The Relationship of Fat Mass to Lower Body Muscular Fitness Using Isokinetic Measures in Young and Middle-aged Women

by

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A Thesis Presented in Partial Fulfillment
of the Requirements for the Degree
Master of Science

Approved April 2011 by the
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ARIZONA STATE UNIVERSITY

May 2011

ABSTRACT

Larger people generally have more muscle mass and are stronger than smaller people. Muscular strength usually decreases with age, possibly as a function of increases in body fat percentage. However, the effect of age, body fat, and lean mass on peak muscular strength or muscular fatigue is not clear. This was an observational study to determine: a) the relationship of fat mass (FM) and fat free mass (FFM) to peak knee extensor strength and fatigue in young (Y) and middle-aged (MA) women, and b) to determine differences in peak torque between Y and MA women. Participants included 132 women from two age cohorts (Y: 18-33 yrs, n = 70 and MA: 45-65 yrs, n = 62). Data from the MA cohort were collected as part of a previous study and combined with data from the Y group. Both cohorts completed physical activity questionnaires and were measured for body fat using bioelectrical impedance analysis. Both cohorts used identical procedures and machinery to assess isokinetic knee extensor peak torque (PT) at 60°/sec and to determine fatigue index (FI). FI was calculated as the percent decline of PT during 50 maximal repetitions at 240°/sec. Data were assessed for normality, and appropriate Pearson or Spearman correlations were used to compare PT and FI with body composition variables. A one-way ANOVA was used to examine differences in PT and body composition indices between age groups. In Y, FFM and FM were strongly correlated with peak torque. The correlation of FM to PT disappeared when controlling for FFM. There were no significant correlations between FFM or FM and PT in MA. PT was negatively correlated with FI in the combined groups. PT normalized for body mass and

FFM were similar between age groups, but decreased with increasing size. In conclusion, PT was positively related to FFM in the combined age groups. Higher FM was not detrimental to absolute PT in Y or MA, but was detrimental to relative PT in both groups. These data suggest that perhaps FM may attenuate the normal relationship between PT and body mass.

ACKNOWLEDGMENTS

I would like to thank my committee for their help and support of this project. I would especially like to thank Dr. Swan for helping me plan the study, and for the hours of help with revisions and data analysis.

I would also like to thank the young women who participated in the study. Many of them took several hours out of their day and traveled quite a few miles to help me, and I am grateful.

Lastly, I would like to thank the Graduate and Professional Student Organization at ASU for funding for the study.

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Chapter 1

INTRODUCTION

The effect of strength-training on body composition in older individuals is well-known (Avila, Gutierres, Sheehy, Lofgren, & Delmonico, 2010; Goodpaster et al., 2008; Hanson et al., 2009; Carmeli, Reznick, Coleman, & Carmeli, 2000). However, the relationship between strength gains and fat and lean mass changes are not clear. Koster et al. (2010) examined the relationship between physical fitness and strength in older men and women. Very fit men and women had significantly greater knee extensor strength per kilogram of both body weight and lean mass than less-fit men and women did. While this relationship is important, it is not known whether the strength is a surrogate marker for fitness, or if it is more a marker for body composition (i.e., increased lean mass or reduced fat mass). For example, Hulens et al. (2001) found trunk and knee extension absolute strength to be greater in obese 20-65-year-old females compared to age-matched lean women. However, once the influence of fat-free mass (FFM) was removed, a strength advantage no longer existed, and in fact, relative strength was lower in the obese than in the lean women. It is unknown in this analysis if this was an effect of overall fitness level. It may raise the possibility that fat mass (FM) per se can be detrimental to strength.

Miller, Nickols-Richardson, Wootten, Ramp, & Herbert (2004) studied 18-25-year-old women to examine the relationship between bone mineral density (BMD) and isokinetic strength. They also measured body fat and FFM in order to correct for these variables. The only relationship that correlated positively with

strength was FFM. Other studies have identified varying correlations between body composition measures and leg strength in young women, depending on age, fitness level, and body composition of the subjects. Body fatness is positively correlated with strength in some women (Maciaszek, Osinski, & Szeklicki, 2001), while only lean mass is positively associated with strength in others (Lafortuna, Maffiuletti, Agosti, & Sartorio, 2005; Maciaszek et al., 2001).

Most of the literature on body composition and strength has focused on the effect of strength training and/or other types of physical activity on lean mass or muscle hypertrophy, rather than assessing the effect FM may have on strength (Lafortuna et al., 2005; Koster et al., 2010; Hunter, Thompson, & Adams, 2000) None have evaluated whether or not the FM to strength relationship changes with age.

Discerning the effect body composition has on strength over the course of a woman's lifetime may help determine appropriate exercise prescriptions at each stage of life. If fat is found to independently negatively impact strength and/or function, steps that include both exercise and nutrition can be taken to reduce it when appropriate. The primary objective of this cross-sectional comparison was to examine the relationship between body composition variables and isokinetic strength and endurance of the hamstrings and quadriceps in young (Y) and middle-aged (MA) women, and then to compare peak torque (PT) values and fatigue index (FI) values between the two groups. The specific aims of this study are:

Primary Aims:

1. What are the associations of body fat mass and fat free mass to peak torque and 30-repetition fatigue index of right and left knee extensors and flexors in women?
2. Are there differences in peak torque per kilogram of fat free mass between young and middle-aged women?

The primary research hypotheses are:

Hypotheses:

1. There will be a significant positive relationship between fat free mass and peak torque, and a significant inverse relationship between fat free mass and fatigue index.

   1a. There will be no significant relationship between fat mass and peak torque.

   1b. There will be a significant positive relationship between fat mass and fatigue index.
2. Peak torque per kilogram of fat free mass will be significantly higher in young women than in middle-aged women.

Definitions:

BMI: Body mass index (mass [kg]/height [m^2]

Normal: BMI of 18-24.9 kg/m^2

Obese: BMI $\geq$ 30 kg/m^2

Overweight: BMI of 25 to 29.9 kg/m^2

Lean body mass/Fat free mass: All components of the body except adipose tissue (e.g. bone, muscle)

Isokinetic strength: Strength measured using a machine that maintains constant movement speed no matter how much force is applied

Peak torque: The maximum torque produced during an extension/flexion

Fatigue index: The difference of initial peak torque minus final peak torque divided by initial peak torque

Initial peak torque: The average of the peak torque values for the first three repetitions of an endurance test

Final peak torque: The average of the peak torque values for the last three repetitions of an endurance test

Young women: 18-33 years old

Middle-aged women: 45-65 years old

Delimitations:

- Younger subjects are females from 18 to 33 years of age.
- Subjects have no musculoskeletal issues that may affect strength assessment.
- Subjects have not participated in a regular program of lower body bodybuilding/professional strength training within the past three months.

- Subjects cannot be in ACSM's high-risk category for cardiovascular disease.
- Subjects will be allowed to practice the specific tested movements.

Limitations:

- Data were compared to previously collected data on the older women.
- Body composition assessment was limited to the methods used in the previous study.
- Subjects completed self-reported physical activity questionnaires to assess their fitness levels.

Chapter 2

BACKGROUND LITERATURE

Much of the literature concerning changes in strength with gain of FFM or loss of FM focuses on elderly populations because sarcopenia becomes a serious risk as individuals age. However, by focusing solely on the elderly without investigating body composition to strength relationships in younger populations as well, it is difficult to determine when and why sarcopenia becomes a problem. It is also difficult to determine whether it is a change in body composition in older age that initiates the disorder, or whether a body composition that was not detrimental to strength in youth and middle age becomes sarcopenia in old age.

Strength differences among individuals depend on a number of variables. Because some of these variables, such as motivation, are not measureable, the relationship between strength and anthropometric measurements is not examined as often in observational studies as it is in intervention studies. It is more common to take baseline measurements and compare these to post-physical-activity-intervention data. This is considered more reliable because of the likelihood that unmeasurable factors will remain the same within an individual, whereas they can vary greatly among subjects. However, utilizing a physical activity intervention makes it more difficult to isolate the effects that FFM and FM have on strength, independent of activity.

A review of the literature addressing these independent correlations will first be examined according to age groups (young, middle aged, and older), followed by a review of research that employed a physical activity intervention.

Relationship of fat mass and fat-free mass to strength in young, middle-aged, and older women

In women under the age of 30, FFM seems to exert the most influence on overall strength, regardless of fat amounts. Miller et al. (2004) and Ribom et al. (2004) primarily examined the relationship between strength and BMD in men and women between ages 18 and 26. Along with BMD, they also measured fat, lean body mass (LBM), and body mass index (BMI) of their subjects. Every subject had a BMI less than 25. In addition to finding knee flexion and extension to be positively correlated with total body BMD in women, Ribom et al. (2004) also found LBM to be an independent predictor of bone mineral content. This then would indicate a positive correlation between LBM and knee extensor and flexor strength. Similarly, Miller et al. (2004) discovered concentric thigh strength to be positively correlated with total body and total proximal femur BMD, and eccentric thigh strength to be positively correlated with femoral neck and greater trochanter BMD. However, once FFM was corrected for, any associations between BMD and strength disappeared. Both of these studies support the idea that FFM amounts in young women not only predict leg strength, but BMD as well.

However, both investigations used subjects with low BMIs. Lafortuna et al. (2005) on the other hand, examined the relationship of strength and power to body composition in young (mean age of 29) morbidly obese individuals, or those with a BMI over 40. Their female obese subjects had an average body fat percentage of 51.6%, compared with 24.8% in the female controls. Lower-body

muscle strength was determined by performing a 1 repetition maximum (1RM) on the leg press, and a 1RM chest press. Lower body absolute strength of the obese women was significantly greater than that of the controls. Upper body strength, though, was not significantly different between the two groups. When total strength measures were corrected for FFM, strength became equal between groups, suggesting that strength is proportional only to the amount of FFM a young woman has, regardless of fat amounts.

This finding concerning general strength measures was further supported by Boyce, Jones, Schendt, Lloyd, and Boone (2009) in their examination of changes in police officer strength over a twelve and a half year period. Female officers in the Charlotte-Mecklenburg Police Department were tested at initial recruitment when their average age was 24. Body fat and weight measurements were taken, and 1RM bench press was assessed. Although women had a five percent body fat increase over the course of the 12.5 years, their 1RM bench press also increased significantly. Relative strength only increased when normalized for lean weight; strength per kilogram of overall body weight remained the same.

Not only does this investigation support lean mass as the determining factor for strength, it also supports the idea that, in women under 40, strength does not necessarily decrease with age. Although it seems that a population of female police officers would not represent the average female, the job of an officer is generally sedentary with some periods of maximal exertion. Boyce et al. (2009) did not provide information about the daily physical activity of the officers.

Therefore, it is impossible to know whether the officers maintained strength because of training, or in spite of not training.

Similar findings have been reported in middle-aged women. Sipilä et al. (2004) investigated correlations between body composition and knee extensor strength in early postmenopausal women aged 50 to 57. The correlation between LBM and knee extensor strength almost reached significance, whereas the relationship between FM and knee extensor strength did not approach significance. Rolland, Perry, Patrick, Banks, and Morley (2007) did not simply investigate one-time relationships, but examined how, during a 36-month period, a number of variables influenced the loss of appendicular muscle mass (AMM) and muscle strength (MS) of the knee extensors in young postmenopausal women. Their results indicated that no significant relationship existed between the amount of FM and loss of MS or loss of AMM.

The relationships between strength, fat mass, lean mass, and functional ability become an important consideration as women age. In older women strength is not a superfluous measure, but one that could make a life and death difference. Zoico et al. (2004) investigated the FFM, FM, strength, functional ability relationships in healthy women between 67 and 78. Relative muscle mass, measured as total body skeletal mass divided by height squared, was significantly associated with isometric leg strength. Women in the four higher quintiles of relative muscle mass had significantly higher isometric leg muscular strength than did women in the lowest quintile. No significant correlation existed among fat percentage quintiles and leg strength. On the other hand, functional limitations

were significantly more prevalent in women in the highest quintile of body fat percentage than in those in the lowest quintile, regardless of FFM.

But not all research has found FFM to be the determining factor in strength. Hulens et al. (2001) examined the difference in isokinetic knee extension and flexion strength between lean (BMI < 26 kg/m^2) and obese (BMI > 30 kg/m^2) 40-year-old women. Their findings on absolute strength of the extensors agreed with the previously reviewed studies. Knee extensor strength was significantly higher in the obese group than it was in the lean group. This was not the case, however, for the knee flexors, which were comparable in strength between the two groups. Additionally, when strength was corrected for FFM, extensors were slightly but significantly weaker in the obese subjects, and flexors were up to 20% weaker.

Maffiuletti et al. (2007) addressed the issue of muscle fatigue in obese versus lean subjects, although they studied men. As was the case in most of the previously mentioned studies, peak torque on an isokinetic dynamometer was equal between groups when normalized for FFM. Unlike most studies though, they included a measure of fatigue by having the subjects perform 50 knee extensions at 180°/sec as fast as possible. Obese subjects had a significantly greater amount of muscle fatigue than lean subjects did.

As mentioned previously, studies like those addressed above, which explore direct correlations between body composition and strength, are rare compared to research investigating the effects of exercise and/or diet on body

composition and strength. The relationship of physical activity to strength and body composition will be discussed here.

Effects of physical activity

Kozakai et al. (2005) investigated the correlation of strength with recent leisure time activity and with exercise during adolescence. They hypothesized that not only would recent leisure activity predict greater strength in 40 to 79-year-old women, but that a greater amount of exercise during the adolescent years would also correlate positively with leg strength later in life. Their results supported their hypothesis. However, since they did not match body composition measures with activity levels it is unknown whether the higher measures of strength also correlated with FFM as was the case with most of the studies previously mentioned.

Hunter et al. (2000) did address the issue of body weight and lean mass along with physical activity levels and age. The relationships they found were similar to those of Kozakai et al. (2005) in that the most active women had greater knee extensor strength than the most inactive did. They also found that the more active women had greater FFM, lower body fat percentage, and greater cross-sectional area of the midthigh. Additionally, when absolute strength was normalized for body weight and FFM, active women were still stronger than inactive. Age was negatively correlated with all strength, physical activity, and body composition variables except percent fat with which it was positively correlated.

Koster et al. (2010) had almost identical findings in a longitudinal study of older subjects (70-79-yr-olds). Over the seven-year study period, weight, fat mass, and lean mass were highest in the least fit quintile and decreased with increasing fitness quintiles. Knee extensor strength normalized for body mass and FFM was exactly the opposite, increasing as fitness quintiles increased. There was no difference, however, in the rate of decline among all variables and all four quintiles as subjects aged. Thus, greater fitness predicted higher levels of body mass and strength at every time point from age 70 to 86, but these body mass and strength variables were nevertheless still lost with age at the same rate regardless of fitness level.

Lebrun, Schouw, de Jong, Grobbee, and Lamberts (2006) took these same correlations a step further in an attempt to identify more precisely the role of fat in strength measures. Their results differed from others in that FM was positively correlated with leg extensor strength, and higher lean mass was not significantly associated with physical activity. However, once the former relationship was adjusted for lean mass, and the latter adjusted for FM, these relationships reversed. Fat mass was no longer positively correlated with leg strength, and greater lean mass was correlated with higher levels of physical activity.

The researchers used a functional ability measurement to investigate the role body composition and muscle strength played in determining disability in their subjects (healthy postmenopausal women under 75). Their results led them to hypothesize that in older healthy women, although higher amounts of fat may not directly result in decreased strength, fat seems to be the determining factor in

disability. As women age, sarcopenia, which results from decreasing lean mass, becomes the determining factor.

In correlational studies such as these it is impossible to ascertain cause and effect. Are older women weaker because their physical activity levels decrease, or does their physical activity decrease because they become weaker? Does physical activity result in greater strength regardless of age, or are stronger women more physically active because it is easier and more enjoyable for them? Does age cause FFM to decrease and fat percentage to increase, or is this a result of decreased physical activity with age?

The findings of Tarpenning, Hawkins, Marcell, and Wiswell (2006) suggested that the cause-and-effect relationship may depend on what the specific physical activity is. They explored the relationship of body composition to leg strength between runners and sedentary women between 43 and 69 years old. After dividing subjects into age groups (40s, 50s, and 60s) they found that absolute isokinetic knee-extensor torque decreased as age groups increased, but torque within age groups did not differ between runners and non-runners. Furthermore, when strength was normalized for FFM sedentary women were significantly stronger than runners, but strength between age groups did not differ. In contrast, strength normalized for body weight was equal between runners and sedentary groups, and decreased significantly with age.

Although the decrease in strength with age regardless of activity was in agreement with most of the literature, the finding that strength normalized for FFM was actually lower in the runners was in opposition to that of Hunter et al.

(2000) and Koster et al. (2010). It was also a different result than has been found in men. Tarpenning, Hamilton-Wessler, Wiswell, and Hawkins (2004) reported that in male endurance runners from 40 to 88 years old, strength normalized for FFM was maintained at the same level until they reached their 70s, at which time it declined.

An abundance of intervention studies have been performed to examine the effects of strength training on body composition and strength. Neural adaptations to training make the reverse association (the effect of body composition on strength) questionable in this type of intervention, as there is often an increase in strength without a concomitant increase in muscle mass (Sale, 1988). Nevertheless, three studies with varying results will be addressed here.

Schmitz, Jensen, Kugler, Jeffery, and Leon (2003) examined strength and body composition changes in response to a strength-training program in women between the ages of 30 and 50. After 39 weeks of a 2-days-per-week upper and lower body training program, FFM, 1RM bench press values, and leg press values in the treatment group increased significantly more than these variables did in the control group who performed regular daily activities. Fat mass change during this same time period however, was not significantly different between the two groups. This is in agreement with the previously mentioned findings in younger women that FFM influences strength, but FM does not.

In contrast, Wang, Miller, Messier, and Nicklas (2007) found that weight loss as a result of a strength training and diet intervention resulted in loss of both lean and fat mass in women over 60. Absolute concentric knee extensor strength,

and concentric knee extensor strength normalized for body weight and FFM increased significantly in the intervention group, whereas the control group experienced no change in strength. Thus, strength increased in spite of a decrease in FFM. It should be noted, however, that fat mass also decreased in the weight loss/strength gain group.

Sillanpää et al. (2009) included endurance training in their study to add another physical activity variable. They divided 39 to 64-year-old women into three different 21-week training programs and a control group to ascertain the physiological effects of each program. The training groups included strength training, endurance training, and combined strength and endurance training. At the end of the training, overall body fat percentage decreased significantly in the endurance group and in the strength plus endurance group. Total LBM increased significantly in these same two groups. However, 1RM bilateral leg press values increased significantly more in the strength and strength plus endurance groups than they did in the endurance group, indicating that simply increasing LBM did not necessarily translate into greater strength.

Muscle quality

Although FFM has been shown to be highly positively correlated with strength (Miller et al., 2004, Ribom et al., 2004, Lafortuna et al., 2005, Boyce et al., 2009, Zoico et al., 2004, Maffiuletti, 2007, Schmitz et al. 2003), studies in women over the age of 50 show that age more consistently predicts lower strength measures, regardless of body composition or physical activity level (Hunter et al., 2000, Koster et al., 2010, Tarpenning et al., 2006). Additionally, fat mass is

sometimes correlated negatively with strength in women (Hulens et al., 2001). Therefore, while decreased lean mass somewhat predicts the loss of strength that often leads to sarcopenia in older individuals, it appears that other physiological factors also contribute to this age-related loss of strength.

The Health, Aging and Body Composition (Health ABC) Study addressed this issue in a five-year longitudinal observational study of 3075 subjects between 70 and 79 years of age at baseline. From axial midthigh computed tomography (CT) scans, a measure of muscle density called the skeletal muscle attenuation coefficient was determined. Lower values equate to lower muscle density because of higher lipid content in the muscle (Goodpaster et al., 2001). Skeletal muscle and intermuscular and subcutaneous adipose tissue areas were determined as well. Additionally, isokinetic strength of the knee extensors and flexors at 60°/sec was assessed on a dynamometer.

Baseline results of the study indicated that both strength and muscle attenuation values decreased with increasing age. As BMI, total fat mass, and percent fat mass increased, muscle attenuation decreased (indicating lower muscle density and higher muscle lipid content). Furthermore, muscle CSA was negatively correlated with age, and positively correlated with BMI, fat, and strength (Goodpaster et al., 2001).

After both three years and five years of follow-up, strength had decreased two to five times more on average in the cohort than had CSA (Goodpaster et al., 2006; Delmonico et al., 2009). This decline in strength was not prevented by maintenance or gain in lean mass, but was accompanied by an increase in muscle

fat infiltration. Moreover, the increase in intermuscular fat (IMF) occurred even in the absence of a change in body mass or subcutaneous fat.

In a separate one-year randomized controlled trial, Goodpaster et al. (2008) explored what effects physical activity may have on skeletal fat infiltration and strength. The non-exercising control group gained 18% intermuscular adipose tissue (IMAT) over the course of one year, while the exercising group gained almost none. Neither group gained subcutaneous fat. In addition, the control group lost significantly more specific torque (peak torque per unit area of quadriceps muscle) than the exercise group did.

It appears, therefore, that while muscle size (CSA) contributes to muscular strength, and that loss of CSA results in strength losses in older individuals, IMF may be a better predictor of the loss of strength that accompanies aging. This strength loss and IMF gain can be somewhat ameliorated, however, with exercise. It is unknown whether IMF is the cause of strength loss, because increased IMF was also associated with increases in the proinflammatory cytokines interleukin-6 (IL-6) and tumor necrosis factor-α (TNF-α) in this same cohort (Visser et al., 2002). Furthermore, these inflammatory markers were negatively correlated with appendicular muscle mass, muscle area, and knee extensor strength. Cytokines have been associated with muscle wasting in rats in other experimental studies (Goodman, 1991; Goodman, 1994), and have also been negatively correlated with lean mass in patients with higher levels of proinflammatory markers as a result of disease (Schols et al., 1996; Anker et al., 1999).

Therefore, although one explanation of the loss of strength that occurs with aging may be the greater amount of fat infiltration into skeletal muscle that occurs with age regardless of physical activity, the cause-and-effect relationship is still unclear. Both IMF and inflammatory markers were associated with a loss of strength in the subjects in the Health ABC study. It is possible that IL-6 and TNF-α caused the loss of lean mass and strength, and IMF was harmless.

Frontera et al. (2000) also investigated the role of individual skeletal muscle fibers isolated from neural influences in age-related strength reduction. Their major findings were: 1) Type I and IIa fibers from older subjects generated less force than those from younger subjects did. 2) Older men exerted more maximal force than did older women, independent of fiber size. The researchers hypothesized that this gender difference may be attributable to the reduction in estrogen that occurs at menopause. Some research supports estrogen's influence on the number, force, or sensitivity to force-reducing metabolites of cross bridges (Phillips, Rook, Siddle, Bruce, & Woledge, 1993; Wattanapermpool & Reiser, 1999).

In conclusion, the most likely explanation for the decrease in strength that occurs even in physically active women as they age is a combination of interacting factors. Although these factors cannot be completely eliminated, physical activity can slow the process of strength deterioration. If women begin participating in physical activity when they are young when FM does not seem to be detrimental to either strength or functional ability, there is a better chance they will maintain a physically active lifestyle and experience less strength loss as they

age. Moreover, in spite of the strength disadvantages women begin to experience at menopause, FFM continues to exert influence on strength, just as it does in youth. Further research should be conducted to better understand the mechanisms involved in loss of strength experienced by older individuals.

Chapter 3

METHODS

Subjects

Two cohorts of subjects were utilized in this study, most of whom were recruited from the greater Phoenix metropolitan area. Data on the first cohort of 73 women aged 45-65 was previously collected in the Evaluation of Physical Activity Measures in Middle-Aged Women (PAW) study (Pettee Gabriel et al., 2009). The second cohort was a comparable group of younger women between 18 and 33 years old.

Subjects for both cohorts were excluded if they had any musculoskeletal problems, or if they were in the American College of Sports Medicine's high-risk category for cardiovascular disease. Exclusion criteria also included participation in lower body bodybuilding within the previous three months. Protocols were approved by the institutional review board at Arizona State University.

Design

This is a cross-sectional comparison of isokinetic leg strength and body composition between two groups of women. A previously collected data set of middle-aged (MA) women aged 45-65 was analyzed and compared to a group of younger (Y) (age 18-33) women. While fitness and physical activity data were previously analyzed and described, data on strength and body composition has not been previously evaluated in this cohort (Pettee Gabriel et al., 2009, Pettee Gabriel et al., 2010, Mitros et al., 2011). Associations between peak torque, muscular fatigue and indices of body composition (such as fat mass, fat

percentage, lean mass) were evaluated within and between groups. Differences in peak torque/lean mass were compared between groups.

Procedures

Procedures and equipment used are identical for both cohorts unless specifically described. Subjects completed a health history form (appendix A). They also completed the Women's Health Initiative (WHI) Physical Activity Questionnaire (PAQ) (appendix B). However, only women in the Y cohort completed the International Physical Activity Questionnaire (IPAQ) (appendix C). The WHI PAQ was initially developed for middle-aged women (Petee Gabriel et al., 2009). It was found to have high test-retest reliability (0.91; $P < 0.0001$) and to correlate strongly with estimated VO_{2max} (0.46; $P < 0.001$) in middle-aged women (Petee Gabriel et al., 2009). The IPAQ was developed to be a globally standardized measurement of physical activity in adults aged 18-65 years (Craig et al., 2003). It was found to have correlation coefficients with all physical activity of 0.66 and 0.88 in two different areas of the United States (Craig et al., 2003).

Anthropometric measures

Height was measured using a wall-mounted stadiometer. Body weight and composition (i.e., percent body fatness, fat-free mass and fat mass) were obtained using bioelectrical impedance (Tanita Body Composition Analyzer, TBF-300A Tanita, Arlington Heights, IL).

Muscular fitness

Muscular strength and endurance of the quadriceps and hamstrings were measured bilaterally using an isokinetic dynamometer (HUMAC NORM; Computer Sports Medicine, Inc., Stoughton, MA). Positioning of the subjects was standardized according to the instructions (Computer Sports Medicine, Inc, 2006) (appendix D). All torques were corrected for gravity using the Humac software. Strength was expressed as peak torque in foot-pounds (ft-lbs). Peak torque is the highest torque value from all the points in the range of motion.

After positioning the subject, two practice trials were performed at 240°/sec for familiarization with the movement. Maximal trials were then performed at 60°/sec, 180°/sec, and 240°/sec. Two sets of two repetitions were performed at each angular velocity. Thirty seconds of rest was given between each repetition. The order in which angular velocities was tested was randomized among subjects. Right legs were tested first 50% of the time. Subjects were verbally encouraged to exert as much force as possible on each repetition.

Subjects then performed 50 maximal repetitions at 240°/sec as fast as possible to measure muscular endurance. Verbal encouragement to continue as hard as possible was given throughout the 50 repetitions. Muscular endurance was quantified using a fatigue index score. The fatigue index is the percentage that peak torque declined during the endurance test. It is computed as the percent change from initial peak torque to final peak torque ($(IPT - FPT)/IPT$). Initial and final peak torques are the averages of the peak torque values for the first three

and last three repetitions of an endurance test, respectively. Muscular endurance is inversely related to the fatigue index score.

Statistical analysis

Pearson product-moment or Spearman rank-ordered correlations were used to examine the associations of whole body fat mass and fat free mass to peak torque and fatigue index of the knee flexors and extensors. Partial Pearson or Spearman correlations were also used to examine these associations after adjustment for physical activity or to investigate the association between fat mass and peak torque after adjustment for fat free mass. Self-reported physical activity level was used as a covariate. A one-way ANOVA, independent t-test, or Mann-Whitney U test was used to test mean differences for age, height, weight, BMI, percent fat, and WHI across Y and MA women. General linear models were used to test mean differences for peak torque and body composition indices (fat mass and fat free mass) between these groups with or without adjustment for a covariate (i.e., physical activity). All P-values were two-sided, and values <0.05 were considered to indicate statistical significance. In addition, subjects were stratified according to BMI category (underweight, normal, overweight, or obese), as well as self-reported activity level (low, normal, or high) to determine differences in peak torque by BMI or activity using separate one-way ANOVAs. All statistical analyses were performed using PASW 18.0 (SPSS Inc., Chicago, IL).

Chapter 4

RESULTS

Eleven subjects from the MA cohort were excluded because of missing data. This included missing all data ($n = 4$), peak torque ($n = 2$), percent fat ($n = 1$), right leg peak torque at 60° ($n = 1$), and peak torque and percent fat ($n = 2$). One subject was excluded for a peak torque value much higher than two standard deviations from the mean ($n = 1$). And additional three members of the MA cohort were missing physical activity questionnaire (PAQ) data, but they were still included in data analysis. Thus a total of 62 MA subjects were used in subsequent analyses.

In the Y cohort one participant was disqualified because she was too small for the equipment. Physical activity questionnaire data from two participants was excluded because they reported that they were performing extremely high (> 2 SD above the mean) amounts of physical activity. Fatigue index data on one subject was excluded because it was a negative value. Thus a total of 70 Y subjects were used in the final analyses.

All variables were examined for normality. Table 1 provides the results from the Kolmogorov Smirnov test for normality. Non-parametric tests were used on any variables that were not normally distributed.

TABLE 1. Tests of normality

	Y (n=70)	MA (n=62)	C (n=132)
Age (yrs)	.000	.009	.000
Height (cm)	.200*	.200*	.200*
Weight (kg)	.008	.053*	.007
BMI (kg/m^2)	.002	.017	.001
% Fat	.200*	.200*	.200*
FFM (kg)	.200*	.200*	.200*
FM (kg)	.000	.196*	.000
WHI ($MET \cdot hr \cdot wk^{-1}$)	.200*	.057*	.179*
PTE60R (ft-lbs)	.200*	.200*	.029
FIER (%)	.010	.014	.011

*Normally distributed
Y: young; MA: middle-aged; C: combined groups

A paired samples t-test showed no significant difference in values ($MET \cdot hr \cdot wk^{-1}$) between the two physical activity questionnaires evaluated in the Y cohort: WHI ($M = 31.4$, $SD = 14.2$) and IPAQ ($M = 44.1$, $SD = 17.1$). In order to standardize physical activity assessment among subjects in both cohorts only the WHI scores were used to estimate physical activity.

Participant characteristics of younger women, middle-aged women, and both groups combined are shown in Table 2. Mean age of Y was about 24 years, and mean age of the MA cohort was about 53 years. Body fat percentage between groups was significantly higher in MA, but neither FM nor FFM amounts differed.

TABLE 2. Subject characteristics for the young (Y), middle aged (MA), and combined (C) groups

	Y (n=70)	MA (n=62)	C (n=132)
Age (yrs)	24.2 ± 4.0	52.6 ± 5.5*	37.5 ± 15.0
Height (cm)	166.3 ± 6.4	163.4 ±6.7*	164.9 ± 6.6
Weight (kg)	68.1 ± 18.6	70.6 ± 13.0	69.2 ± 16.2
BMI (kg/m^2)	24.6 ± 6.3	26.6 ± 5.1*	25.5 ± 5.8
% Body fat	29.9 ± 10.4	34.9 ± 7.8*	32.2 ± 9.5
Fat-mass (kg)	22.2 ± 13.8	25.5 ± 10.0§	23.7 ± 12.2
Fat-free mass (kg)	45.9 ± 5.2	45.1 ± 3.9	45.5 ± 4.7

*$p < 0.05$
§Mann-Whitney ($p = 0.011$)

Strength and endurance measurements by group are shown in Table 3. Peak torque of flexors differed between groups at all angular velocities on both right and left legs. Peak torque of the extensors differed at 180° and 240° on both right and left legs. Peak torque of the extensors at 60° did not differ on either the right or left leg between groups. Peak torque at 60° (PTE60R) had the highest overall absolute value for both groups. Thus mean values of peak torque (PT) on the right extensors at 60° were used for all subsequent statistical analysis. Change in torque over 50 repetitions using the right extensors at 240° was used for determining fatigue index (FI).

TABLE 3. Strength and endurance measures in young (Y), middle aged (MA), and combined (C) groups

	Y (n=70)	MA (n=62)	C (n=132)
PTE60R	72.4 ± 10.2	73.5 ± 19.3	72.9 ± 15.1
PTF60R	48.9 ± 11.4	42.2 ± 12.0*	45.8 ± 12.1
PTE60L	71.3 ± 10.0	73.6 ± 16.3	72.4 ± 13.3
PTF60L	48.1 ± 10.2	43.3 ±10.6*	45.9 ± 10.6
PTE180R	62.4 ± 11.6	46.5 ± 11.8*	55.0 ± 14.1
PTF180R	37.0 ± 9.5	28.8 ± 10.5*	33.2 ± 10.7
PTE180L	61.9 ± 11.7	45.0 ± 11.6*	54.0 ± 14.3
PTF180L	35.9 ± 9.1	29.1 ± 9.3*	32.7 ± 9.8
PTE240R	55.9 ± 13.5	38.3 ± 11.4*	47.6 ± 15.3
PTF240R	33.1 ± 9.0	26.2 ± 9.5*	29.8 ± 9.8
PTE240L	56.0 ± 12.8	37.8 ± 10.5*	47.5 ± 14.9
PTF240L	33.3 ± 8.1	26.4 ± 8.3*	30.1 ± 8.9
FIER	54.1 ± 14.6	50.2 ± 12.7§	52.3 ± 13.9
FIFR	44.2 ± 17.2	43.1 ± 12.0	43.7 ± 14.9
FIEL	55.0 ± 12.7	47.5 ± 20.1*	51.5 ± 16.9
FIFL	47.5 ± 13.5	40.8 ± 26.3	44.4 ± 20.5

*$p < 0.05$
§Mann-Whitney ($p = 0.037$)
PTE: peak torque extensors; PTF: peak torque flexors; FIE: fatigue index extensors; FIF: fatigue index flexors; 60: 60°/sec; 180: 180°/sec; 240: 240 °/sec; R: right; L: left

The relationships between descriptive characteristics (age, anthropometric measurements, body composition, and physical activity) and PT and FI were investigated using Pearson or Spearman correlations (Table 4). In the combined groups, PT was moderately positively correlated with height, weight, percent fat, FFM, and FM (Table 5; Figures 1 & 2). There was a moderate negative correlation between age and FI in all groups. (Tables 4 & 5). There was a

moderate positive correlation between height and PT (Table 4). In Y, all body composition variables were strongly positively correlated with PT (Table 4). However, the correlation was no longer significant between FM and PT in the combined or Y groups when the relationship was corrected for FFM using a partial correlation. Figures 3 and 4 show the correlations of FFM and FM to PT according to age groups.

TABLE 4. Correlations of peak torque (PTE60R) and fatigue index (FIER) with subject characteristics in young and middle-aged subjects

	Young (n=70)				Middle aged (n=62)			
	PT		FI*		PT		FI*	
	r	*p*	*r*	*p*	*r*	*p*	*r*	*p*
Age (yrs)	-.169	.163*	-.330	.006	-.215	.093*	-.315	.013
Ht (cm)	.487	.000	-.072	.558	.415	.001	.062	.637
Wt (kg)	.662	.000*	.119	.329	.049	.704	.049	.709
BMI ($kg/m^{2)}$	.553	.000*	.176	.147	-.041	.753*	.061	.641
% Fat	.566	.000	.188	.121	-.020	.879	-.005	.967
FFM (kg)	.632	.000	.053	.665	.167	.193	.220	.085
FM (kg)	.628	.000*	.154	.206	-.001	.991	.049	.706
WHI (MET•hr •wk^{-1})	.034	.786	-.038	.758	.119	.371	.156	.238
PT (ft-lbs)			.209	.085			.212	.101

*Spearman correlations

TABLE 5. Correlations of peak torque (PTE60R) and fatigue index (FIER) with subject characteristics

	Combined groups* (n=132)			
	PT		FI	
	r	*p*	*r*	*p*
Age (yrs)	-.022	.801	-.315	.000
Ht (cm)	.449	.000	.032	.719
Wt (kg)	.397	.000	.078	.380
BMI (kg/m^2)	.271	.002	.073	.412
%Fat	.302	.000	.079	.374
FFM (kg)	.433	.000	.033	.708
FM (kg)	.344	.000	.076	.391
WHI ($MET \cdot hr \cdot wk^{-1}$)	-.006	.944	-.120	.184
PT (ft-lbs)			.180	.040

*Spearman correlations

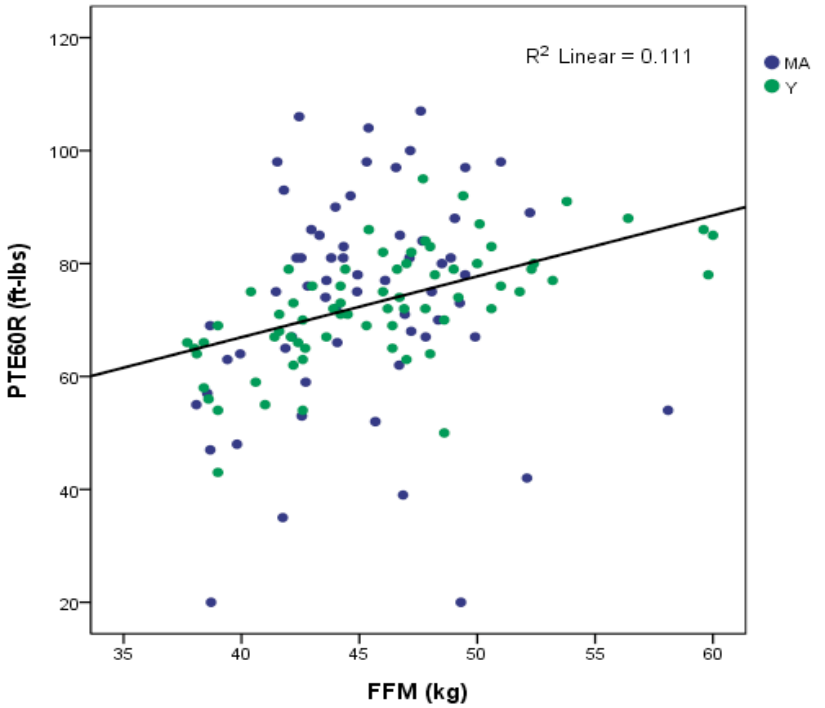


FIGURE 1. Relationship of fat free mass (FFM) to peak torque (PTE60R) in young (Y) and middle-aged (MA) women combined

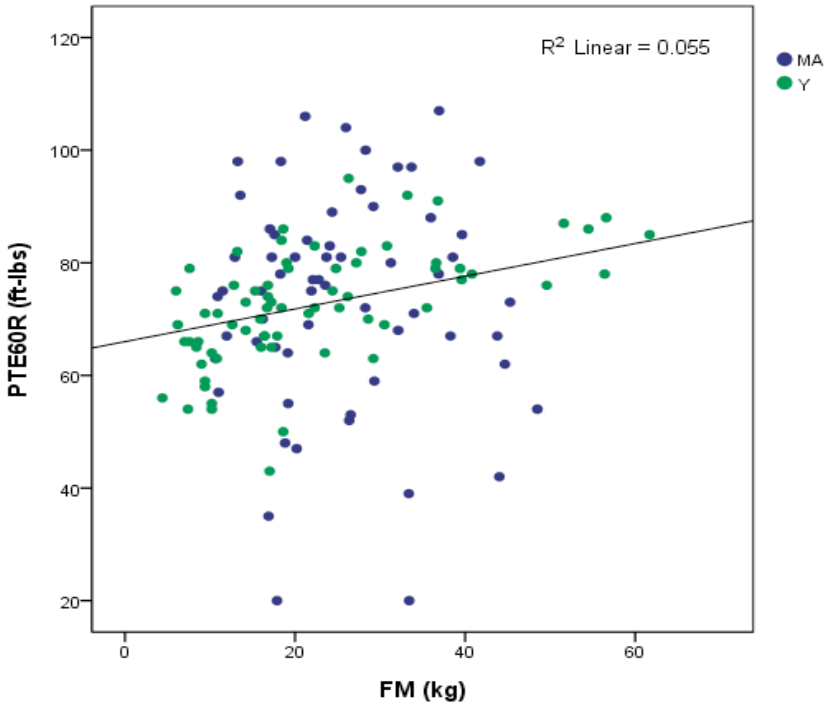


FIGURE 2. Relationship of fat mass (FM) to peak torque (PTE60R) in young (Y) and middle-aged (MA) women combined

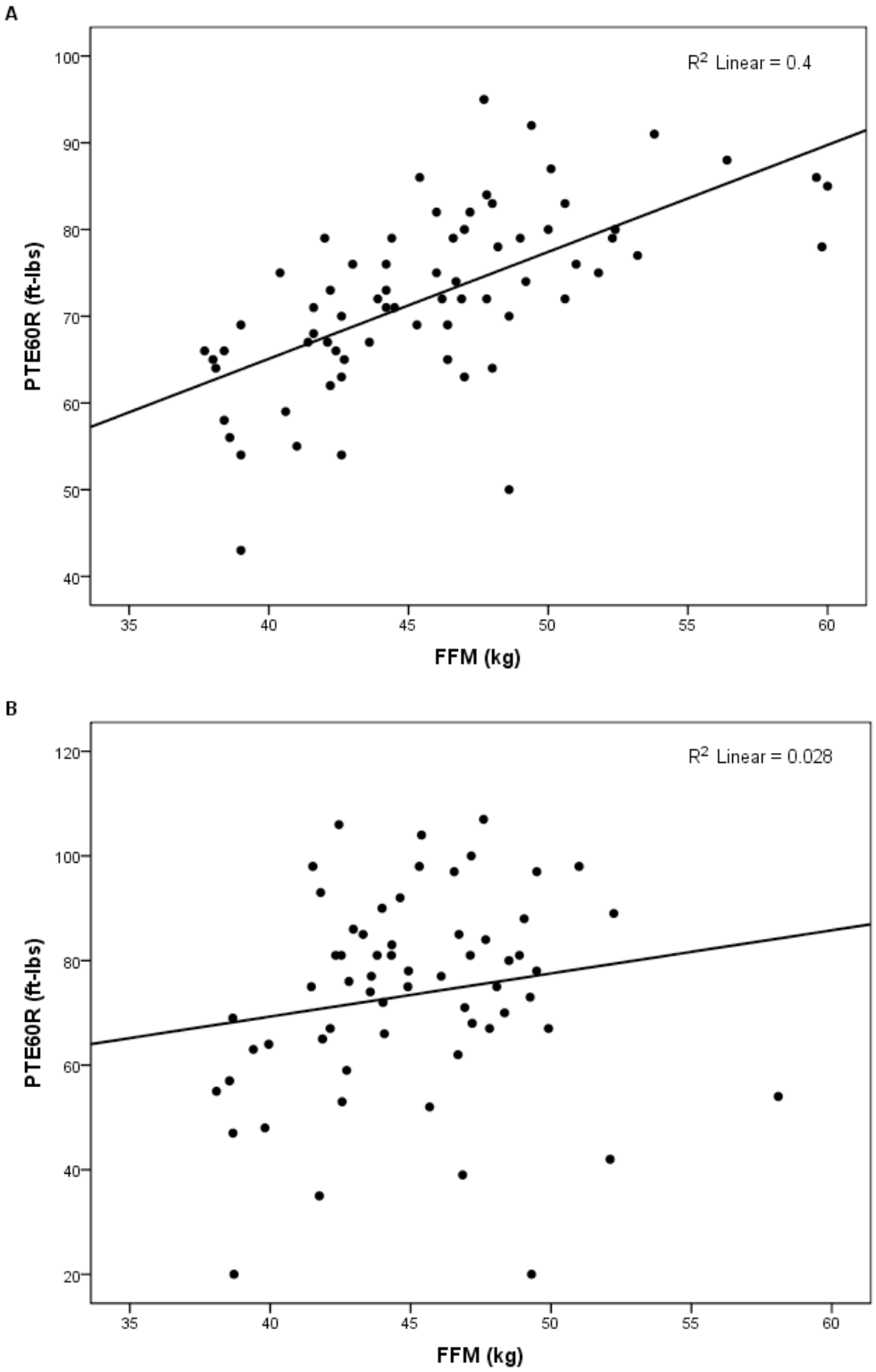


FIGURE 3. Relationship of fat free mass (FFM) to peak torque (PTE60R) in young (A) and middle-aged (B) women separated by group

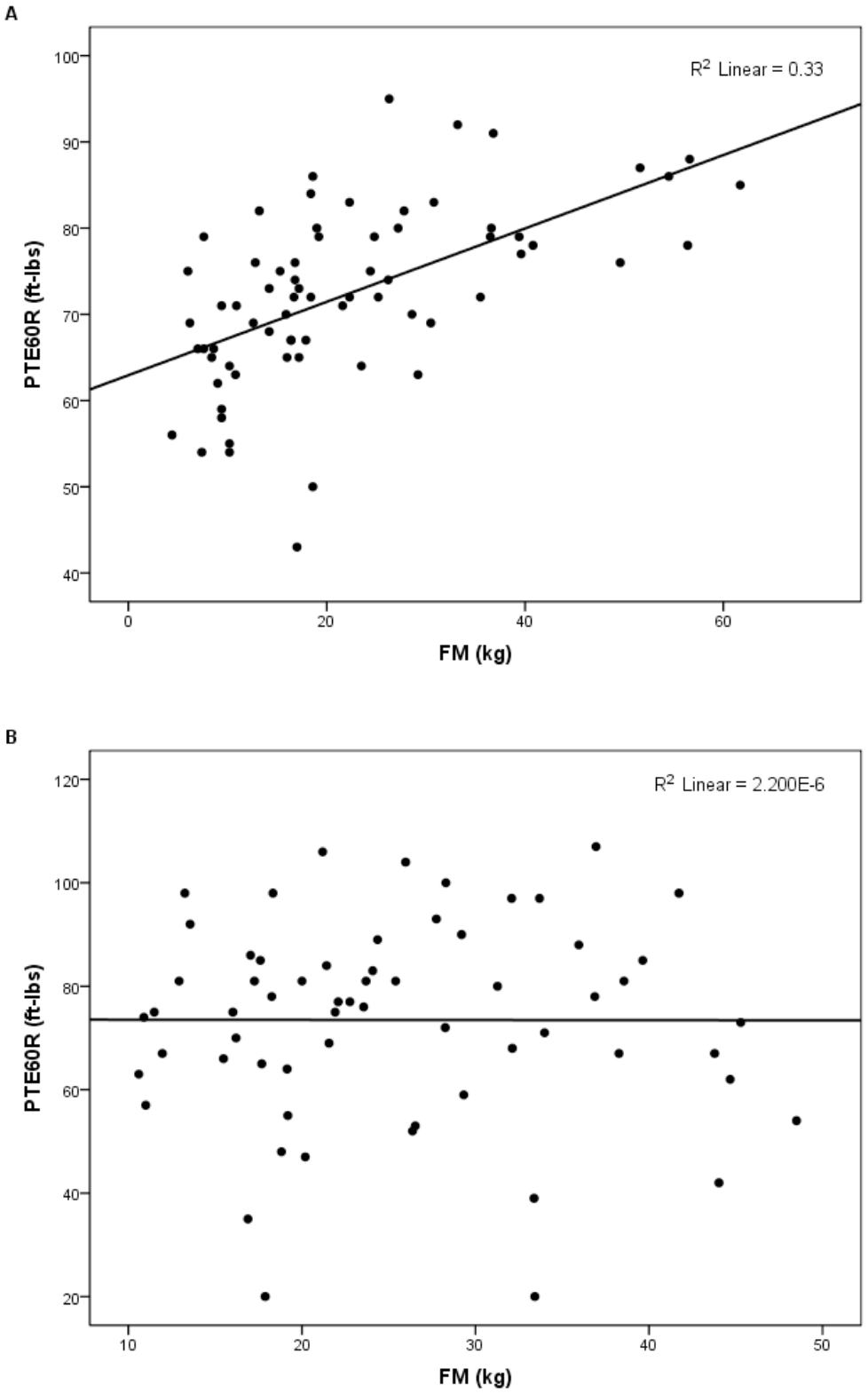


FIGURE 4. Relationship of fat mass (FM) to peak torque (PTE60R) in young (A) and middle-aged (B) women separated by group

Partial Pearson correlation was used to explore the relationships between the same variables shown in tables 3 and 4, while controlling for physical activity (WHI PAQ). An inspection of the zero order correlations suggested that controlling for physical activity had very little effect on the strengths of any of the relationships.

An independent t-test was conducted to compare PT per kg of FFM values between age groups. There was no significant difference in values for Y (M = 1.58, SD = 0.18) and MA (M = 1.63, SD = 0.42) groups, t (79.652) = .939, p = .351 (Figure 5). The magnitude of the differences in the means (mean difference = .05, 95% CI: -.06 to .17) was very small (eta squared = .007). A Mann-Whitney U test revealed no significant difference in PTE60R per kg between Y (Md = 1.13, n = 70) and MA groups (Md = 1.13, n = 62) (U = 2071, z = -.45, p = .65, r = .04). A Mann-Whitney U test was also used to reveal a significant difference in PT per kg of FM between the two groups (young: Md = 4.07, n = 70; older: Md = 3.21, n = 62; U = 1643, z = -2.40, p = .016, r = .2).

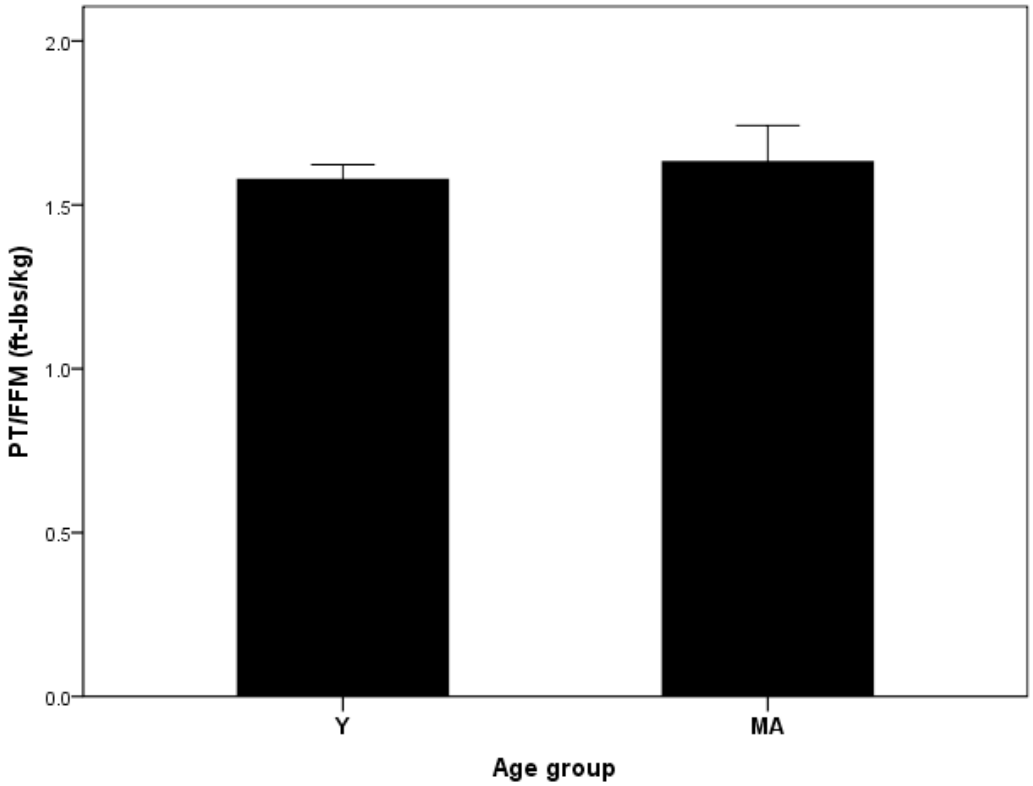


FIGURE 5. Peak torque per kg of fat free mass determined by age group (MA: middle-aged; Y: young)

One-way ANOVAs were conducted to explore the impact of indices of body size, body composition and physical activity on peak torque and FI. Subjects were divided into BMI groups according to the standard BMI categories (American College of Sports Medicine, 2006). In addition, tertiles or quartiles of body weight, body composition indices (% fat, FFM, FM) and physical activity levels ($MET \cdot hr \cdot wk^{-1}$) were determined. Post-hoc comparisons using the Tukey HSD test were used to indicate differences between groups. Table 8a-e (appendix E) indicates no differences in peak torque with percent fat ($p = .202$), or physical activity ($p = .139$) groups. However, there were statistical differences in peak torque when the women were divided into BMI, weight, FFM, and FM groups. Post-hoc comparisons indicated that absolute peak torque was greater as body

mass and size increased. There were no differences between any of the groups and FI. However, post-hoc comparisons also indicated that peak torque/kg decreased with increasing weight, FM, and FFM groups (Figures 6-8).

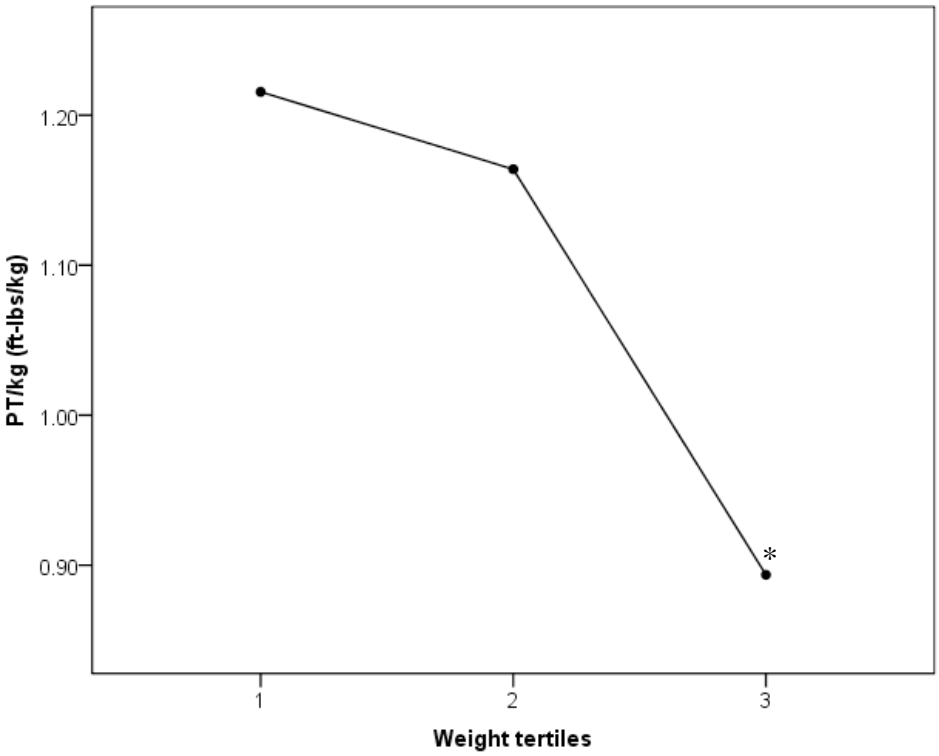


FIGURE 6. Peak torque per kg with increasing body weight tertiles (1: <60 kg; 2: 73.6 kg; 3: >73.6 kg)
*Significantly different from 1 (p = .000) and 2 (p = .000)

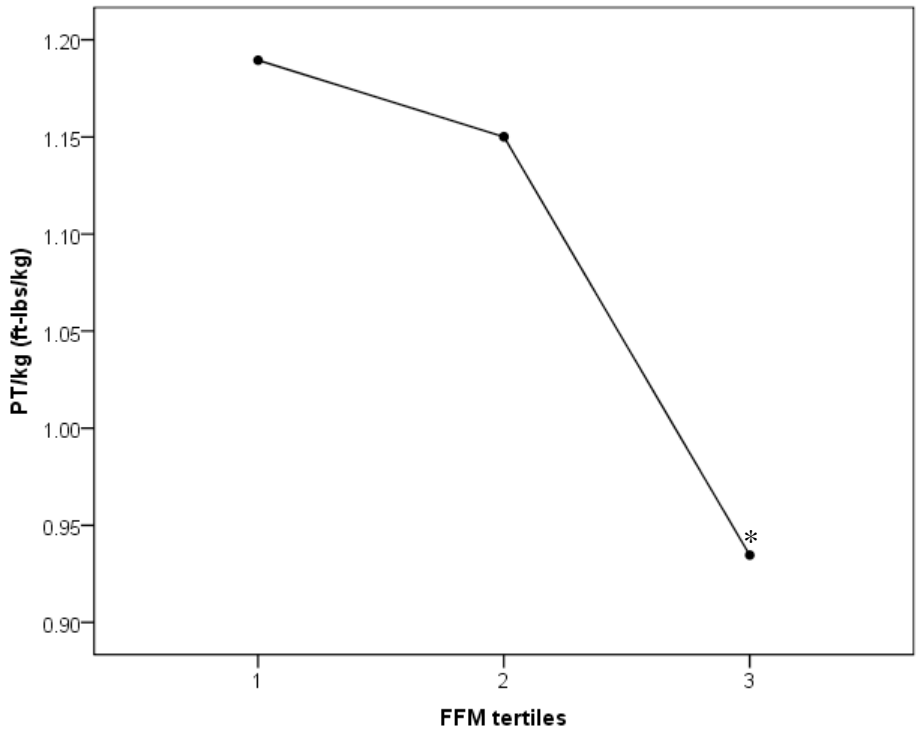


FIGURE 7. Peak torque per kg with increasing FFM tertiles (1: <42.9 kg; 2: 42.9-47.2 kg; 3: >47.2 kg)
*Significantly different from 1 (p = .000) and 2 (p = .000)

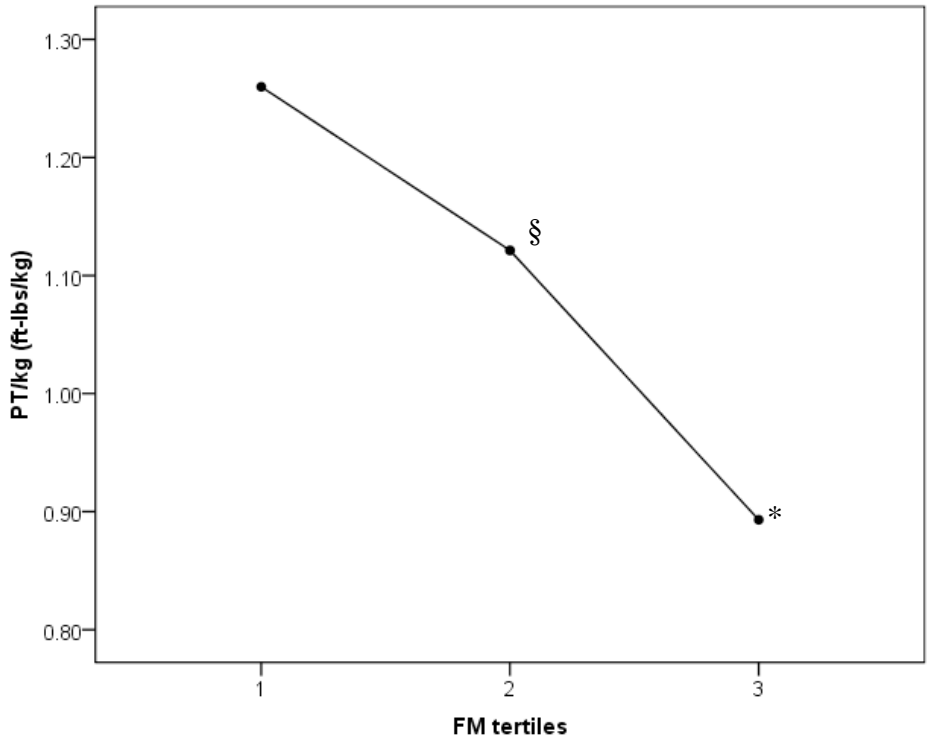


FIGURE 8. Peak torque per kg with increasing FM tertiles (1: <17 kg; 2: 17-27 kg; 3: >27 kg)
*Significantly different from 1 (p = .000) and 2 (p = .000)
§Significantly different from 1 (p = .012)

Chapter 5

DISCUSSION

The women in this study covered every BMI category (17-43 kg/m^2), and ranged in weight from 43 to 123 kg. They also varied widely in body fat percentage, with the lowest woman at 10% and the highest at 51%. Additionally, physical activity levels covered a broad spectrum, from almost completely sedentary (0.5 $MET \cdot hr \cdot wk^{-1}$) to extremely active (82 $MET \cdot hr \cdot wk^{-1}$). These wide ranges allowed for broad analysis.

A primary finding of this study was that whole body FM and FFM were associated with PT, but not with FI, in a combined group of Y and MA women. The association with PT was driven by the younger group, as evidenced by the lack of correlation in MA women and the strong correlation in Y women.

It was hypothesized that FFM would correlate positively with strength in both age groups. The lack of association in MA women is somewhat surprising based on the findings of other studies that FFM was positively correlated with strength, regardless of age or other measures of body composition (Miller et al., 2004; Ribom et al., 2004; Lafortuna et. al, 2005; Zoico et al., 2004).

Absolute strength in the Y women was purely a function of body size. As size increased, no matter the body composition, strength increased as well. Conversely, the smallest women, even those with a high percentage of lean mass, had the lowest peak torques. However, although FM was associated with higher peak torques, this association disappeared once FFM was controlled for. Furthermore, when PT was corrected for body weight, the associations reversed.

Women in the lowest tertiles of body weight, FFM, and FM were the strongest, while those in the highest tertiles were weakest. If relative strength only decreased with an increase in FM and body weight, it could be concluded that FFM was the major predictor of strength. However, relative strength decreased with increasing FFM tertiles as well. In this cohort overall body size was a function of the amount of fat the women had, i.e. the higher the percent body fat, the higher the weight and FFM of the woman. Therefore, it appears not only that FFM did not positively impact relative strength, but that FM adversely affected it.

Another hypothesis that was not supported in this study was that higher amounts of FFM would be associated with a lower FI (indicating greater muscular endurance), and that more FM would correlate with lower muscular endurance. Although neither of these held true, PT was positively correlated with FI. This is a logical relationship due to the oxidative versus hypertrophic nature of muscle fibers, i.e. stronger muscles possess less endurance, and vice versa (van Wessel, 2010). If the greater amount of FFM was a result of training for strength by the subjects, their ratio of type IIB/IIX to type I fibers would be higher, thus decreasing endurance and increasing strength (van Wessel, 2010).

Similarly, as individuals age type I fiber percentage increases and type II percentage decreases (Lee, Cheung, Qin, Tang, & Leung, 2006). This could explain the decreased fatigue in the MA women. However, if this is the case it must be concluded that, when they were between 18 and 33 years old, this cohort of MA women was stronger than the Y cohort is now. If type II muscle fibers

have decreased in the MA women, it is reasonable to assume they used to be stronger. It is impossible to know since this was a cross-sectional study.

The lack of a correlation between physical activity and strength, fatigue, or body composition also differed from the literature (Kozakai et al., 2005, Hunter et al., 2000, Koster et al., 2010, Lebrun et al., 2006, Schmitz et al., 2003, Sillanpää et al., 2009). Moreover, when used as a covariate physical activity did not change any relationships. One possible explanation for this may be that, although the physical activity questionnaire used in the study correlated strongly with VO_{2max} values, self-report values can easily be over- or underestimated.

Peak torque normalized for both FFM and body weight were the same between age groups. Although most studies have reported greater strength per kg of FFM in every age group, these strength values usually decrease across age groups after the age of 50 (Hunter et al., 2000, Koster et al., 2010, Tarpenning et al., 2006). The most likely explanation for the lack of difference in strength measures between Y and MA is that the average age of the MA women was only 52. Muscle density has been found to decrease with age as a result of greater intermuscular fat infiltration, and is associated with an increase in overall body fat levels, as well as decreased strength (Goodpaster et al., 2001; Goodpaster et al., 2006; Goodpaster et al., 2008; Delmonico et al., 2009). The greater amount of fat in the middle-aged women may indicate that some have begun to experience the decrease in muscle density, but it has not yet affected strength.

The study had some limitations. First, the study design was limited by the procedures used in the first cohort. This limitation could have influenced the

measure of body composition. For example, Dual-energy X-ray absorptiometry (DXA) is considered a more accurate way of estimating body composition than the BIA, especially in older women. DXA takes into consideration bone mineral density that could be very different between an older and younger cohort. In addition, a true measure of fitness cannot be assessed without a VO_{2max} test. The WHI PAQ is strongly correlated with VO_{2max} values in middle-aged women. However, estimation error or intentional misreporting to make oneself "look better" is possible on questionnaires. Furthermore, the WHI PAQ is intended for middle-aged women, but mean $MET \cdot hr \cdot wk^{-1}$ were found to be the same between the WHI PAQ and IPAQ also given to the young women. For the sake of consistency therefore, WHI scores were used for all subjects. Finally, because part of the goal of this study was to ascertain whether general physical activity affected strength and body composition, resistance training status was not specifically obtained on the subjects. Differences in this training variable among subjects could have affected the outcomes.

It is important to understand the relationship of fat mass to strength in women, and to understand how this relationship changes with age. Sarcopenia is a serious concern in older women, and they should learn how best to delay or completely block its occurrence. Those prescribing exercise need to prescribe age-specific exercises that will result in optimal health.

This study suggests that relative strength, but not absolute strength, is adversely affected by body fat, in young and middle-aged women. The finding that body fat may be detrimental to relative strength can be useful in prescribing

diet and exercise. It is not clear whether absolute or relative strength is more important than the other, but they both contribute to functional ability (Knutzen et al., 2002). Although absolute strength was not negatively affected by fat, increasing relative strength by decreasing fat would likely also result in increased absolute strength. However, young and middle aged women should also take into consideration the positive effect that body size had on absolute strength and not become unreasonably concerned with reducing body size.

REFERENCES

American College of Sports Medicine. (2006). *ACSM's guidelines for exercise testing and prescription* (7th ed.). Baltimore, MD; Philadelphia, PA.

Anker, S. D., Ponikowski, P. P., Clark, A. L., Leyva, F., Rauchhaus, M., Kemp, M., . . . Coats, A. J. S. (1999). Cytokines and neurohormones relating to body composition alterations in the wasting syndrome of chronic heart failure. *European Heart Journal, 20*, 683-693.

Avila, J. J., Gutierres, J. A., Sheehy, M. E., Lofgren, I. E., & Delmonico, M. J. (2010). Effect of moderate intensity resistance training during weight loss on body composition and physical performance in overweight older adults. *European Journal of Applied Physiology, 109*, 517-525.

Boyce, R. W., Jones, G. R., Schendt, K. E., Lloyd, C. L., & Boone, E. L. (2009). Longitudinal changes in strength of police officers with gender comparisons. *J Strength Cond Res, 23*(8), 2411-2418.

Carmeli, E., Reznick, A. Z., Coleman, R., & Carmeli, V. (2000). Muscle strength and mass of lower extremities in relation to functional abilities in elderly adults. *Gerontology, 46*, 249-257.

Computer Sports Medicine Inc. (2006). *Humac/Norm testing and rehabilitation system user's guide* [Instructional manual]. Stoughton, MA.

Craig, C. L., Marshall, A. L., Sjostrom, M., Bauman, A. E., Booth, M. L., Ainsworth, B. E., . . . Oja, P. (2003). International physical activity questionnaire: 12-country reliability and validity. *Medicine & Science in Sports & Exercise, 35*(8), 1381-1395.

Delmonico, M. J., Harris, T. B., Visser, M., Park, S. W., Conroy, M. B., Velasquez-Mieyer, P., . . . Goodpaster, B. H. (2009). Longitudinal study of muscle strength, quality, and adipose tissue infiltration. *Am J Clin Nutr, 90*, 1579-1585.

Frontera, W. R., Suh, D., Krivickas, L. S., Hughes, V. A., Goldstein, R., & Roubenoff, R. (2000). Skeletal muscle fiber quality in older men and women. *Am J Physiol Cell Physiol, 279*, 611-618.

Goodman, M. N. (1991). Tumor necrosis factor induces skeletal muscle protein breakdown in rats. *Am J Physiol, 260*, E727-E730.

Goodman, M. N. (1994). Interleukin-6 induces skeletal muscle protein breakdown in rats. *Proc Soc Exp Biol Med, 205*, 182-185.

Goodpaster, B. H., Carlson, C. L., Visser, M., Kelley, D. E., Scherzinger, A., Harris, T. B., . . . Newman, A. B. (2001). Attenuation of skeletal muscle and strength in the elderly: The health ABC study. *Journal of Applied Physiology, 90*, 2157-2165.

Goodpaster, B. H., Chomentowski, P., Ward, B. K., Rossi, A., Glynn, N. W., Delmonico, M. J., . . . Newman, A. B. (2008). Effects of physical activity on strength and skeletal muscle fat infiltration in older adults: A randomized controlled trial. *Journal of Applied Physiology, 105*, 1498-1503.

Goodpaster, B. H., Park, S. W., Harris, T. B., Kritchevsky, S. B., Nevitt, M., Schwartz, A. V., . . . Newman, A. B. (2006). The loss of skeletal muscle strength, mass, and quality in older adults: The health, aging and body composition study. *Journal of Gerontology, 61A*(10), 1059-1064.

Hanson, E. D., Srivatsan, S. R., Agrawal, S., Menon, K. S., Delmonico, M. J., Wang, M. Q., & Hurley, B. F. (2009). Effects of strength training on physical function: Influence of power, strength and body composition. *Journal of Strength and Conditioning, 23*(9), 2627-2637.

Hulens, M., Vansant, G., Lysens, R., Claessens, A. L., Mults, E., & Brumagne, S. (2001). Study of differences in peripheral muscle strength of lean versus obese women: An allometric approach. *International Journal of Obesity, 25*, 676-681.

Hunter, S. K., Thompson, M. W., & Adams, R. D. (2000). Relationships among age-associated strength changes and physical activity level, limb dominance, and muscle group in women. *Journal of Gerontology, 55A*(6), B264-B273.

Knutzen, K. M., Brilla, L., Caine, D., Chalmers, G., Gunter, K., Schot, P. (2002). Absolute vs. relative machine strength as predictors of function in older adults. *Journal of Strength and Conditioning Research, 16*(4), 628-640.

Koster, A., Visser, M., Simonsick, E. M., Yu, B., Allison, D. B., Newman, A. B., . . . Harris, T. B. (2010). Association between fitness and changes in body composition and muscle strength. *Journal of the American Geriatric Society, 58*, 219-226.

Kozakai, R., Doyo, W., Tsuzuku, S., Yabe, K., Miyamura, M., Ikegami, Y., . . . Shimokata, H. (2005). Relationships of muscle strength and power with leisure-time physical activity and adolescent exercise in middle-aged and elderly japanese women. *Geriatrics and Gerontology International, 5*, 182-188.

Lafortuna, C. L., Maffiuletti, N. A., Agosti, F., & Sartorio, A. (2005). Gender variations of body composition, muscle strength and power output in morbid obesity. *International Journal of Obesity, 29*, 833-841.

Lebrun, C. E. I., van der Schouw, Y. T., de Jong, F. H., Grobbee, D. E., & Lamberts, S. W. (2006). Fat mass rather than muscle strength is the major determinant of physical function and disability in postmenopausal women younger than 75 years of age. *Menopause: The Journal of the North American Menopause Society, 13*(3), 474-481.

Lee, W.S., Ceung, W.H., Qin, L., Tang, N., & Leung, K.S. (2006). Age-associated decrease of type IIA/B human skeletal muscle fibers. *Clinical Orthopaedics and Related Research, 450*, 231-237.

Maciaszek, J., Osinski, R., & Szeklicki, R. (2001). Body fatness, static strength and explosive power measured by eurofit tests among 10-14 year-old girls. *Acta Kinesiologiae Universitatis Tartuensis, 6*, 161-162.

Maffiuletti, N. A., Jubeau, M., Munzinger, U., Bizzini, M., Agosti, F., De Col, A., . . . Sartorio, A. (2007). Differences in quadriceps muscle strength and fatigue between lean and obese subjects. *European Journal of Applied Physiology, 101*, 51-59.

Miller, L. E., Nickols-Richardson, S. M., Wootten, D. F., Ramp, W. K., & Herbert, W. G. (2004). Relationships among bone mineral density, body composition, and isokinetic strength in young women. *Calcified Tissue International, 74*, 229-235.

Mitros, M. R., Pettee Gabriel, K., Ainsworth, B. A., Lee, C. D., Herrmann, S., Campbell, K., Swan, P. D. (2011). Comprehensive evaluation of a single-stage treadmill walking protocol in healthy middle-aged women. *European Journal of Applied Physiology, 111*(1), 47-56

Neder, J. A., Nery, L. E., Shinzato, G. T., Andrade, M. S., Peres, C., & Silva, A. C. (1999). Reference values for concentric knee isokinetic strength and power in nonathletic men and women from 20 to 80 years old. *Journal of Orthopaedic and Sports Physical Therapy, 29*(2), 116-126.

Petee Gabriel, K., McClain, J. J., Lee, C. D., Swan, P. D., Alvar, B. A., Mitros, M. R., & Ainsworth, B. E. (2009). Evaluation of physical activity measures used in middle-aged women. *Medicine and Science in Sports and Exercise, 41*(7), 1403-1412.

Pettee Gabriel, K., Rankin, R. L., Lee, C. D., Charlton, M. E., Swan, P. E., Ainsworth, B. E. (2010). Test-retest reliability and validity of the 400-meter walk test in healthy middle-aged women. *Journal of Physical Activity and Health*. *7*(5), 649-657.

Phillips, S. K., Rook, K. M., Siddle, N. C., Bruce, S. A., & Woledge, R. C. (1993). Muscle weakness in women occurs at an earlier age than in men, but strength is preserved by hormone replacement therapy. *Clin Sci, 84*, 95-98.

Ribom, E., Ljunggren, O., Piehl-Aulin, K., Ljunghall, S., Bratteby, L. E., Samuelson, G., & Mallmin, H. (2004). Muscle strength correlates with total body bone mineral density in young women but not in men. *Scand J Med Sci Sports, 14*, 24-29.

Rolland, Y. M., Perry III, H. M., Patrick, P., Banks, W. A., & Morley, J. E. (2007). Loss of appendicular muscle mass and loss of muscle strength in young postmenopausal women. *Journal of Gerontology, 62A*(3), 330-335.

Sale, D. G. (1988). Neural adaptation to resistance training. *Medicine & Science in Sports & Exercise, 20*(5), S135-S145.

Schmitz, K. H., Jensen, M. D., Kugler, K. C., Jeffery, R. W., & Leon, A. S. (2003). Strength training for obesity prevention in midlife women. *International Journal of Obesity, 27*, 326-333.

Schols, A. M., Buurman, W. A., Staal van den Brekel, A.J., Dentener, M. A., & Wouters, E. F. (1996). Evidence for a relation between metabolic derangements and increased levels of inflammatory mediators in a subgroup of patients with chronic obstructive pulmonary disease. *Thorax, 51*, 819-824.

Sillanpää, E., Laaksonen, D. E., Hakkinen, A., Karavirta, L., Jensen, B., Kraemer, W. J., . . . Hakkinen, K. (2009). Body composition, fitness, and metabolic health during strength and endurance training and their combination in middle-aged and older women. *European Journal of Applied Physiology, 106*, 285-296.

Sipilä, S., Koskinen, S. O. A., Taaffe, D. R., Takala, T. E. S., Cheng, S., Rantanen, T., . . . Suominen, H. (2004). Derterminants of lower-body muscle power in early postmenopausal women. *Journal of the American Geriatric Society, 52*, 939-944.

Tarpenning, K. M., Hawkins, S. A., Marcell, T. J., & Wiswell, R. A. (2006). Endurance exercise and leg strength in older women. *Journal of Aging and Physical Activity, 14*, 3-11.

van Wessel, T., de Haan, A., van der Laarse, W. J., & Jaspers, R. T. (2010). The muscle fiber type-fiber size paradox: Hypertrophy or oxidative metabolism? *European Journal of Applied Physiology, 110*, 665-694.

Visser, M., Pahor, M., Taaffe, D. R., Goodpaster, B. H., Simonsick, E. M., Newman, A. B., . . . Harris, T. B. (2002). Relationship of interleukin-6 and tumor necrosis factor-a with muscle mass and muscle strength in elderly men and women: The health ABC study. *Journal of Gerontology, 57A*(5), M326-M332.

Wang, X., Miller, G. D., Messier, S. P., & Nicklas, B. J. (2007). Knee strength maintained despite loss of lean body mass during weight loss in older obese adults with knee osteoarthritis. *Journal of Gerontology, 62A*(8), 866-871.

Wattanapermpool, J., & Reiser, P. J. (1999). Differential effects of ovariectomy on calcium activation of cardiac and soleus myofilaments. *Am J Physiol Heart Circ Physiol, 27*, H467-H473.

Zoico, E., Di Francesco, V., Guralnik, J. M., Mazzali, G., Bortolani, A., Guariento, S., . . . Zamboni, M. (2004). Physical disability and muscular strength in relation to obesity and different body composition indexes in a sample of healthy elderly women. *International Journal of Obesity, 28*, 234-241.

APPENDIX A

HEALTH HISTORY FORM

Name: _____ Age: _____ Date: _____

Emergency contact: _____Contact's phone: _____

Please answer all questions to the best of your knowledge.

1. Blood pressure
   Do you have high blood pressure? Yes No
   Have you had high blood pressure in the past? Yes No
   Are you on medication for high blood pressure? Yes No

2. Cholesterol
   Do you have high cholesterol? Yes No
   Are you on cholesterol-lowering medication? Yes No

3. Smoking
   Do you smoke? Yes No
   Are you a former smoker? Yes No
   If yes, please give the date you quit. _____

4. Diabetes
   Do you have diabetes? Yes No

5. Heart problems
   Have you ever had a heart attack? Yes No
   Have you ever had heart surgery? Yes No
   Have you ever had angina (pain in your chest)? Yes No

6. Family history
   Have any of your blood relatives had heart disease, heart surgery, or angina? Yes No

7. Orthopedic problems
   Do you have any serious orthopedic problems that would prevent you from exercising? Yes No
   If yes, please explain
   _____
   _____
   _____

8. Other problems
   Do you have any reason to believe you should not exercise? Yes No
   If yes, please explain
   _____
   _____
   _____

APPENDIX B

WOMEN'S HEALTH INITIATVE PHYSICAL ACTIVITY QUESTIONNAIRE

Questions

The following questions are about your usual PA and exercise. This includes walking and sports.

1. Think about the walking you do outside the home. How often do you walk outside the home *for more than 10 minutes without stopping?* (Mark only one.)

    1.1 When you walk outside the home for more than 10 minutes without stopping, for how many minutes do you usually walk?

    1.2 What is your usual speed?

Not including walking outside the home, *how often each week* (**7** days) do you usually do the exercises below?

2. STRENUOUS OR VERY HARD EXERCISE (you work up a sweat and your heart beats fast.) For example,
aerobic dancing, jogging, tennis, swimming laps.

    2.1 How long do you usually exercise like this at one time?

3. MODERATE EXERCISE (not exhausting). For example, biking outdoors, using an exercise machine (like a stationary bike or treadmill), calisthenics, easy swimming, popular or folk dancing.

    3.1 How long do you usually exercise like this at one time?

4. MILD EXERCISE. For example, slow dancing, bowling, golf.

    4.1 How long do you usually exercise like this at one time?

For each of the ages below, did you usually do strenuous or very hard exercises *at least 3 times a week?* This would include exercise that was long enough to work up a sweat and make your heart beat fast. (Be sure to mark 'No' if you did not do very hard exercises at the ages listed below.)

    5.1 18 years old

The next set of questions ask about some of your usual activities.

6. About how many hours each week do you usually spend doing heavy (strenuous) indoor household chores such as scrubbing floors, sweeping, or vacuuming?

7. About how many months during the year do you usually do things in the yard, such as mowing, raking, gardening, or shoveling snow?

    7.1 When you do these things in the yard, how many hours *each* week do you do them?

8. During a usual *day and night* about how many hours do you spend sitting? Be sure to include the time you spend sitting at work, sitting at the table eating, driving or riding in a car or bus, and sitting up watching TV or talking.

9. During a usual *day and night* about how many hours do you spend sleeping or lying down with your feet up? Be sure to include the time you spend sleeping or trying to sleep at night, resting or napping, and lying down watching TV.

APPENDIX C

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

   _____ **days per week**

   ☐ No vigorous physical activities → ***Skip to question 3***

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

   _____ **hours per day**

   _____ **minutes per day**

   ☐ Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

   _____ **days per week**

   ☐ No moderate physical activities → ***Skip to question 5***

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you might do solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

_____ **days per week**

☐ No walking → ***Skip to question 7***

6. How much time did you usually spend **walking** on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

This is the end of the questionnaire, thank you for participating.

APPENDIX D

INFORMED CONSENT

INFLUENCE OF BODY COMPOSITION ON LEG STRENGTH AND FATIGUE

INTRODUCTION

The purposes of this letter are to provide you (as a prospective research study participant) information that may affect your decision as to whether or not to participate in this research and to record the consent of those who agree to be involved in the study.

RESEARCHERS

Dr. Pamela Swan, Associate Professor in Exercise and Wellness at Arizona State University, and Robin DeWeese, an Exercise and Wellness Master's student have invited your participation in a research study.

STUDY PURPOSE

The purpose of the research is to examine the relationship of body composition to leg muscular strength and endurance, and to compare the results from women your age with those of middle-aged women.

DESCRIPTION OF RESEARCH STUDY

If you decide to participate, you will join a study involving research examining the association of body fat and fat free mass to muscular strength and endurance of the hamstrings and quadriceps muscles of the legs. You will be asked to come to the ASU Polytechnic campus one time. At that time you will complete a brief health history form to demonstrate the absence of medical conditions that may impact the study, and you will fill out 2 physical activity questionnaires to assess your fitness level. Your weight, height, and body composition will be measured and recorded, and your leg strength and endurance will be measured and recorded. The entire visit should take approximately one and a half hours.

Body composition measurements and leg exercises are detailed below.

Body Composition

Your body composition will be determined using bioelectrical impedance analysis. For this method you will stand on a scale, which will send an electrical impulse from one foot to the other. The scale will measure the time it takes for the impulse to complete this path. You will not feel any electrical impulses, nor will they cause you any harm. This test will assess your body percent fat and fat free mass.

Muscular Fitness of the Legs

Muscular fitness is a measure of muscular strength and endurance. For this test you will be asked to sit on a chair attached to an isokinetic dynamometer (strength-testing machine). Your foot/ankle will be placed between a padded foot lever adjusted to your leg length. Straps on your trunk, thigh, and lower leg will secure you. You will be asked to extend (kick) and flex (pull back) your leg at the

knee to determine your range of motion. After a few warm-up repetitions you will complete four tests (at three different speeds) to determine the strength and endurance of your quadriceps (muscles on the front of your upper leg) and hamstrings (muscles on the back of your upper leg). Each test speed will be chosen randomly. The tests will be done on each leg. During the strength tests, you will extend and flex 2 times as hard as you can, but the machine will allow the lever to move only a certain speed. Thus the more effort you provide, the more resistance you may feel. The idea is to give your maximal effort for each trial. The endurance test requires you to extend and flex 50 times.

RISKS

The muscular fitness tests may result in muscular strain, soreness, or knee injury. However, this technique is the safest way available to assess muscular strength. This is the technique that is used for patients following knee injury or surgery. All technicians are experienced in adjusting the machine appropriately and safely to minimize risk. To avoid the risk of a breach of confidentiality, all data will be number coded, and no names used to identify participants. While this study is considered very safe, as with any research, there is some possibility that you may be subject to risks that have not yet been identified.

BENEFITS

You will be provided with feedback regarding your body composition and your lower body muscular fitness levels. This information can be useful if you are planning to begin a physical activity program, or to assess the effectiveness of a current physical activity program. The estimated cost of these measures performed in a medical setting is valued at over $500.

NEW INFORMATION

If the researchers find new information during the study that would reasonably change your decision about participating, they will provide this information to you.

CONFIDENTIALITY

All information obtained in this study is strictly confidential unless disclosure is required by law. The results of this research study may be used in reports, presentations, and publications, but the researchers will not identify you. In order to maintain confidentiality of your records, Dr. Swan will use subject codes on all data collected, maintain a master list separate and secure from all data collected, and limit access to all confidential information to the study investigators.

WITHDRAWAL PRIVILEGE

It is ok for you to say no. Even if you say yes now, you are free to say no later, and withdraw from the study at any time. Your decision will not affect your relationship with Arizona State University or otherwise cause a loss of benefits to which you might otherwise be entitled.

COSTS AND PAYMENTS

You will receive a $10.00 gift card for your participation. There are no costs to you for participating in this study. The researchers want your decision about participating in the study to be absolutely voluntary.

COMPENSATION FOR ILLNESS AND INJURY

If you are injured during this research, you will be treated at Campus Health, or 911 will be called and emergency technicians will be brought to you. However, no funds have been set aside to compensate you in the event of injury.

VOLUNTARY CONSENT

Any questions you have concerning the research study or your participation in the study, before or after your consent, will be answered by Dr. Pamela Swan, 7350 E Unity Ave, Mesa, AZ 85251; (480) 727-1934.

If you have questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at 480-965-6788.

This form explains the nature, demands, benefits and any risk of the project. By signing this form you agree knowingly to assume any risks involved. Remember, your participation is voluntary. You may choose not to participate or to withdraw your consent and discontinue participation at any time without penalty or loss of benefit. In signing this consent form, you are not waiving any legal claims, rights, or remedies. A copy of this consent form will be given (offered) to you.

Your signature below indicates that you consent to participate in the above study.

_____	_____	_____
Subject's Signature	Printed Name	Date

INVESTIGATOR'S STATEMENT

"I certify that I have explained to the above individual the nature and purpose, the potential benefits and possible risks associated with participation in this research study, have answered any questions that have been raised, and have witnessed the above signature. These elements of Informed Consent conform to the Assurance given by Arizona State University to the Office for Human Research Protections to protect the rights of human subjects. I have provided (offered) the subject/participant a copy of this signed consent document."

Signature of Investigator_____ Date_____

APPENDIX E

HUMAC NORM SYSTEM USER'S GUIDE

KNEE: EXTENSION/FLEXION (SEATED)

Parts Needed

- Knee/Hip Adapter
- Knee/Hip Pad
- Contralateral Limb Stabilizer
- Lumbar Cushion

Scale or Position	Scale or Position Setting	Right Limb Scale	Left Limb Scale
Chair Rotation Scale	40°	Teal	Black
Chair-Back Angle	85°		
Chair-Seat position	Up		
Dyna Tilt Scale	0°		
Dyna Height Scale	8		
Dyna Rotation Scale	40°	Teal	Black
Monorail Scale	38		

Reclining Chair Preparation

- Install Contralateral Limb Stabilizer in chair receiving tube #2 (if indicated.)

Dynamometer Preparation

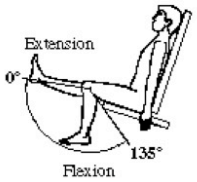
- To install adapter on dyna input arm:
  1. Secure Knee/Hip Pad on Knee/Hip Adapter with the pad offset toward the dynamometer.
  2. Insert adapter into long end of input arm and secure.

Position Patient

- Position patient appropriately on chair; provide *Lumbar Cushion* (if indicated.)
  1. Have patient move forward or back on seat until the knee is just lightly touching the chair-seat cushion.
  2. Rotate Crank to adjust chair-back to meet patient's back.
  3. Secure Seat Belt and Shoulder Belts.
- Chair-Seat Fore/Aft: Move and secure chair at an appropriate distance from dyna to properly align knee axis of rotation with dyna axis.
- Position *Knee/Hip Pad* on patient's leg and secure.
- Secure Thigh Stabilizer Strap.
- Test patient's ROM. Adjust set-up if required.
- Record all scale values and click OK.

Figure 5-1 Knee: Extension/Flexion - Seated.

The most accurate fixed axis for rehab or testing of the knee is a line passing transversely through the femoral condyles.



Pattern Begins n Full Flexion

Before Conducting the Session

- Check that all clamps and knobs are secure.
- Check that the mechanical ROM stops are properly positioned according to the patient's range of motion, and that they are secure, before conducting the session.

APPENDIX F

COMPARISON OF PEAK TORQUE BY GROUPS

Comparison of Peak Torque by Different Groups					
Table 8a					
Peak Torque by BMI Groups (kg/m^2)		1	2	3	4
		<18.5	18.5-24.9	25-29.9	>29.9
		n=7	n=65	n=32	n=28
	mean ± sd	61.9±7.3	71.7± 5	79.0±12.6*	71.5±17.2
	*sig diff from 1; p < 0.05				
Table 8b					
Peak Torque by % Fat Groups		1	2	3	4
		<25	25-32	32.1-39.9	>39.9
		n=30	n=36	n=33	n=33
	mean ± sd	68.7±10.7	71.5±15.1	75.3±14.9	75.8±18.1
Table 8c					
Peak Torque by Body Weight Groups (kg)		1	2	3	
		<60	60-73.6	>73.6	
		n=45	n=43	n=44	
	mean ± sd	64.7±13.5	77.0±11.7*	77.3±16.4*	
	*sig diff from 1; p < 0.05				
Table 8d					
Peak Torque by Fat Free Mass Groups (kg)		1	2	3	
		<42.9	42.9-47.2	>47.2	
		n=44	n=44	n=44	
	mean ± sd	64.7±15.0	76.8±12.0*	77.2±15.0*	
	*sig diff from 1; p < 0.05				
Table 8e					
Peak Torque by Fat Mass Groups (kg)		1	2	3	
		<17	17-27	>27	
		n=44	n=44	n=44	
	mean ± sd	67.8±11.1	74.0±15.9	76.9±16.6*	
	*sig diff from 1; p < 0.05				