifestyle, i.e. a recommended exercise and dietary regimen, is needed to deliver for all older people.

Several questions remain unanswered regarding nutrition and strength training in older people. Future studies are needed to address the following:

1. How do older people with a long-term history of strength training differ from their sedentary peers in terms of physical function (e.g. strength, mobility and balance), metabolic risk factors, morbidity and disability?

2. What are the effects of combined strength training and dietary intervention on muscle strength, mobility and nutritional status in malnourished institutionalized older women with a high risk of frailty?

3. To what extent can strength training improve physical function (e.g. muscle strength and mobility) and metabolic health profiles in sarcopenic obese older women?

4. Can the inclusion of endurance training to a strength training regimen restore obesity related impairments in physical function (e.g. mobility) and metabolic risk factors better than diet-induced weight loss in obese older men?

# 7 PRIMARY FINDINGS AND CONCLUSIONS

The present thesis indicated that strength training can reduce the risk of frailty by increasing muscle mass and strength, and improving metabolic health in older adults. Furthermore, an officially recommended moderate fat diet with appropriate protein and energy intake resulted in an enhancement of strength training-induced muscle hypertrophy, and produced favorable changes in metabolic health indicators in older women.

The conclusions related to the specific hypotheses are:

1. Older men with a long-term history of strength training had greater muscle strength and lean body mass than the controls, but no group effect was recorded in muscle thickness. Body weight adjusted dietary intake did not differ between the strength trained and control men.

2. Dietary intervention based on appropriate energy and protein intake improved muscle hypertrophy in older women during strength training. However, dietary intake did not contribute to strength development during strength training.

3. A recommended moderate fat diet did not change serum anabolic hormone concentrations compared to a normal higher fat diet in older people during strength training.

4. Recommended dietary fat intake produced favorable changes in serum lipid and lipoprotein profiles in older women during strength training.

5. Continued reduced frequency of strength training preserved strength training-induced improvements in muscle strength and metabolic health indicators in older men.

# 8 YHTEENVETO

Euroopan alueella väestö ikääntyy nopeinta vauhtia Suomessa suurten ikäluokkien jäädessä eläkkeelle 2010- ja 2020 -luvuilla. Vaikka ikääntyvät ovat entistä terveempiä, kasvaa apua tarvitsevien vanhusten määrä eliniän pidentyessä. Vanhuksen hauraus-raihnausoireyhtymällä tarkoitetaan ikääntymiseen liittyvää fysiologisten säätelyjärjestelmien heikkenemistä, mikä on yhteydessä vanhuksen terveyden ja toimintakyvyn menetykseen. Oireyhtymään liittyviä piirteitä ovat mm. yleinen heikkous, painon lasku sekä tasapainon ja toimintakyvyn heikkeneminen. Riippumatta syistä, oireyhtymälle on ominaista lihasmassan vähentyminen ja lihasheikkous. Voimaharjoittelun on osoitettu ehkäisevän tehokkaasti ikääntymiseen liittyvää lihasmassan, voiman ja toimintakyvyn heikkenemistä. Ravinnonsaannin vaikutusta elimistön säätelyjärjestelmien toimintaan voimaharjoittelun yhteydessä ei kuitenkaan tunneta kovin hyvin ikääntyvillä.

Tämän väitöstutkimuksen tarkoituksena oli selvittää ravinnonsaannin yhteyttä voimaharjoittelun aikaansaamiin muutoksiin lihasmassassa, voimassa, seerumin hormonipitoisuuksissa ja aineenvaihdunnallisissa riskitekijöissä 50-70 -vuotiailla naisilla ja miehillä. Tutkimus koostui viidestä osatutkimuksesta. Poikkileikkaustutkimuksessa (tutkimus 1) yhdeksää keski-ikäistä (52±5 v.) ja kahdeksaa ikääntyvää (72±4 v.) voimaurheilijaa (yleisurheilun heittäjät) verrattiin vastaavan ikäisiin vertailumiehiin (n=11+10) jalkojen maksimaalisen isometrisen ojennusvoiman, ulomman reisilihaksen lihaspaksuuden, ravinnonsaannin ja kehonkoostumuksen osalta.

Tutkimuksissa 2-4 verrattiin toisiinsa ravitsemusohjausta (RO) saavia ja normaalisti ruokailevia (NR) naisia (RON: 59±7 v., n=25 & NRN: 58±7 v., n=26) ja miehiä (ROM: 59±6 v., n=22 & NRM: 59±7 v., n=23), jotka voimaharjoittelivat 21 viikkoa 2 x viikossa nousujohteisesti (harjoituspainot 40-80% maksimista). Ravitsemusohjausta annettiin tutkimuksen aikana kahdesti tavoitteena ohjata tutkittavia kiinnittämän huomiota riittävään energian ja proteiinin saantiin sekä suositeltuun rasvan ja kuidun saantiin. Mitattavat muuttujat olivat: ravinnonsaanti, reiden ojentajalihasten poikkipinta-ala, jalkojen maksimaalinen konsentrinen ojennusvoima, seerumin testosteroni, kasvuhormoni ja sukupuolihormoneja sitova globuliini (SHBG), lepoverenpaine sekä veren rasva-arvot ja verensokeri paastossa. Viidennessä tutkimuksessa edellä mainittua ryhmää voimaharjoittelevia miehiä (NRM) verrattiin vertailumiehiin (ei harjoittelua) (KM: 58±6 v., n=21) 21 viikon voimaharjoittelujakson ja jatketun 21 viikon vähennetyn voimaharjoittelun (3 harjoitusta /2 viikkoa) aikana. Vastemuuttujina olivat jalkojen maksimaalinen konsentrinen ojennusvoima ja aineenvaihdunnalliset riskitekijät (verenpaine, rasva-arvot ja verensokeri).

Poikkileikkaustutkimus osoitti, että jatkuvasti voimaharjoittelua harrastavilla miehillä lihasvoima säilyi vertailuhenkilöitä suurempana vielä vanhemmalla iälläkin. Myös voimaurheilijoiden kehon rasvaton massa oli vertailuhenkilöitä suurempi, mutta reiden lihaspaksuus ei eronnut ryhmien välillä. Kehonpainoon suhteutettu ravinnonsaanti ei eronnut ryhmien välillä.

Ravitsemusohjaus paransi ruokavalion rasvan laatua vähentämällä tyydyttyneen rasvan saantia sekä naisilla että miehillä. Lisäksi proteiinin saanti kasvoi naisilla ja hiilihydraattien ja kuidun saanti miehillä ravitsemusohjauksen seurauksena.

Ravitsemusohjaus lisäsi voimaharjoittelun aikaansaamaa reiden lihasmassan kasvua naisilla (RON: 10% ja NRN: 7%). Miehillä reiden lihasmassan kasvussa (5-6%) ei ollut eroa ryhmien välillä. Lihasvoiman kasvussa ei ollut ryhmäeroja naisilla (24-29%) eikä miehillä (16-20%) 21 viikon voimaharjoittelun jälkeen. Jatkettu 21 viikon vähentynyt voimaharjoittelu ylläpiti kasvaneen lihasvoimatason miehillä (NRM).

Seerumin vapaan testosteronin (testosteroni /SHBG -suhde) ja kasvuhormonin pitoisuudessa ei ollut eroja ryhmien välillä voimaharjoittelun jälkeen. Seerumin keskimääräinen testosteroni/SHBG –suhde korreloi positiivisesti keskimääräisen kehonpainoon suhteutetun kokonaisenergian, proteiinin ja rasvan saannin kanssa yhdistetyllä ryhmällä miehiä.

Molemmilla sukupuolilla lepoverenpaine laski lievästi ja paastoverensokeri säilyi muuttumattomana 21 viikon voimaharjoittelujakson aikana. Jatkettu 21 viikon vähentynyt voimaharjoittelu säilytti paastoverensokeritason ennallaan voimaharjoittelevilla miehillä (NRM) verrattuna paastoverensokerin nousuun kontrolliryhmässä (KM). Ravitsemusohjaus voimisti voimaharjoittelun aikaansaamaa laskua seerumin LDL –kolesterolipitoisuudessa ja seerumin kokonaiskolesteroli /HDL –kolesteroli -suhteessa naisilla. Voimaharjoittelu ei aiheuttanut muutoksia veren rasva-arvoihin miehillä (NRM).

Tutkimus osoitti, että molemmilla sukupuolilla voimaharjoittelulla voidaan tehokkaasti vähentää vanhuuden hauraus-raihnausoireyhtymän riskiä lisäämällä lihasmassaa ja voimaa sekä parantamalla aineenvaihdunnallista terveyttä. Ikääntyvillä naisilla ravitsemussuositusten mukainen riittävästi energiaa ja proteiinia sisältävä ruokavalio edesauttoi voimaharjoittelun aikaansaamaa lihasmassan kasvua ja positiivisia muutoksia veren rasva-arvoissa. Myönteinen tulos saatiin siitä huolimatta, että ravitsemusneuvontaa annettiin vain kahdesti koko tutkimusjakson aikana.

Käytännössä tutkimus antoi lisätietoa hauraus-raihnausoireyhtymää ehkäisevistä elämäntavoista puoltaen ohjatun kuntosaliharjoittelun soveltuvuutta ikääntyville. Tutkimuksen perusteella kuntia voidaan suositella helpottamaan ikääntyvien kuntosaliharjoittelua mm. järjestämällä ohjattua ”seniorikuntosaliharjoittelua”. Lisäksi tutkimus kannustaa kuntia järjestämään ravitsemusohjausta hauraus-raihnausoireyhtymän riskiryhmään kuuluville ikääntyville henkilöille. Väitöskirjan tuloksia voidaan siten hyödyntää valtakunnallisella tasolla ikääntyvän väestön terveyden ja fyysisen kunnon edistämisessä ja säilyttämisessä sekä kuntatasolla mm. liikuntapalvelujen järjestämistä ja vanhusten kuntoutusta suunniteltaessa.

Avainsanat: Ikääntyminen, ravitsemus, voimaharjoittelu, lihasmassa, lihasvoima, aineenvaihdunnalliset riskitekijät

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