Muscle Strength and Body Cell Mass in Postmenopausal Women

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(ABSTRACT)

It has been observed that the normal process of aging is associated with a decline in muscle strength and mass. It has also been observed that total body potassium and intracellular water (ICW) decrease with age, reflecting a loss of body cell mass (BCM), 60% of which is the skeletal muscle. It is generally accepted that traditional high-intensity strength training (ST) regimens can not only attenuate, but in some cases, reverse some of these aging-related changes. Periodization, a nontraditional approach to strength training, has been demonstrated to stimulate more rapid increases in muscle strength than traditional approaches in young adults; however, it has not been comprehensively evaluated in postmenopausal women. Investigators have consistently reported an increase in muscle strength in older adults undergoing both short- and long-term traditional ST programs. It is fairly well accepted that early increases in muscle strength are attributable to neurologic adaptations. There has been less consistency in the literature regarding the timing and nature of changes in muscle quality and mass with ST. Although several investigators have reported increased muscle protein synthesis rates as early as 2 weeks after ST initiation in older adults, the majority of published reports support the notion that significant NET gains in intracellular protein, and thus, gains in muscle mass/volume/hypertrophy do not occur before 9-10 weeks. Changes in intracellular water, which would be expected to occur with changes in intracellular protein, have not been studied during short-term ST interventions in older adults. Bioimpedance spectroscopy (BIS) has been validated as a field technique to accurately measure ICW (and BCM) changes in HIV infected individuals. The primary aim of the current study was to determine if muscle strength would increase in postmenopausal women undergoing a novel (periodized) ST intervention of 10 weeks duration. A secondary aim was to determine if BIS would detect a change in ICW in the study subjects from baseline to study conclusion.

Study participants were eleven, healthy postmenopausal women between the ages of 60 and 74 (mean age: 65 ± 4.4 y) who had not engaged in ST in the six months preceding the study. ICW and muscle strength were assessed at baseline and at study conclusion. The ST program was conducted twice a week for 10 weeks at the Senior Center in Blacksburg, VA. Participants performed seven different exercises incorporating upper body and lower body muscle groups. The women performed one set of 8-12 repetitions at an intensity of 80% of one repetition maximum (1 RM) the first week, progressing to 2 sets of 8-12 repetitions at the same intensity during the second week. The remaining weeks consisted of three sets of 8-12 repetitions, performed at an intensity of 80%, 75%, and 70% of their current 1 RM, respectively. One RM was reassessed every other week. The major result from this study was that muscle strength of all trained muscle groups increased in postmenopausal women undergoing 10 weeks of pyramid ST ($P<0.05$). In addition, the pyramid ST protocol utilized in this study was well-tolerated and resulted in no injuries in any of the older women in the study, indicating that this approach may be used safely in this population. Mean ICW measured by the field method BIS did not change over the course of the study. This result was consistent with other published data reporting no changes in lean body mass or muscle volume/area by more sophisticated techniques.

Dedication

This Thesis is dedicated to my father, Cal, my inspiration, role model, and guardian angel who is always by my side and constantly in my thoughts. I love you, Dad.

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Chapter 1: Introduction

Health-related issues in the aging population have become increasingly more important as the number of individuals over the age of 65 and their life expectancy continues to increase. In fact, people over 65 years of age represent the fastest growing portion of the population (Tsutsumi et al., 1997). The U.S. Bureau of the Census estimates that currently 13% (35 million) of the U.S. population is over 65 and this population is expected to double over the next 30 years, growing to 70 million by the year 2030.

The normal aging process is associated with significant alterations in body composition. Researchers have suggested that after the age of 50, lean body mass (LBM) declines and a decrease in physical strength accompanies this LBM reduction (Vandervoort and McComas, 1986). The specific component of the LBM that is primarily lost is body cell mass (BCM), 60% of which is skeletal muscle. The decrease in skeletal muscle mass accompanied by a reduction in muscle strength has been termed sarcopenia (Rosenberg, 1989; Roubenoff, 2000). As the loss of strength with aging progresses, it can impair functional capacity and mobility leading to an increased risk for fractures and falls (Lexell, 1995; Taunton et al., 1997; Taaffe et al., 1999). These issues are more pronounced in older women when compared to older men (Dawson-Hughes and Harris, 1992; Poehlman et al., 1995).

Guo et al (1999) suggested that women are more prone to the aging-related decline in skeletal muscle mass and strength due to the sudden decrease in estrogen concentration after menopause. The depletion of estrogen is thought to accelerate the loss of muscle mass. Furthermore, most women live one-third of their lives in the postmenopausal stage, which could greatly impact their health status and independence. Consequently, women in general are weaker in muscle strength than men, and therefore would be expected to experience greater difficulty in many strength-related activities of daily living as they age. This was confirmed by the results from the Framingham Study, which indicated that 40% of the female population between 55-64 years old, 45% of the women aged 65-74, and 65% of the women ages 75-84 were not able to lift 4.5 kg (Jette et al., 1981). This study was published 20 years ago, and although there is not an equivalent update of these figures based upon current data, it is likely that these numbers may be higher today due to the fact that the population over 65 years is expanding.

Strength training has been demonstrated to attenuate the aging-related changes in body composition and strength (Mazzeo et al., 1998). It has been suggested that only strength training (ST) can stop or reverse sarcopenia, the age-related decrease in lean body mass (LBM) and muscle strength observed in older adults (Evans, 1998; Vandervoort and Symons, 2001). Increases in muscle strength and mass in older individuals can be the first step towards a lifetime of increased physical activity and a realistic strategy for maintaining functional status and independence (Taunton et al., 1997; Evans, 1998; Taaffe et al., 1999).

High-intensity (80% of one repetition maximum, 1 RM), progressive resistance training protocols have been successful at increasing muscle mass and/or muscle strength in older adults (Fiatarone, 1990; McCartney et al., 1995; Evans and Cyr-Campbell, 1997; Mazzeo, 1998; Taaffe et al., 1999; Bemben et al., 2000). However, it is unclear if high-intensity, traditional strength training is the most effective approach for the older population. Alternative approaches to ST have recently become of interest in the older population (Maddalozzo and Snow 1998, 1999; Fleck, 1999).

Periodization is a nontraditional approach to ST that has been used by athletes (high school, college, olympian) for about 40 years (Fleck and Kraemer, 1997; Baechle and Groves, 1998); however, it has only recently begun to be investigated in older adults (Madalozzo and Snow, 1998, 1999). Periodized ST has been shown to be more effective at rapidly increasing muscle strength and hypertrophy when compared to traditional ST regimens (Stone et al., 1981). Also, periodized STkeeps the muscle stimulated without causing overuse injuries due to the adequate rest periods incorporated in periodization (Fleck and Kraemer, 1997). Fleck (1999) has asserted that there is a need to examine the use of periodized ST for its utility in older populations.

The assessment of body composition in older adults is particularly useful when evaluating responses to ST interventions. There is no direct method to measure skeletal muscle mass. Research methods such as computerized tomography (CT), magnetic resonance imaging (MRI), dual x-ray absorptiometry (DXA), total body potassium counting, and dilution methods provide measures of various lean tissue compartments, but are time-consuming, expensive, and frequently quite invasive. Field methods have traditionally lacked the ability to specifically measure BCM. Bioimpedance spectroscopy is a field technique that has been proven to measure ICW, which serves as a surrogate measure of BCM. It also has the added benefits of being noninvasive, relatively inexpensive, and easy to use.

The current study was designed to determine if muscle strength would improve in healthy postmenopausal women undergoing a 10 week periodized ST program. Another aim of this study was to determine if ICW measured by BIS would increase after a 10 week ST program in this same population.

Statement of the Problem

Older individuals lose muscle mass and/or strength with increasing age, and this deterioration is termed sarcopenia (Rosenberg, 1989). Previous ST studies in older adults have resulted in increases in muscle strength and/or mass. However, these studies have used traditional ST approaches. It is not known whether or not older individuals can tolerate a nontraditional approach to ST, such as periodization. Subsequently, it is unclear if periodized ST can promote increased muscle strength and mass in older individuals. It has been observed that older people retain the capacity to increase muscle volume and protein synthesis rates in response to ST (Charete et al., 1991; Evans and Cyr-Campbell, 1997; Hakkinen et al., 1998b; Tracy et al., 1999; Hikida et al., 2000; Ivey et al., 2000, Yarasheski et al., 1999; Welle and Thornton, 1998). It is unclear whether or not an increase in ICW would occur with a short-term periodized ST approach.

Significance of the Study

This is the first study to use heavy to light periodized ST in healthy postmenopausal women to improve muscle strength. In addition, this is the first ST study in postmenopausal women to assess changes in ICW, and thus BCM, by BIS.

Research Hypotheses

H_o (1): Muscle strength in healthy postmenopausal women will not change after 10 weeks of periodized ST.

H_o (2): ICW in healthy postmenopausal women will not change after 10 weeks of periodized ST.

Assumptions

1. Subjects accurately answered the questions in the PAR-Q and the Health Status Questionnaire.
2. Subjects correctly reported no previous strength training 6 months prior to the study.
3. Subjects complied with all pre-testing instructions, specifically abstinence from food, caffeine or alcohol consumption 12 hr prior to testing and no exercise 24 hr prior to testing.
4. Standard protocol was consistently followed for the bioimpedance measurements, thus minimizing inter-observer error.
5. Subjects put forth their greatest effort in all 1 RM assessments.

Limitations

1. Due to several logistical reasons, this was not a randomized, controlled study.
2. The subject group was not representative of the entire population of postmenopausal women in Blacksburg, VA; only healthy women were included in the study.
3. Male subjects were excluded, and thus, the results cannot be applied to older men.
4. Results can only be generalized to individuals of same gender, age and activity level.
5. A learning effect may have occurred over the course of the study, even though an orientation session was conducted to make subjects comfortable with the exercise protocol and the equipment and to minimize any novel components of the exercises.
6. The facility where the ST program was conducted was limited in terms of the hours of availability of the weight room, and the type of weight training equipment.

Definitions and Symbols

- **Activities of Daily Living (ADLs)**: a list of activities (bathing, dressing feeding oneself, using the toilet, and transferring between bed and chair), which relate to personal care that has been developed to measure functional status as related to the ability to live independently or the need for care
- **Bench Press**: strength training lift to develop chest muscles, deltoid, and tricep muscles
- **Bicep Curl**: strength training lift to develop the biceps brachii and brachioradialis muscles
- **Cool-down**: a period of light activity following moderate to heavy exercise

- **Hypertrophy**: muscle enlargement due to increase in size of existing fibers, not the generation of new fibers
- **Intensity**: the degree of difficulty (higher = harder, lower = easier)
- **Lat Pulldown**: strength training lift to develop extensors and adductors of the shoulders as well as develop the latissiums dorsi
- **Leg Extension**: strength training lift to develop the quadriceps muscle group
- **Leg Press**: strength training lift to develop the quadriceps muscle group
- **Load**: any force of resistance against a muscle or muscle group
- **Motor Unit**: the motor neuron and all of the muscle fibers it innervates
- **Muscle strength**: maximal force a muscle or a muscle group can generate at a given velocity
- **One repetition maximum (1 RM)**: the gold-standard of dynamic strength testing; the heaviest weight that can be lifted only once using good/correct form
- **Progressive resistance training**: strength training programs in which a muscle adapts to a resistance, and a great resistance is then chosen to overload the muscle and continue to increase strength.
- **Rate of Perceived Exertion (RPE)**: how hard a subject perceives his/her workout; used to quantify the subjective feeling of physical effort by using a scale from 0 to 10.
- **Repetition**: the number of muscle contractions executed during each set (number of lifts)
- **Row**: weight training lift used to develop chest muscles, latissiums dorsi
- **Set**: Includes the number of repetitions to be lifted at one time
- **Triceps Extension**: strength training lift to develop the triceps muscles
- **Type I fibers**: slow-oxidative or slow twitch fibers contain large numbers of oxidative enzymes, myoglobin, capillaries; large capacity for aerobic metabolism and high resistance to fatigue due to the high number of mitochondrial enzymes
- **Type II fibers**: Two types: Type IIb and Type IIa;
  - **Type IIb** are fast-twitch or fast-glycolytic fibers which have small number of mitochondira and a limited capacity for aerobic metabolism and are less resistant to fatigue than slow fibers.

  - **Type IIa** are intermediate fibers of fast-oxidative glycolytic fibers that can be viewed as a mixture of both Type I and Type IIb fibers.
- **Warm-up**: exercise conducted prior to a performance or workout session

The Current Study

The primary aim of the current study was to investigate changes in muscle strength in postmenopausal women undergoing a 10-week periodized ST program. A secondary aim was to determine if ICW, measured by BIS, would increase in this same population after a short-term ST program. In order to provide the appropriate context for the aims addressed in this investigation, a full review of the relevant literature is presented in Chapter 2.

Chapter 2: Literature Review

Aging-Associated Changes in Body Composition

The normal aging process is associated with profound changes in body composition, marked by significant losses of lean tissue and a concomitant loss of muscle strength (Evans, 1995; Roubenoff, 2000a). These changes are thought to be a major cause for the diminished functional capacity experienced by many older adults (Foster-Burns, 1999). Fat-free mass (FFM), and muscle tissue in particular, has been shown to decrease with age in older adults, in conjunction with a loss of bone mineral and a proportional increase in body fat (Baumgartner, 1993). Older adults with a higher proportion of FFM have a lower risk of morbidity than those experiencing greater losses of FFM (Taunton et al., 1997). The specific component of the lean tissue that is primarily lost is body cell mass (BCM), reflected by a loss of total body potassium and intracellular water (ICW; Kehayias et al., 1997). BCM is the metabolically active tissue of the body, 60% of which consists of the skeletal muscle mass (Moore and Boyden, 1963; Shizgal, 1990). In support of this observation, body composition studies at the elemental level have observed a decrease in total body protein, potassium, and calcium with aging; with the decrease in potassium being observed primarily in the BCM compartment (Heymsfield et al., 1989; Kehayias et al., 1997; Roubenoff et al., 1997). The loss of bone mineral density and muscle mass is especially problematic for older women, who experience an accelerated loss and an increased risk of osteoporosis after menopause (Mazess, 1987). Guo et al. (1999) reported that the decline in estrogen concentration is a major contributor to the loss in FFM and muscle strength and the increase in body fat and body weight observed in postmenopausal women. Historically an understudied population, postmenopausal women are currently receiving attention from researchers interested in interventions to improve strength and functional capacity. The current study also targets this population.

The involuntary loss of skeletal muscle mass with an accompanying loss of strength that occurs in many aging individuals is a progressive syndrome that has been termed “sarcopenia” (Rosenberg, 1989; Roubenoff, 2000a, b). This syndrome is considered by many to be a normal consequence of the aging process (Vandervoort and Symons, 2001). Interestingly, sarcopenia has been observed to occur even in active older adults, who despite maintaining their functional status, continue to lose muscle mass as they grow older (Roubenoff, 2000a). Sarcopenia, particularly as it progresses, is thought to adversely affect quality of life for elderly women by decreasing the ability to perform the activities of daily living (Lexell, 1995).

There is accumulating published data to support the relationship between maintenance of strength and physical function in older adults (Taaffe et al., 1999; Taunton et al., 1997). The application of ST to the older population is of particular interest because loss of muscle mass and strength are major deficits with increasing age (Evans and Cyr-Campbell, 1997). Any reduction in strength may lead to a loss of physical independence in activities of daily living and is a risk factor for both falls and hip fractures (Taunton et al., 1997; Taaffe et al., 1999). The decline of muscle strength with age has been quantified as about 15% per decade after the age of 50 (Vandervoort and McComas, 1986). This can be particularly problematic for older women, for whom the loss of strength has been associated with loss of physical function, independence, and mobility (Taunton et al., 1997; Carmeli et al., 2000; Meuleman et al., 2000). A 1989 paper by Evans and Meredith reported the results of a US survey that indicated after the age of 74 years, 66% of women cannot lift objects weighing more than 4.5 kg. A recent report by Zamboni et al. (1999) underscored the relationship between body composition and physical performance. Physical function was assessed in 144 women ages 68 to 75 years old using a combination of the activities of daily living (ADL) scale, the instrumental activities of daily living (IADL) scale, walking 800 meters, climbing stairs, and performing heavy housework. Two groups were formed based on physical function assessment results; individuals with no physical limitations and those with physical limitations. These investigators found that normal women (no physical limitations) had significantly lower body mass index and percent body fat (by dual-energy ex-ray absorptiometry, DXA) than the women who had physical impairment. FFM was higher in the normal women when compared to the women with physical impairment. Furthermore, these investigators suggested the women with the least amount of muscle strength had significantly lower FFM compared to the women with the greatest muscle strength (Zamboni et al, 1999).

Kehayias and Heymsfield (1997) have suggested that slowing down the depletion of BCM is likely to significantly improve quality of life for the very old. Clearly, a better understanding of the factors associated with the age-related changes in body composition would facilitate the development of effective strategies to improve overall health and functional status as individuals age (Guo et al., 1999). Strength training is one intervention strategy that has been shown to be effective in attenuating some of the aging-related changes in body composition.

Strength Training in Older Adults

Traditional Approach to ST

It is now generally accepted that traditional ST programs can positively impact muscle strength and body composition in older adults. ST has been shown to increase muscle strength, as well as bone density assessed by DXA, in postmenopausal women (Rhodes et al., 2000. These positive changes can decrease the risk of falls and fractures, and improve functional capacity (Nelson et al., 1994; Rhodes et al., 2000), thus allowing many older men and women to perform such daily activities as climbing stairs, carrying packages, and even walking (Evans and Cyr-Campbell, 1997).

There are several general definitions of ST in the literature. Evans and Cyr-Campbell (1997) have defined ST (also termed progressive resistance training) as training in which the force of resistance generated against a muscle is progressively increased over time and utilizes few contractions against a heavy load, defined to be 80-100% of one repetition maximum (1 RM). Baechle and Groves (1998) define "traditional" ST as a program that increases intensity gradually over time. The American College of Sports Medicine (ACSM) recommends ST as a component of an overall fitness program. The ACSM Position Stand on Exercise and Physical Activity for Older Adults states that ST can offset the loss in muscle mass and strength that are associated with normal aging (Mazzeo et al., 1998).

Furthermore, the ACSM has advocated high intensity (80% of 1 repetition maximum, RM: defined as the maximum amount of weight an individual can lift one time using correct form) ST regimens in older adults as more effective and just as safe as lower intensity regimens, even in frail elderly individuals (Mazzeo et al., 1998). This position stand is reinforced by the results of many studies examining the effectiveness of moderate to high intensity traditional ST programs in older adults. The majority of these studies reported significant strength gains after an average of 8-16 weeks. The most significant changes in muscle strength have been shown to occur when exercising against a resistance of 60-100% of 1 RM (Evans and Cyr-Campbell, 1997), which is considered to be moderate to high intensity (Lexell et al., 1995). A training level of moderate to high intensity was used in the current investigation.

Muscle Strength and Traditional ST in Older Adults

ST Studies in Older Men

The majority of ST studies in older adults have focused primarily on male subjects. The results of two short-term (defined to be < 16 weeks) ST studies in men are presented here. Hakkinen et al.

(1998b) conducted a 10 week long investigation on muscle strength gains in 18 men (8 young men; mean age: 29 ± 5 y; 10 old men; mean age: 61 ± 4 y.) after ST. The ST program consisted of squat exercise, knee extension, knee flexion, trunk extension and flexion exercises, calf raises, and bench press. Subjects trained 3 times per week, lifting 6 – 8 repetitions per set. The first session of the week involved lifting 8-10 RM sets, the second session of the week involved 3-5 RM sets, and the third session involved 15 RM sets of squat and knee extension exercises. All sets consisted of 6 to 8 repetitions. The results were significant increases (15%, 16.5%) in knee extension force for young and older men, respectively. These findings were recently confirmed by Hikida et al. (2000), who studied 22 men aged 58 to 78 years old for 16 weeks. The men were randomly assigned to a control (n=10) or training group (n=12). The resistance training protocol consisted of 3 sets of 6 to 8 repetitions to failure for each set two times a week for 16 weeks. The exercises performed were knee extension, double leg press, and half squat. The weight was increased as necessary to stay within 6 to 8 repetitions for each set. The most important finding in this study was that muscle strength in all three lower body exercises increased significantly after 16 weeks of ST in the trained group: leg press 72.3%; leg extension, 50.4%; and half squat, 83.5%. The control group experienced no change in strength (Hikida et al., 2000).

ST Studies in Both Older Men and Women

Several additional studies have investigated the impact of short-term ST on muscle strength gains in older men and women (Fiatarone et al., 1990; Evans and Cyr-Campbell, 1997; Tracy et al., 1999; Yarasheski et al., 1999; Ivey et al., 2000). Fiatarone et al. (1990) conducted an eight week long, three days per week, ST program in ten 89-91 year olds (6 women, 4 men). After eight weeks of high intensity (80% of 1 RM) ST, the average observed strength gain measured by change in 1 RM was 174% for the right side ($P < 0.0001$) and 180% for the left side ($P < 0.0001$). Evans and Cyr-Campbell (1997) also reported additional evidence that significant increases in muscle strength can be observed after a short period of ST. They observed a 180% increase in knee flexor and extensor muscle strength after the first eight weeks of ST in 10 elderly men and women with a mean age of 90 years (range 87 to 96 years). Furthermore, these investigators observed gains in strength with only two days per week of ST. Tracy et al. (1999) investigated the effects of ST on muscle quality (MQ, defined to be strength per muscle volume of the trained muscle) in 23 subjects (12 men and 11 women) aged 65 to 75 years. The ST program met three times per week for 9 weeks. The program design consisted of unilateral training (one-leg) of the knee extensors of the dominant leg. The untrained leg did not participate in any muscular contractions. The first set was a warm-up of 5 repetitions at 50% of 1 RM. The second set consisted of 5 repetitions at the current 5 RM value. This 5 RM value was increased as the training program progressed. The third set involved 10 repetitions, with the first 4 or 5 repetitions at the current 5 RM value and then the resistance was lowered so the subject could complete one or two more repetitions before muscle fatigue. This process was repeated until 10 repetitions were performed. The fourth and fifth sets used this same process; however, the fourth set included 5 repetitions at the 5 RM value and then 10 more repetitions at lower resistance. During the fifth set, 5 repetitions were completed at the 5 RM value and then subjects had to perform 15 more repetitions at a lower resistance. The investigators of this study concluded that the ST program significantly increased the 1 RM strength, by 27 ± 3% and 29 ± 4% of the trained legs of both the men and the women, respectively (Tracy et al., 1999). Consequently, this same group of investigators conducted another study comparing the effects of 9 weeks of unilateral ST in young men and women (aged 20 to 30 y) and old men and women (aged 65 to 75 y) using the same ST protocol as described above (Ivey et al., 2000). They observed significant increases in 1 RM strength in all subjects (young women: 40.3%; young men: 27.9%; older women: 28.8%; older men: 26.5%) after 9 weeks of training (Ivey et al., 2000).

A slightly longer ST program was investigated by Yarasheski et al. (1999), who recruited seventeen subjects (12 women, 5 men) aged 76 to 92 years to participate in a 3 month ST program. Eight women and four men were assigned to the 3 day per week supervised exercise program and four women and one man were assigned to the home exercise group. The supervised exercise protocol involved 1 to 2 sets of 6 to 8 repetitions at 65-75% of 1 RM initially, and then progressed to 3 sets of 8-12 repetitions at an intensity of 85-100% of their initial 1 RM. The at home exercise group engaged only in light stretching activities. The 1 RMs in the supervised exercise group increased in the leg press (35 ± 7%, 27 ± 4%); knee extension (39 ± 4%, 42 ± 24); leg flexor (16 ± 7%, 6 ± 6%); and seated row (12 ± 4%, 18 ± 4%) in the women and men, respectively.

The influence of longer term (defined to be > 6 months duration) ST programs on muscle strength gains in men and women has been examined by several different investigators (McCartney et al., 1995; Taaffe et al., 1999; Hakkinen et al., 2000). For example, Taaffe et al. (1999) studied 19 women and 34 men aged 65 to 79 years for 24 weeks. The subjects were either part of a control group or one of three exercise groups (EX 1, EX 2 or EX 3). The exercise groups participated in a high-intensity, progressive resistance training program for 1, 2, or 3 days per week for 24 weeks. The training protocol involved three sets of eight exercises at 80% of their current 1 RM. These investigators suggested that older adults who engage in ST regimens two times per week can achieve strength gains similar to those strength gains seen in older individuals who strength train three times per week. Hakkinen et al. (2000) also saw significant strength gains in a two day per week ST program. They observed a group of 12 middle-aged (M; mean age of 41 y, comprised of 6 women and 6 men) and a group of 10 elderly (E; mean age of 70 y, comprised of 5 women and 5 men) volunteers involved in a multi-phase ST study. The ST program met two days per week for 24 weeks. The ST protocol consisted of 3 to 4 sets with 10-15 repetitions at an intensity level of 50-70% of 1 RM. There was a significant increase in overall muscle strength after 24 weeks of ST: M 27% and E 29%, ($P < 0.001$). These investigators concluded that both middle-aged and elderly adults exhibit large increases in strength after 24 weeks of resistance training.

In addition, McCartney et al., (1995) reported significant increases in muscle strength measured by change in 1 RM ranging from 20% to 65% during 10 months of moderate or high intensity resistance training in 193 men and women ages 60 to 80 years old. The quickest rate of strength gain was observed in the first six weeks of training (McCartney et al., 1995). The rapid adaptation observed in this and other long-term studies suggests that even a short period of moderate to high intensity resistance training can promote increases in strength (McCartney et al., 1995).

ST Studies in Older Women

While the majority of studies have examined the effects of ST in older men or a combination of both older men and women, several studies have focused solely on older women (Charete et al., 1991; Nichols et al., 1993; Morganti et al., 1995; Nelson et al., 1996; Bemben et al., 2000; Rhodes et al., 2000). Charete et al. (1991) conducted a short-term, 12 week long weight training program in 22 women with a mean age of 69 years old. These women were randomly placed either in a control group or an exercise group. The exercise group participated in a resistance training program which met three times a week for 12 weeks and consisted of lifting 3 sets of 6 repetitions each session. Seven exercises performed to assess strength of the hips and legs; leg press, leg flexion, leg extension, hip adduction, hip abduction, hip extension, and hip flexion. One RMs were measured to assess muscle strength. The control group did not engage in the ST program. These investigators found that the training group exhibited significant increases in strength for all 7 exercises. The increases in strength ranged from 28% to 115% of baseline values. The greatest percent change was experienced with the leg curl (115 ± 27%) and the smallest percent changes were in the leg press (28.3 ± 6%) and hip extension (28.3 ± 4%). The final 1 RM values were significantly ($P< 0.001$ to $P< 0.05$) different between the control group and the training group in all exercises except for the leg press ($P= 0.19$).

A long-term study in older women conducted by Bemben et al. (2000) compared the effects of a high intensity, low repetition (HL) resistance training protocol and a high-repetition, low intensity (HR) resistance training protocol on muscle strength and size in early postmenopausal women. These investigators studied 25 healthy, estrogen-deficient postmenopausal women between the ages of 41-60 years old. These women were randomly assigned to either resistance training or to a non-resistance training control group. The HL and HR group both lifted 3 sets on 3 nonconsecutive days each week for 6 months. However, the HL group performed 8 repetitions of each exercise at an intensity of 80% 1 RM, while the HR group performed 16 repetitions of each exercise at an intensity of 40% 1 RM. Both training groups were performing the same volume of work. The results showed both training protocols produced significant increases in upper body and lower body exercises. Furthermore, the percent changes in muscle strength on average for all exercises were 30% for HL and 27% for HR. In addition, there was a 20% improvement in rectus femoris cross sectional area (CSA), measured by ultrasound, for subjects on both protocols and there was a 33% increase for the HL group and 28% increase for the HR group in the biceps CSA. Bemben et al. (2000) concluded that both HR and HL training protocols were effective in improving muscle strength and size in early postmenopausal women.

Although most studies in older populations have observed the effects of ST on previously untrained or even sedentary individuals, Nichols et al. (1993) studied a sample of 36 active women over the age of 60 years, who met the following inclusion criteria: active for at least 6 months (defined as 3 days/week of exercise for at least 30 minutes), no previous weight training, no known or history of cardiovascular disease, no thyroid or cardiac medications, and physician's consent to participate. These investigators reported an average net change in strength of 5% for knee flexion ($P < 0.009$) up to 65% for the shoulder press ($P < 0.0001$) after 18 weeks, 3 days/week of 3 sets of 8-10 repetitions at an intensity of 80% of 1 RM. In addition, FFM measured by dual energy radiography increased by 1.5 kg ($P <0.0001$). The fact that these active sixty year old women experienced strength gains in upper body strength is functionally significant, due to the fact that the majority of the activities of daily living, including grocery shopping, household work, and yard work, require some upper body strength (Nichols et al., 1993). Furthermore, the fact that the women in this study still showed strength gains even though they were already active, reinforced the notion that resistance training may be beneficial as a supplementary mode of exercise for active older women (Nichols et al., 1993).

Three other studies reported the benefits of year-long ST programs in older women. Morganti et al. (1995) reported that muscle strength continues to improve over an entire year of progressive resistance training in postmenopausal women. Forty women (21 in the ST group, 19 in the control group) participated in this study: all were postmenopausal for at least five years, and the average age was 57 years for controls and 61 years for ST group. The resistance program took place on two days per week for 52 weeks at an intensity level of 80% of 1 RM. Three sets of eight repetitions were completed on each machine during each training session. Average observed strength gains were 61.2% for lat pull-down by 6 months and 77.0% by 12 months; 25.9% for double leg press by 6 months and 35.1% by 12 months; 65.8% for knee extension by 6 months and 73.7% by 12 months for the exercise group ($P < 0.0001$ for all comparisons).

Another year-long study by Nelson et al. (1996) confirmed these findings. These investigators conducted a 52-week long ST study in postmenopausal women. The ST regimen in this study involved a training intensity of 80% of 1 RM for 3 sets of 8 repetitions on 2 days/week. The average gain in muscle mass measured by 24 h urinary creatinine was 9% (1.4 kg) ($P < 0.01$) after 1 year. In addition, FFM measured by underwater weighing increased by 1.3 ± 0.7 kg ($P = 0.0001$). A third year-long study by Rhodes et al. (2000) studied 44 females between the ages of 65 and 78 years old. These women were not involved in any type of organized physical activity. The women performed 3 sets of 8 repetitions at an intensity of 75% of 1 RM for the eight different exercises three times a week for one hour each session. The strength increases ranged from 19-53% over the one year period.

The results of these studies provide support for the benefits of traditional ST regimens in older women, although additional studies are needed to document more specifically the changes in body composition that occur. Furthermore, it is not clear from the available published data whether or not a traditional ST approach is the most effective approach to use in older individuals. Nontraditional approaches, such as periodization, have been advocated by some as more effective than the traditional approach for rapidly inducing hypertrophy and strength gains in younger populations (Leighton et al., 1967; Willoughby, 1993).

Pyramid Approach to ST

Periodization is a nontraditional approach to ST that is defined by varying a training program at regular time intervals in an attempt to optimize strength gains, power, hypertrophy, and motor performance (Fleck, 1999). Periodized training is a planned variation of the acute program variables

(Fleck and Kraemer, 1997). The training variables that can be manipulated in an attempt to optimize the training program include the number of sets performed of each exercise, number of repetitions per set, rest periods between sets, type of muscle action performed (eccentric, concentric, isometric), resistance of a set, and the number of training sessions per day and per week (Fleck, 1999). Periodization prevents performance plateau and overtraining by allowing for adequate rest periods, which keeps the exercise stimulus-response effective (Fleck and Kraemer, 1997). Periodization is popular among resistance trainers because it allows for variation; variation is needed in training in order to achieve optimal gains (Fleck and Kramer, 1997). Variation in the training volume and intensity is extremely important for optimal gains in strength (Matveyer, 1981; Stone et al., 1981; O'Bryant et al., 1988; Willoughby, 1993). Stone et al. (1981) reported periodization leads to greater gains in 1 RM strength than nonperiodized resistance training. Furthermore, Fleck and Kraemer (1997) found variation in a ST program leads to greater and faster gains in strength and power.

Pyramid training is a type of periodized training that is designed to develop hypertrophy and strength (Baechle and Groves, 1998). Pyramid training is a method of multi-set training in which loads get progressively heavier or lighter (Baechle and Groves, 1998). Pyramid ST has been shown to effectively increase muscle strength more rapidly than other ST regimens in college students and athletes (Leighton et al., 1967).

There has been a renewed interest in periodization approaches to ST in both younger and older adults, including women (Maddalozzo and Snow, 1998, 1999; Nindl, et al., 2000; Marx et al., 2001). Marx et al. (2000) studied 34 untrained, young women (mean age: 22 years) undergoing a periodized ST regimen for 24 weeks. Each woman was assigned to one of three groups: a low-volume, single-set circuit (SSC) training group (n= 12); a periodized, multiple-set, high-volume (MS) group (n=12); or a non-resistance training, control (CON) group (n=10). Muscle strength was measured by 1 RMs. The SSC group lifted a single set of 8 to 12 reps to muscle failure for each exercise on three nonconsecutive days per week. The MS group trained 4 days per week lifting 2 to 4 sets per exercise. On Monday and Thursday the intensity was either heavy (3-5 RM), moderate (8-10 RM), or light (12-15 RM) loads. On Tuesday and Friday, subjects performed moderate lifts (8-10 RM). The CON group continued to participate in their normal activities and did not strength train. These researchers observed a significant increase in the 1 RMs of bench press and leg press for both SSC and MS groups after 12 weeks of ST. However, the MS group experienced significant increases in both the bench press and leg press from 12 weeks to 24 weeks of training (26.9 ± 1.4 kg to 32.0 ± 2.7 kg and 115.5 ± 7.5 to 126.0 ± 6.3 kg), respectively. Therefore, these researchers concluded that the MS group demonstrated greater increases in upper and lower body maximal strength when compared to the SSC training group (Marx et al., 2001). Furthermore, FFM measured by hydrostatic weighing was demonstrated to increased by 2.2 kg ($P < 0.05$) in the MS group, where as there was an insignificant 1.0 kg change in FFM in the SSC group.

Furthermore, Maddalozzo and Snow (1998, 1999) reported significantly greater strength gains in older adults (mean age 53 years) with periodization vs. traditional resistance and the periodization regimen was reported to be safe in older women (1999). In 1998, Maddalozzo and Snow conducted a study which compared two different training protocols, circuit resistance training (CRT) and periodized resistance training (PRT) in men and women (mean age: 54.6 y) for 24 weeks. PRT consisted of upper and lower body exercises using free weights at an intensity of 70-90% of 1 RM. The CRT program used machine weights with an intensity of 50-60% of 1 RM. After 24 weeks of ST it was observed that both groups (PRT and CRT) increased strength in all exercises between 30-72%. In 1999, Maddalozzo and Snow investigated two ST protocols and their effects on strength in 24 men (mean age: 54.6 y) and 18 women (mean age 52.8 y). Nine women and 12 men were in the PRT group and 9 women and 12 men were in the moderate intensity group (MIT). The training programs were performed 3 days per week for 6 months. The PRT group used the same protocol as in 1998 and the MIT group used machine weights with an intensity of 60% of 1 RM. These investigators observed greater 1 RM percent changes in both upper and lower body muscle groups for the men and women in PRT group compared to the MIT group. Furthermore, the women of the PRT group experienced the greatest improvements Maddalozzo and Snow, 1999). Fleck (1999) identified the need for studies examining the response of females, children, and seniors to periodized weight-training programs.

The ST protocol utilized in the current study was developed after careful consideration of the published literature on ST in older adults. The efficacy of shorter term ST programs to stimulate increases in muscle strength, in addition to the limited availability of data on nontraditional ST approaches in older women, led to the development of the current study. The periodized ST protocol utilized in the current investigation involved 3 sets (at an intensity level of 80%, 75%, and 70%, respectively, of the subjects' current 1 RM) of 7 exercises performed two days per week for 10 weeks.

Muscle Morphology in Older Adults

It is now generally accepted that the aging-related loss of muscle strength and mass is due in large part to age-related lack of activity and disuse, and in some cases, chronic disease (Roubenoff, 2000a). However, there are changes that occur in the muscle itself that are an intrinsic part of the aging process. While morphologic changes in skeletal muscle were not investigated in the current study, it is useful to review the available data from the published literature with this regard. In particular, the anticipated changes in skeletal muscle with ST influenced the development of the secondary aim of the current study, which was to investigate changes in ICW in response to ST.

Aging-Related Changes in Muscle

Aging results in significant changes in the muscle, including a reduction in the number of motor units, a reduction of muscle area (specifically type II fibers), and a decreased rate of muscle protein synthesis (Lexell, 1995; Kraemer, Fleck and Evans, 1996). Frontera et al. (2000) reported the results from a 12-year longitudinal study demonstrating significant reductions in skeletal muscle strength, cross sectional area (CSA) of type I fibers, and capillary-to-fiber ratio in 12 healthy, sedentary older men (mean age 65.4 ± 4.2 years at baseline). In another study, magnetic resonance imaging (MRI) was used to evaluate the contractile and noncontractile CSA of 23 healthy, young adults aged 25 to 45 years old in comparison to 21 healthy, older adults aged 65 to 85 years old (Kent-Braun et al., 2000). Men exhibited a larger total contractile and noncontractile CSA than women; and both male and female young adults had larger contractile CSA than that of the older adults. Furthermore, there was a two to threefold increase in noncontractile CSA in older adults when compared to the younger adults (Kent-Braun et al., 2000). These investigators made the further observation that 6% of the anterior compartment of young men and women was noncontractile tissue compared to about 15% in older adults ages 65 and older.

It is known that there are a reduced number of motor units with increasing age, and this decrease has been associated with a loss of muscle strength (Porter et al., 1995). Interestingly, these non-muscle mass components of strength loss have been shown to be reversed with resistance training (Roth et al., 2000). It remains to be fully explained what is happening to the muscle in older individuals in response to resistance training.

Muscle Morphology Changes with Traditional ST

Although changes in muscle mass are an important determinant of strength loss with age and strength gains with ST, it is clearly not the only factor involved (Roth et al., 2000). Several studies have been conducted investigating the impact of resistance training on aging muscle. While there is some disagreement in the published literature regarding the timing and nature of the changes that occur in the muscle in response to ST, there appears to be concensus that early gains in muscle strength in older adults undergoing ST are associated primarily with neurologic adaptations (Hakkinen et al., 1998a, b; Tracy et al., 1999; Hakkinen et al., 2000; Ivey et al., 2000), including enhanced efficiency of motor unit firing rates and recruitment (Roth et al., 2000) and improved motor unit synchronization (Kraemer, Fleck and Evans, 1996). Although the contribution of neural adaptations to gains in muscle strength with ST has been well-documented, several investigators have also observed increases in muscle volume/area (Charete et al., 1991; Hakkinen et al., 1998b; Tracy et al., 1999; Hikida et al., 2000; Ivey et al., 2000) or an increase in muscle protein synthesis (Yarasheski et al., 1993; Welle et al., 1995; Welle and Thornton, 1998; Yarasheski et al., 1999).

Changes in Muscle Volume/Area

Hakkinen et al. (1998b) observed significant enlargement in the muscle fiber area of type I and IIa fibers and in the total cross-sectional area (CSA) of the knee extensors in young and old men. Tracy et al. (1999) evaluated muscle volume in older men and women undergoing 9 weeks of ST. These investigators observed significant increases (12%) in quadriceps muscle volume measured by MRI in the trained legs of both men and women after 9 weeks of training. These investigators also observed significant changes in the 1 RM strength of the untrained leg, which would indicate an adaptation at some level of the nervous system. These findings suggest that in addition to muscle hypertrophy, the observed strength increases also involved neuromuscular adaptations. These findings were confirmed by Ivey et al. (2000), who observed a significant increase in the quadriceps muscle volume in the trained legs of both young and old men and women after 9 weeks of ST.

Evans and Cyr-Campbell (1997) reported significant gains in muscle area in 10 male and female nonagenarians after 8 weeks of ST. In addition, Hikida et al. (2000) reported that type I, IIa, and IIb fibers exhibited a 30% increase in size after 16 weeks of ST in men aged 58 to 78 years old. These researchers concluded on the basis of the observed hypertrophy of the trained muscle fibers that ST can slow or somewhat reverse the age-related atrophy of skeletal muscles (Hikida et al., 2000).

These findings have been confirmed in older women (Charete et al., 1991). A significant increase (20.1 ± 6.8%, P=0.02) in type II fiber area was observed in exercising subjects, whereas no change in type II fiber area was observed in control subjects. These investigators concluded that progressive weight training can produce significant strength gains in 64 to 86 year old women, and that their skeletal muscle retains the capacity to undergo hypertrophy in response to weight training (Charete et al., 1991).

Changes in Muscle Protein Synthesis

Several investigators have observed that ST can increase muscle protein synthesis rates in older adults (Yarasheski et al., 1993; Welle et al., 1995; Welle and Thornton, 1998; Yarasheski et al., 1999). Welle and Thornton (1998) investigated the effect of ST on protein synthesis with varying levels of protein intake. There were 18 subjects (9 men, 9 women) ages 62 to 75 years old that participated in this 7 day long study. These subjects exercised the quadriceps muscle of one leg by performing 4 sets of 10 repetitions at an intensity of 80% of 1 RM on days 1 and 4 and then by performing 5 sets of 10 repetitions at 80% of 1 RM on day 6. The level of protein intake had no effect on the rate of myofibrillar protein synthesis in exercised muscle or in sedentary muscle. On the other hand, the exercised muscle exhibited a faster rate of synthesis when compared to the sedentary muscle. It was concluded from these results that, although older subjects have a slower rate of protein synthesis in untrained muscle than young people, there is no evidence that muscle protein synthesis is stimulated less in older individuals (Welle and Thornton, 1998).

Another group of investigators studied this issue in sedentary, physically frail older men and women (Yarasheski et al., 1999). These investigators observed that the resistance training exercise induced an increase in whole body muscle mass assessed by urinary creatinine and 3-methylhistidine, which was accompanied by greater rates of muscle protein synthesis of the vastus lateralis. These results would suggest that skeletal muscle of 76 to 92 year olds retains the ability to increase the rate of muscle contractile protein synthesis in response to a progressive weight training program (Yarasheski et al., 1999).

Clearly, there is concensus that changes in muscle strength in response to short-term ST in older adults can be attributed in large part to neurologic adaptations. However, increases in both muscle volume/area and rate of muscle protein synthesis have been observed to occur, even after only 9 weeks of ST. Any increase in muscle volume/area would likely be accompanied by an increase in intracellular protein, which in turn would be expected to be accompanied by an increase in ICW, thus reflecting an increase in BCM (Beddoe et al., 1985). It is not clear whether an increase in ICW would be observed in older individuals undergoing 10 weeks of periodized ST at moderate to high intensities. The measurement of ICW changes would potentially provide a surrogate measure of skeletal muscle changes. A discussion of body composition assessment methods follows.

Body Composition Assessment in Older Adults

Body composition assessment has gained recognition within the nutrition community as providing valuable information about overall health and nutritional status in both healthy and ill populations of all ages. The assessment of body composition in older adults is particularly useful, given the many physiological changes associated with the aging process that may skew standard anthropometric measurements. Changes in stature, the elasticity of the skin, the composition and distribution of adipose tissue, and muscle composition make conventional anthropometric measures such as body weight and body mass index (kg/m^2, BMI) more difficult to interpret in elderly individuals (Baumgartner et al., 1995). Specifically, body weight is a rather crude indicator of nutritional status and can be significantly skewed by hydration changes and changes in body composition. For example, fluid accumulation (edema) can mask a nutritional deficit by causing weight to appear normal. Aging individuals, particularly women, tend to experience an increase in extracellular water (ECW) with increasing body fat and loss of BCM (Mazariegos et al., 1994; Proctor et al., 1999). In addition, BMI is similarly problematic because muscle weighs more than fat tissue and a muscular person may appear obese when evaluated in terms of BMI (Meredith et al., 1992). Guo et al. (1999) suggested that body composition assessment can provide invaluable information that can be utilized to assess functional status, disability, and risk for mortality in older adults.

Body Cell Mass

Generally speaking, body composition at the most basic level can be expressed as a two-component model, which divides the body into fat and FFM (Heymsfield et al., 1996). This global division is problematic, in that the FFM contains within it several components that are not relevant when assessing nutritional and health status. Furthermore, there is notable confusion in the literature regarding the correct use of the terms “FFM”, “lean body mass” (LBM), and “BCM”. These terms, although similar, are not interchangeable. FFM is a broader term, which includes BCM, comprised of cellular components and intracellular water, and extracellular mass (ECM), which includes bone mineral mass and extracellular water (ECW; Shizgal, 1990). The classic definition of BCM as put forth by Moore and Boyden (1963) is “that component of body composition containing the oxygen-exchanging, potassium-rich, glucose-oxidizing, work-performing tissue.” Sixty percent of the BCM consists of skeletal muscle, while 20% consists of the viscera, and the remaining 20% consists of the cells of adipose tissue, tendon, bone, cartilage, and the red blood cells (Shizgal, 1990). Furthermore, the ECM of the LBM, consisting of ECW and the structural bone matrix, lies totally outside the cells, is metabolically inactive, and its primary functions are transport and support (Shizgal, 1990).

Because cells are comprised of 70% water, measurement of ICW provides an excellent measure of BCM (Moore and Boyden, 1963). BCM can be closely approximated by measuring intracellular water (ICW), because acute changes in body protein occur mainly in the cellular compartment (James et al., 1984), and changes in body protein are accompanied by changes in ICW (Beddoe, et al., 1985). Changes in muscle volume and protein synthesis with ST are likely to be accompanied by an increase in ICW.

The measurement of BCM has gained recognition as an important parameter of nutritional status and potent predictor of morbidity and mortality in studies involving clinical populations including HIV infected individuals (Kotler et al., 1989); however, it has not gained the same recognition in studies involving older adults. Due to the critical loss of lean tissue that occurs with aging, and the potent impact of this loss on health and functional status, it would be very useful to measure BCM as the target tissue for intervention strategies, given that BCM is the most important measurable component of lean tissue at the cellular level (Heymsfield et al., 1997). Only one group of investigators has evaluated BCM changes in response to ST in older adults using a valid research technique (total body potassium; Nelson et al., 1996). The majority of ST intervention studies of older adults have not measured BCM at all or have used invalid methods to measure it. Other parameters measured have included muscle volume/area by computerized tomography (CT) or magnetic resonance imaging (MRI) or the nonspecific LBM or FFM by dual-energy x-ray absorptiometry (DXA) or skinfold measurements.

Field Methods to Assess Body Cell Mass

Body composition assessment methods fall into one of two categories, field methods and criterion methods. There are no direct methods for measuring BCM. Criterion methods can estimate BCM by quantifying total body potassium content via total body potassium counting, by measuring total body nitrogen via neutron activation analysis, or by quantifying intracellular water using dilution methods (Forbes, 1987). These criterion methods are costly and time-consuming, therefore, a valid field method to estimate BCM is needed.

The two primary techniques that have traditionally been available for measuring body composition in the field are the measurement of skinfolds and circumferences and bioelectrical impedance analysis (BIA). The underlying basis of these two methods is the two component model of body composition. This two compartment model involves several key assumptions, including that FFM has a constant hydration of 73% water, that bone mineral content remains constant, and that the distribution of water between intra- and extracellular compartments remains constant (Heymsfield et al., 1996). These assumptions are often violated as a result of the physiological changes that occur with disease and the aging process (Chumlea and Baumgartner, 1989). Historically, these field methods have not been capable of measuring BCM. However, a new development within the field of bioelectrical impedance analysis has shown great promise for measuring ICW, and thus BCM in the field setting.

Bioelectrical Impedance Analysis

Generally speaking, bioelectrical impedance analysis (BIA) is a safe, noninvasive field technique, which measures tissue conductivity, i.e. the differential opposition or impedance of tissues, in response to a small, applied current (500 :A – 800 :A; Foster and Lukaski, 1996; Ellis et al., 1999). BIA is based on the assumption that biological tissues act as conductors or insulators, and the flow of the applied current through the body will follow the path of least resistance. In essence, the current is conducted poorly by fat and bone, but conducted well by tissues predominantly made up of water and electrolytes. Because fat is a poor conductor of the current, the total body impedance reflects the volumes of the water and cellular components of the FFM and ECW (Kushner, 1992). In other words, tissue conductivity is directly proportional to the amount of electrolyte-containing fluid present (Heymsfield et al., 1996).

Total body impedance (Z) is a function of two components, the resistance (R) of the tissues themselves, and the additional opposition (reactance, X) due to the capacitance of cellular membranes, tissue interfaces, and nonionic tissues (Heyward and Stolarczyk, 1996). Cell membranes act as the capacitors (C_m). In addition, Z is frequency-dependent, such that the impedance of tissues to the flow of current changes as the frequency at which the current is applied changes (DeLorenzo et al., 1997). In the low-frequency range, there is minimal conduction through the cells due to the high Z of the C_m and as frequency increases, Z decreases because the C_m decreases to insignificant proportions, and therefore, the current can flow through both ECW and ICW compartments (DeLorenzo et al., 1997).

The basic principle underlying BIA is that impedance through the body is directly related to the length (height) of the conductor (body) and inversely related to its volume (TBW; Kushner, 1992). This relationship is represented by the equation: Volume = Height^2/Z, where Z = Square Root of $(R^2 + X^2)$. Because R is much greater than X at almost any frequency, when measuring whole body impedance, R is the primary predictor of TBW and FFM; therefore, the index Height^2/R is often used in BIA prediction equations (Lukaski, 1996).

Single-frequency devices measure impedance data at a single frequency (50 KHz), and thus, the method that is based upon these instruments is called single-frequency BIA. Single-frequency BIA is by far the most dominant commercial application of BIA technology, and up until now, has been the primary method used in field settings. However, the characteristics of the technology underlying single-frequency BIA limit its application to the measurement of TBW and FFM; it cannot be considered valid to measure ICW or BCM.

Single-frequency BIA

Single-frequency BIA is the most common bioimpedance method used in field settings. The traditional use of this method has been the estimation of FFM by using impedance data to predict TBW, and then using the equation: FFM = TBW/0.73 (Heymsfield, 1996). Two primary assumptions underlying this method that are of concern in aging and clinical populations are that FFM maintains constant hydration at 73% and that the ECW to ICW ratio remains constant. Although in healthy younger people it has been shown that hydration remains fairly constant (van Marken Lichtenbelt, 1994; Wang et al., 1999), it is known that disturbances in fluid distribution and balance occur with normal aging (Baumgartner et al., 1991). A third assumption that is likely to be violated with older populations is that a frequency of 50 kHz is high enough to cross through cell membranes to give an accurate quantification of TBW.

To better understand this third assumption, a term called "characteristic frequency" needs to be defined. DeLorenzo et al. (1997) defined the characteristic frequency as the frequency of maximum reactance. In basic terms, characteristic frequency can be defined as the frequency at which the applied alternating current passes through all biological tissues to quantify TBW by measuring both extracellular and intracellular fluid volumes (Cole, 1972). Furthermore, the characteristic frequency has been shown to change with alterations in ECW, ICW, or cell membranes (Lofgren, 1951). The significance of this is characteristic frequency can vary significantly under different physiological conditions (different disease states, abnormal hydration, advancing age), such that a single-frequency measurement at 50 kHz may or may not be high enough to pass through both extracellular and intracellular compartments to provide an accurate estimate of TBW (DeLorenzo et al., 1997). In fact, it has been demonstrated that the characteristic frequency can vary from an average of 50 kHz in healthy young people, to 200 kHz in dialysis patients (DeLorenzo, 1997), and up to 500 kHz in young children with diarrheal disease (Meyer et al., 1998). Characteristic frequency is not measured by single-frequency devices; therefore, it is not possible to ascertain if 50 kHz is indeed high enough to quantify TBW in any individual. Characteristic frequency is, however, measured by BIS; this is one of the reasons why BIS is considered by some to be superior to other BIA methods, because it allows for interindividual variation in the factors which can alter characteristic frequency.

Despite significant theoretical and technological limitations to the single-frequency BIA method for measuring body composition beyond the two component model, this method has been used to derive estimates of ICW and BCM. Several commercially available single-frequency devices are equipped with software that will generate comprehensive reports indicating ICW and BCM. In addition, several investigators have advocated the use of impedance data measured at a single-frequency to predict ICW and/or BCM in both healthy and HIV-infected populations (Paton et al., 1998; Kotler, 1999). Although in healthy populations, the correlation between body water compartments may be close enough to provide accurate predictions of ICW and BCM through statistical relationships at least some of the time, these methods must be questioned when applied to other populations.

Bioelectrical Impedance Spectroscopy

BIS promises to replace single-frequency BIA as the preferred field method for measuring ICW, thus BCM, because BIS does not rely on the same assumptions underlying single-frequency BIA which may be violated as a result of the aging process and disease. In contrast to the other BIA methods, BIS does not require the application of a limited amount of impedance data (measured at only one or two frequencies) to prediction equations to derive volume measurements. Instead, all of the impedance data measured across the spectrum of frequencies is utilized to provide a more direct measure of body water compartments (ECW and ICW) through the use of Cole-Cole modeling and mathematically derived equations incorporating Hanai mixture theory (Matthie et al., 1998). Because of the capacity to determine the characteristic frequency for any individual, BIS has the added advantage of being able to accommodate interindividual variation in body water compartmentalization, hydration status, and cell membrane integrity. Unlike single-frequency BIA, BIS can distinguish between ECW and ICW (De Lorenzo et al., 1997; Ellis et al., 1998). In addition, BIS is just as simple, noninvasive, and inexpensive as single-frequency BIA. Ellis et al. (1999) reported several other advantages of BIS as a field method, including: the instrumentation requires minimal maintenance and operator training; measurements can be repeated as often as needed; and the results are available immediately.

Several investigators have advocated the BIS approach to measure ICW and other body water compartments. Matthie et al. (1998) reported that the BIS approach provided a better prediction of ECW and ICW than did single-frequency impedance. Van Loan et al. (1995) measured the accuracy of BIS to measure TBW and ECW compared to dilution measurements in ten pregnant women. BIS-estimates of TBW and ECW were not significantly different from dilution-measured TBW and ECW, indicating that BIS was able to accurately predict these water compartments in this population. Although BIS has been used to monitor hydration changes in both healthy men (Armstrong et al. 1997; O'Brien et al., 1999) and in patients on dialysis (Ho et al., 1994), it has only recently gained attention as a field method for measuring BCM.

Although Paton et al. (1998) reported no advantage of BIS over single-frequency BIA in predicting ECW, TBW, and ICW, these conclusions were based on the prediction of absolute volume using correlation, standard error of estimate (SEE), and bias statistics. It is well known that ECW, ICW, and TBW are highly inter-correlated, and that at any frequency, the absolute volume of each body water compartment may be predicted equally well by Z (Van Marken Lichtenbelt et al., 1994; DeLorenzo et al., 1997; Paton et al., 1998). The high inter-correlation of the body water compartments would obscure the detection of systematic error in a given method; thus, the ability of a method to measure change should be the true test of validity of a bioimpedance method (Earthman et al., 2000). In fact, these investigators reported the results of a comprehensive comparison of BIS and several other single- and multi-frequency methods with criterion measures of ICW by multiple dilution in weight-losing HIV-infected individuals undergoing an anabolic treatment, and found that only the BIS approach was capable of accurately measuring ICW and BCM change in this difficult to measure population. Although BIS has never been validated in older adults, the results of this study, provide a strong rationale for the evaluation of BIS to estimate ICW and BCM in older adults.

Body Composition Assessment in ST Studies

Only a few ST intervention studies in older adults have measured body composition. Furthermore, one group has measured BCM using a valid method, total body potassium counting (Nelson et al., 1996). Other investigators who have measured body composition have not measured BCM, instead they have relied on either the field techniques single-frequency BIA or skinfolds to measure FFM, or the research methods computerized tomography (CT) or MRI to measure skeletal muscle mass, or dual-energy x-ray absorptiometry (DXA) to measure LBM.

Although the use of CT, MRI, and DXA have contributed to our understanding of the effect of ST on skeletal muscle and lean tissue in older adults, these methods have their own limitations, and are not widely available beyond the research setting. For example, DXA provides information on bone, fat, and the more global LBM, but cannot measure the more specific BCM. In fact, Proctor et al. (1999) observed that in older adults, DXA overestimates skeletal muscle mass, and fails to detect small changes in muscle mass over time. This can be explained by the fact that DXA is unable to distinguish between body water compartments and bone-free lean tissue (Roubenoff et al., 1993; Proctor et al., 1999). Because older adults frequently exhibit an expanded ECW and a concomitant increase in TBW, measurements of FFM and skeletal muscle mass by DXA will be overestimated (Roubenoff et al., 1993; Proctor et al., 1999). Forbes (1999) also asserts that DXA is not precise enough to detect small changes in LBM. The same criticism can be made of single-frequency bioelectrical impedance analysis (BIA). Although single-frequency BIA purportedly measures BCM, it is not capable of accurately measuring

BCM, particularly in the aging population due to limitations inherent to the method (Forbes, 1999). Due to this deficiency, there is a need for a better field method to monitor ICW and BCM changes in older adults. Finally, because changes in body protein are usually accompanied by changes in ICW (Beddoe et al., 1985), it would not be entirely unexpected to observe a change in ICW with ST. The measurement of ICW by BIS would provide a surrogate measure of skeletal muscle changes with a significant advantage over other research methods, given that BIS is entirely noninvasive and requires less expensive equipment.

The Current Study

The review of the published literature elucidated several issues that could be addressed in this research. First, periodization, until now, has not been extensively utilized in postmenopausal women, and may represent a more effective ST approach for this population. Because of its limited prior application, it is not known whether or not postmenopausal women would: (a) benefit from a periodized ST program, or (b) tolerate this type of heavy to light training protocol without injury. Second, there are widely varying reports in the literature regarding whether or not older adults experience significant gains in skeletal muscle mass or FFM in conjunction with gains in muscle strength in response to ST. In particular, little is known about changes in ICW that might be expected to occur in this population with ST. This is one of the first studies to evaluate changes in body water, and in particular ICW, using the field technique BIS in older women undergoing ST.

Chapter 3: A Periodized Approach to Strength Training in Postmenopausal Women: Muscle Strength and Intracellular Water Changes

Introduction

It is generally accepted that the normal process of aging in both men and women is associated with profound changes in body composition (Baumgartner et al., 1995; Zamboni et al., 1999). Specifically, it has been observed that aging is accompanied by significant decreases in fat free mass (FFM), as well as an increase in adiposity (Baumgartner, 1993; Bross et al., 1999). The specific component of the FFM that is primarily lost has been shown to be body cell mass (BCM), reflected by a loss of total body potassium and intracellular water (ICW, Heymsfield et al., 1989; Kehayias et al., 1997). BCM is the metabolically active tissue of the body, 60% of which consists of the skeletal muscle mass (Moore and Boyden, 1963; Shizgal, 1990). Furthermore, the primary component of the BCM that is lost is skeletal muscle mass (Kehayias et al., 1997; Roubenoff, 2000a).

The aging-associated loss of skeletal muscle is associated with diminished muscle strength, and represents a significant concern for many aging adults. The progressive loss of skeletal muscle mass and strength has been termed "sarcopenia" (Rosenberg, 1989; Evans, 1995; Roubenoff, 2000a). In some individuals, this progressive decline will be associated with a loss of mobility, an increased risk for falls and fractures, and a loss of independence as individuals require increasing assistance to perform the activities of daily living (Lexell, 1995; Taunton et al., 1997; Foster-Burns, 1999). Older women are particularly at risk, given the accelerated decline in FFM after menopause (Mazess, 1987; Dawson-Hughes and Harris, 1992; Poehlman et al., 1995). Guo et al. (1999) reported that the decline in estrogen accounts for the decrease in FFM and the increase in body fat and body weight observed in postmenopausal women. Zamboni et al. (1999) suggested that because women have less muscle mass per unit of weight when compared to men, the decline in muscle mass is more debilitating for women.

It has been well-demonstrated that strength training (ST) can attenuate the aging-related changes in strength and body composition in older adults. It has been suggested that improving physical strength will improve mobility and help older individuals maintain independence longer (Nelson, 1994; Evans and Cyr-Campbell, 1997; Rhodes et al., 2000). In fact, the ACSM

Position Stand on Exercise and Physical Activity for Older Adults states that ST can offset the reduction in muscle mass and strength that is associated with normal aging (Mazzeo et al., 1998). Furthermore, the ACSM has advocated high intensity (80% of 1 repetition maximum, RM: defined to be the maximum amount of weight an individual can lift one time using correct form) ST regimens in older adults as more effective and just as safe as lower intensity regimens, even in frail elderly individuals (Mazzeo, 1998).

Several ST studies in older men and women have demonstrated significant gains in muscle strength and/or muscle mass using high intensity traditional resistance training programs (Fiatarone et al., 1990; McCartney et al., 1995; Evans and Cyr-Campbell, 1997; Tracy et al., 1999; Yarasheski et al., 1999; Ivey et al., 2000). However, from the published data, it is not clear if traditional ST is the most effective approach to improve strength in older individuals. Periodization is a nontraditional approach to ST that is defined by varying a training program at regular time intervals in an attempt to optimize strength gains, power, hypertrophy, and motor performance (Baechle and Groves, 1998; Fleck, 1999). Periodized training is a planned variation of the acute program variables and is less likely to promote overuse injuries because it allows for adequate rest periods and is constantly stimulating the muscle (Fleck and Kraemer, 1997). Furthermore, Sanborn et al. (2000) suggested that multiple set training protocols that use variation in volume and training intensity may enhance performance to a greater extent than a single set to failure training protocol. Fleck (1999) identified the need for examining the response of females, children and seniors to periodized strength training programs.

Alternative approaches such as periodization, have only recently gained attention as a possibility for ST in older populations (Maddalozzo and Snow, 1998, 1999). In a brief research abstract, these investigators reported that a 24-week periodized ST regimen using free weights and an intensity level of 70-90% of 1 RM resulted in greater strength gains than a traditional ST regimen in a group of older men and women (mean age: 54 years). Body composition changes were not evaluated in this study. Furthermore, the exact characteristics of the ST protocol were not discussed in their report; however, their results provide support for the safety and potential benefits of this alternative approach to ST in an older population. Additional research investigating muscle strength and body composition changes in older adults involved in periodized ST is warranted.

Body composition assessment has gained recognition for providing valuable information about overall health and nutritional status, particularly in intervention studies aimed at attenuating the changes associated with the aging process. Data regarding changes in specific body composition compartments in older adults in response to ST interventions has been somewhat limited by the lack of valid field methods. Currently, skeletal muscle mass cannot be measured directly. It can only be evaluated indirectly through the use of several methods available in research settings, including computerized tomography (CT), magnetic resonance imaging (MRI), total body potassium counting, total body nitrogen by neutron activation analysis, dual-energy x-ray absorptiometry (DXA), underwater weighing, and dilution methods. CT and MRI provide estimates of skeletal muscle volume/area, whereas the latter methods provide estimates of lean tissue compartments. The technical expertise and high cost of equipment required for total body potassium counting and neutron activation analysis in particular has relegated the use of these methods to a few select investigators (Hansen et al., 1999). CT, MRI, DXA, and dilution have been applied more extensively than other research methods in ST intervention studies; however, these methods are also not widely available beyond the research setting.

Field methods for evaluating body composition have traditionally relied upon the two-compartment model of body composition, which divides the body into fat mass and FFM (Heymsfield et al., 1996). This model is based on several key assumptions, including that FFM has a constant hydration of 73% water, that bone mineral content remains constant, and that the distribution of water between intra- and extracellular compartments remains constant (Heymsfield et al., 1996). Due to the alterations in body composition with aging, it is likely that at least some of these assumptions may be violated (Chumlea and Baumgartner, 1989; Baumgartner et al., 1995). Older women, in particular, have been shown to exhibit deviations in the extracellular water (ECW) to intracellular water (ICW) ratio (Mazariegos et al., 1994). The two primary techniques for assessing body composition in the field, skinfolds and circumferences and single-frequency bioelectrical impedance analysis (BIA), rely on the two-component model of body composition, and only provide global measures of the lean tissue compartment. Furthermore, these methods are not able to distinguish between body water compartments, they cannot estimate BCM, and violation of key assumptions may reduce their validity for even estimating FFM in older adults.

Bioimpedance spectroscopy (BIS) represents the newest development in the field of bioimpedance technology. BIS promises to replace single-frequency BIA as the preferred method for measuring ICW, and thus BCM in field settings, because it does not rely on the same problematic assumptions as single-frequency BIA, and thus may be applied to various populations, including older adults. Furthermore, BIS uses impedance data measured over an entire range of frequencies (from 1 to 1000 kHz), rather than just a single frequency (50 kHz). Biophysical modeling of the data using the Cole-Cole approach, and the application of Cole model terms to equations based upon Hanai mixture theory allows for more direct measurement of ECW and ICW, and thus, BCM than the single-frequency approach. In addition, because of the underlying principles of the method, BIS allows for the accommodation of interindividual variations in body water distribution. This characteristic would be particularly useful in evaluating body composition changes in older women in response to ST.

Published reports on the impact of short-term ST (9 – 16 weeks) on muscle strength of older adults provide strong support for the beneficial effects of ST in this population. While there is a general concensus in the literature that early gains in muscle strength can be attributed primarily to neurologic adaptations (Kraemer, Fleck and Evans, 1996), there is less consistency regarding the timing and nature of morphological changes in the muscle itself, and FFM of older adults undergoing ST. While several investigators have reported no changes in FFM after short-term ST in older adults (Fiatarone et al., 1990; Tracy et al., 1999; Abe et al., 2000; Houtkooper et al., 2000; Ivey et al., 2000), several other investigators have reported that older adults undergoing short-term ST interventions experience gains in muscle area/volume after 9 weeks (Tracy et al., 1999; Ivey et al., 2000), after 10 weeks (Hakkinen et al., 1998b), after 12 weeks (Charete et al., 1991) and after 16 weeks (Hakkinen et al., 2000). Yarasheski et al. (1993, 1999) demonstrated that older adults exhibited an increased rate of muscle protein synthesis after 2 weeks and after 3 months of ST. It is generally accepted that an increase in intracellular protein is accompanied by an increase in ICW (Beddoe et al., 1985). If one assumes that an increase in muscle area or volume would be associated with a concomitant increase in intracellular protein concentration within individual muscle fibers, then it would logically follow that ICW would also increase. Interestingly, several investigators have reported significant gains in FFM (Nichols et al., 1993; Nelson et al., 1996, Welle et al., 1995) after ST. It is not known if ICW increases after a short-term resistance training program in older adults. BIS has recently been validated to accurately measure ICW change in HIV-infected individuals (Earthman et al., 2000). It was hypothesized that BIS would be able to detect changes in ICW in healthy older women undergoing ST.

The primary aim of this study was to evaluate changes in muscle strength in postmenopausal women undergoing a 10-week periodized ST program. A secondary aim was to determine if ICW, measured by BIS, would increase in this same population after a short-term ST program.

Research Design and Methods

This was a prospective, longitudinal study with a repeated-measures design which investigated changes in muscle strength and ICW in healthy postmenopausal women undergoing 10-weeks of high-intensity pyramid strength training. The methods and procedures used in this investigation were reviewed and approved by the Institutional Review Board of Virginia Tech before data collection. Informed consent for testing and training was obtained from all subjects.

Subjects

Subjects were recruited through email and newsletters. The subjects were 11 healthy, ambulatory, free-living postmenopausal women. The women served as their own controls by undergoing measurements at baseline (prior to initiation of ST) and at study conclusion (at the end of 10 weeks of ST). All subjects were nonsmokers between the ages of 60 and 74 years old who had not participated in any type of ST regimen within the previous 6 months. Based upon written questionnaire regarding health and physical activity habits with verbal follow-up for clarification, the women fell into two groups with regard to participation in aerobic exercise activities. Half of the women (n=5) were considered not active, defined to be participating in less than 60 minutes per week of such activities as walking, biking, or swimming. The other half of the women (n=6) were considered to be active, defined to be participating in more than 60 minutes per week of these same activities. Four of the 11 subjects had been on hormone replacement therapy (HRT) for at least the previous 6 months prior to the start of the study. Because the loss of estrogen has been associated with an accelerated loss of muscle mass, and HRT could potentially have an impact on the magnitude of changes observed, we performed a secondary analysis comparing changes in muscle strength and ICW between the four women on HRT with the remaining women who were not on HRT.

Screening Procedures

Women who expressed interest in study participation were scheduled to come to the Senior Center in Blacksburg, VA for an initial screening and to provide informed consent (Appendix A) for the study. At this initial meeting, subjects were asked to complete two questionnaires regarding their health history and habits, including the PAR-Q (Appendix B) and the Health Status Questionnaire (Appendix C). The subjects were asked to assess their present state of health, to list any medications they were taking, and to state whether or not they were on hormone replacement therapy (HRT), and if so, the duration of HRT. They were also asked questions regarding smoking history, alcohol consumption habits, current physical activity habits, and soy consumption habits. Individuals were excluded from participating in the study who had any chronic diseases/conditions that would preclude maximal exercise, who had a menstrual period within 1 year of the start date, or who had initiated HRT in the 3 months prior to study initiation. Additionally, individuals who met two out of the following criteria were also excluded, including: 1) total plasma cholesterol > 240 mg/dl; 2) plasma LDL cholesterol > 160 mg/dl; 3) smoked more than ½ pack per day; or 4) obesity, defined as a body mass index (BMI; kg/m^2). Any individual taking medications to treat high blood pressure or cardiac conditions were also excluded from the study. Additional inclusion/exclusion criteria are presented in Appendix D. In addition, subjects were given a Medical Clearance Form (Appendix E) to take to their primary care physician in order to obtain physician approval for study participation. All subjects received physician approval prior to the start of the study.

Submaximal Exercise Test

With physician approval, subjects underwent submaximal exercise testing at the Senior Center in order to be further screened for study eligibility. Submaximal exercise testing was conducted by an American College of Sports Medicine (ACSM) Health/Fitness Instructor ® Certified, who holds current CPR and First Aid certifications. Additionally, a Physician Volunteer was present at all submaximal tests.

The submaximal test involved the participant walking on a motorized treadmill (Model TR1800 Series, Star Trac, Tustin, CA) while the treadmill's grade was increased every 2-3 minutes. During the submaximal test, heart rate and blood pressure of the subject was monitored. Rate of perceived exertion (RPE) was assessed during the last minute of each stage of the submaximal test (Noble, 1982).

The ACSM recommends the use of RPE as a tool to monitor exercise tolerance to exercise intensity. The RPE provides people of all fitness levels with easily understood guidelines regarding exercise intensity. Individuals were asked to rate how difficult they felt the level of exercise work was, on a scale from 6 to 20, with 6 being extremely light exertion and 20 being extremely strenuous. Individuals were instructed to describe this as an overall feeling based upon physical effort, stress, and fatigue. RPE is often used in conjunction with heart rate for monitoring response to exercise intensity.

Heart rate was measured with a stethoscope for 15 seconds at 1 minute and 30 seconds into each stage, and blood pressure was measured immediately following each heart rate measurement. Heart rate was measured again within the 3rd minute of each stage. When individuals reached 60% of age-predicted heart rate maximum (calculated as: 220 - age), then the submaximal test was stopped. After the submaximal test, during recovery, heart rate and blood pressure were measured at one minute intervals until levels returned close to baseline.

Women who met inclusion criteria (Appendix D) based upon the results of submaximal testing were given instructions on the protocol to follow in preparation for their first visit to the Body Composition and (Energy) Metabolism (BCM) Laboratory in the Department of Human Nutrition, Foods and Exercise at Virginia Tech for baseline assessment. Subjects underwent body composition analysis twice throughout the course of the study: at baseline (prior to initiation of the ST program) and at study conclusion (the end of 10 weeks of ST). Muscle strength was evaluated every other week throughout the study. Subjects were instructed not to begin any new exercise routine, and to maintain their normal dietary and activity habits throughout the duration of the study. Those subjects who were on HRT were also requested to inform the investigators if any changes were made in their HRT regimen over the course of the study.

One repetition maximum (1 RM) strength test

The strength measurements were conducted at the Senior Center on regular exercise days, and consisted of a 1 RM test. The 1 RM test was conducted every other Wednesday. The subjects came to the Senior Center and warmed-up as usual, with stretches and a brisk 2 minute walk. After warming up, each subject went to a different machine and performed 10 repetitions at 10 pounds for each exercise. Once the subject was warmed-up on the weights then the 1 RM test proceeded as such; the subject then lifted 3 times 75% of their previous 1 RM for that specific exercise. Then the weight was increased by 2.5 or 5 pounds depending on how easily the subject completed the previous 3 repetitions. The subject lifted this new weight two times and then kept increasing the weight by 2.5 or 5 pound increments until she could only lift the weight once using correct form. This was determined to be her current 1 RM for that exercise. This process was completed for all 7 exercises.

Body composition assessment

Body composition was assessed at the BCM Laboratory by BIS. Subjects reported to the BCM Laboratory for testing on non-exercise days, in the morning after an overnight fast. Subjects were instructed to abstain from exercise, alcohol consumption, and caffeine consumption 24 hours prior to testing.

Anthropometry

Body weight was assessed at baseline and at study conclusion, using a SCALE-TRONICS digital stand-on scale (model 5002, SCALE-TRONICS, White Plains, NY). Height was measured using a Heightronic^{TM} 235 digital stadiometer (Measurement Concepts, North Bend, WA) only at baseline.

Bioimpedance Spectroscopy

Measures of ICW and ECW were made using the Hydra 4200 BIS device (Xitron Technologies, San Diego, CA) at 10 minutes after the subject assumed a supine position in a Laz-Y-Boy recliner. Standardized testing procedures were followed as outlined by Kushner et al. (1992), including tetrapolar placement of the electrodes on the right side of the body (Appendix F).

Strength Training Program

Subjects participated in a supervised ST program at the Senior Center twice weekly (Mondays and Fridays) for 45-60 minutes over 10 weeks. There were two preliminary sessions devoted to orientation to the program and facility, including instruction on safety and correct utilization of the equipment in order to prevent injury. Subjects were specifically instructed to avoid breath holding during lifting exercises. After the preliminary sessions, subjects were assessed for their 1 repetition maximum (RM), which is the maximum weight able to be lifted only once using correct form. The strength training program included 7 different exercises incorporating upper body and lower body muscle groups, namely: bench press, lat pulldown, leg press, bicep curls, tricep extensions, knee extensions, and seated row using a multi-station machine (Batca Fitness Systems, Raleigh, NC), and a heavy-to-light pyramid approach was utilized. For the first two weeks: individuals performed 1 set of 8-10 repetitions for each ST exercise; on Monday, the load was be 80% of 1 RM, and on Friday the load was 80% of 1 RM. During week 3 the number of sets increased to two sets per exercise, and the load for the first set was 80% of their current 1 RM, and the load for the second set was 80% of their current 1 RM. During weeks 4, 6, 8, and 10, three sets of 8-10 repetitions were completed on Monday. The 1st set was 80% of their current 1 RM, the 2nd set was 75% of their current 1 RM, and the 3rd set was 70% of their current 1 RM. On the Friday of each of these four weeks, 2 sets were completed. The intensities for these sets were 80% and 70% of their current 1RM, respectively. Three sets were completed on Monday and Friday of the 5th, 7th, and 9th weeks with the intensities of 80%, 75%, and 70% of their current 1 RM, for the 1st, 2nd and 3rd sets, respectively. Each set included 8 - 10 repetitions. The 1 RM of each strength exercise was reassessed, every other Wednesday, as stated above, to allow subjects to increase their resistance loads as the program progressed.

Stretching exercises developed based upon the ACSM Position Stand on the Recommended Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory and Muscular Fitness, and Flexibility in Healthy Adults (1998) were incorporated into a warm-up and cool-down period during each exercise session. At the beginning of each strength training session, there was a 10 minute warm-up period which included a 3-minute brisk walk and 7 minutes of stretching exercises for the muscle groups involved in the strength training. At the end of each training session, there was a 10 minute cool-down period which consisted of stretching exercises of all muscle groups used during the strength training session. Each resistance training session lasted about 45-60 minutes including warm-up and cool-down.

Data Analysis

Data were analyzed using the Statistical Package for Social Sciences (SPSS) for windows, version 10.0 software (SPSS Inc., Chicago, IL). Paired t-tests were used to analyze differences in muscle strength for each major muscle group, body weight, and body water volumes (ICW and ECW) from baseline to study conclusion. Independent samples t-tests were used to compare changes in parameters (body weight, muscle strength, ICW, ECW) in women on HRT compared to the women not taking HRT.

RESULTS

Subjects

All 11 subjects completed the 10-week periodized ST program with full compliance and with no report of any injuries. Subject characteristics at baseline are presented in Table 3.1.

Table 3.1 Subject Characteristics

Age (y)	65.1 ± 4.4
Height (cm)	165.0 ± 5.4
Weight (kg)	70.7 ± 14.3
BMI (kg/m^2)	25.9 ± 4.7

Values are means ± SD for 11 subjects.

On average, subjects were overweight, as defined by the most current guidelines (BMI of 25.0 to 29.9kg/m^2; US Department of Health and Human Services, 1998). At baseline, all subjects were weight-stable by self report. There were no significant changes in body weight over the course of the study.

Muscle Strength

Average muscle strength for all seven exercises (bench press, lat pulldown, bicep curl, tricep extension, leg press, leg extension, and row) significantly increased after 10 weeks of periodized ST (Table 3.2). The average percent change in 1 RM for each exercise from baseline to study conclusion are as follows: bench press 34.7%, lat pulldown 11.2%, bicep curl 24.1%, tricep extension 22.6%, leg extension 56.8%, leg press 15.0%, and row 29.5%. One of the subjects did not participate in the row exercise, due to a chronic injury that prevented her from performing the required motion; thus the percent change in muscle strength for this exercise included the data for only 10 subjects. No differences were detected between the two groups of women (HRT vs non-HRT) in terms of change in muscle strength.

Table 3.2. 1 RM Strength Measurements at Baseline and Study Conclusion

	Baseline	**Study Conclusion**	**Mean % Change**	**P-value**
Bench Press (lbs) n=11	25.91 ± 11.3	34.77 ± 10.6	34.7	P < 0.0001
Lat Pulldown (lbs) n=11	50.91 ± 9.2	56.59 ± 7.4	11.2	P = 0.035
Bicep Curl (lbs) n=11	14.55 ± 2.5	18.00 ± 2.8	24.1	P < 0.0001
Tricep Extension (lbs) n=11	24.32 ± 7.1	29.77 ± 4.1	22.6	P = 0.003
Leg Press (lbs) n=11	81.36 ± 16.8	93.41 ± 14.8	15.0	P = 0.004
Leg Extension (lbs) n=11	50.91 ± 15.1	82.05 ± 16.8	56.8	P < 0.0001
Row (lbs) n=10	54.25 ± 11.7	70.25 ± 8.6	29.5	P = 0.010

Values are means ± SD.

Body Weight and Water Distribution

Body weight and water measurements are presented in Table 3.3. Body weight remained stable over the course of the study. Neither ICW nor ECW changed after 10 weeks of periodized ST. No differences were detected when comparing women on HRT with those not on HRT in terms of change in body weight or water volumes (ICW and ECW).

Table 3.3. Body Weight and Body Water Distribution at Baseline and Study Conclusion

	Baseline	Study Conclusion
Weight (kg)	70.7 ± 14.3	71.2 ± 14.0
ICW (L)	15.6 ± 3.3	15.6 ± 3.2
ECW (L)	14.6 ± 2.6	14.7 ± 2.4
ECW:ICW	0.95 ± 0.009	0.94 ± 0.008

Values are means ± SD.

DISCUSSION

This study was unique in several aspects. This was one of the first studies to utilize a heavy to light periodization ST protocol to promote gains in muscle strength in postmenopausal women. This was also the first study to evaluate changes in ICW by BIS in postmenopausal women undergoing a periodized ST program. The most notable finding in this study was that muscle strength significantly increased in each of the trained muscle groups after 10 weeks of periodized ST. Furthermore, the heavy to light approach, as well as the high intensity and variation in volume, was well-tolerated by the participants. These findings are in agreement with Maddalozzo and Snow (1999), who studied perodized training in older women and men and concluded that older adults could participate in periodized training without injury. Furthermore, several of the women in the current study commented about their improved balance and stamina due to the ST.

The observed changes in muscle strength in this study were similar to the changes reported by other investigators. Interestingly, our postmenopausal women exhibited similar gains in muscle strength in the leg extension exercise (56.8%) after 10 weeks as compared to men aged 58 – 70 y (50.4%) after 16 weeks of ST reported by Hikida et al. (2000). Furthermore, our finding of a 28% gain in overall muscle strength after 10 weeks of ST was in agreement with the reported observation by Hakkinen et al. (2000) of a 29% increase in overall muscle strength after 16 weeks of ST in similar aged subjects. In contrast, muscle strength gains in the row exercise for our subjects differed from those reported by Yarasheski et al (1999). There was an average gain of 29.5% in women aged 60-74 y in the current study, while these investigators reported an average gain of 18.4% in both men and women aged 76-92 y. This discrepancy may be attributable to differences in the age of the subjects and/or the nature of the ST protocol utilized.

Neither ECW nor ICW measured by BIS changed over the course of the study. It was hypothesized that ICW would increase after a short-term ST program. This hypothesis was based upon several published studies of traditional ST in older men and women that had reported significant gains in muscle volume/area and/or muscle protein synthesis after short-term (9-16 weeks) ST (Yarasheski et al., 1993, 1999; Welle et al., 1995; Welle and Thornton, 1998). An increase in ICW would be expected to accompany any increase in intracellular protein (Beddoe et al, 1985). Although BIS has not specifically been validated against dilution measures for measuring ICW in postmenopausal women, it has been proven to provide valid measures of ICW in HIV-infected individuals (Earthman et al., 2000). There is no reason to believe that the methodology was not valid to measure ICW in this study population. Therefore, we conclude that no change in ICW occurred in our subjects. Although somewhat surprising, this finding was not entirely unexpected. Other investigators have reported no significant changes in FFM after ST interventions in older adults (Fiatarone et al., 1990; Tracy et al., 1999; Abe et al., 2000; Houtkooper et al., 2000; Ivey et al., 2000).

There are several possible explanations for this observation. While every attempt was made to standardize the training sessions to maximize the ST stimulus, there were several issues that might have interfered with obtaining maximal results. The women expressed perceived limitations to the amount of weight they felt they could safely lift during 1 RM testing. In an effort to minimize the risk of injury and non-compliance, we respected their reservations and modified our demands. Consequently, this may have led to an inadequate stimulus to cause muscle tissue growth (Kraemer, Fleck and Evans, 1996). In addition, several investigators have noted that one of the influences on muscle strength gains, particularly in the early phases of a ST program, is the stimulation of neural adaptations that occurs in response to ST (Porter et al., 1995; Kraemer, Fleck and Evans, 1996; Tracy et al., 1999; Hakkinen et al., 1998a,b; 2000; Ivey et al., 2000, Phillips, 2000; Roth et al., 2000). In fact, Kraemer, Fleck and Evans (1996) reviewed published data and suggested that neural factors can play a significant role in stimulating strength gains in response to a ST program that may not elicit an increase in cross sectional area (CSA). Furthermore, they suggest that the ability to activate all available motor units relies on the type of ST program utilized. In addition, they assert that if the ST program does not utilize the right intensity and volume, then it will not stimulate significant muscle tissue growth (Kraemer, Fleck and Evans, 1996).

CONCLUSION

In summary, we investigated muscle strength and ICW changes in healthy postmenopausal women after 10 weeks of a periodized ST program. Muscle strength in all major muscle groups exercised increased over the course of the study. All of the subjects fully complied with the heavy to light periodized protocol without incurring any injuries. There was no significant change in ICW or ECW in these women. Although mechanisms were not explored in this investigation, we conclude that the strength gains observed in this study were most likely attributable to neural adaptations (Porter et al., 1995; Kraemer, Fleck, and Evans, 1996; Hakkinen et al., 1998a,b, 2000). Additional research on the application of periodization for older adults is warranted.

Chapter 4: Summary and Recommendations

The purpose of this investigation was to determine if muscle strength would improve in postmenopausal women undergoing 10 weeks of high-intensity periodized ST. A secondary aim was to determine if ICW measured by BIS would increase in this same population after a short-term ST program.

Muscle strength was demonstrated to improve in all trained muscle groups after the 10-week ST program. The high-intensity heavy to light approach was well-tolerated by the women in the study, with full compliance and without injuries. Furthermore, several of the women in the study commented about their improved balance and stamina due to the ST.

The muscle strength gains observed in this investigation were not accompanied by any changes in ICW, as measured by BIS. This finding is supported by several other published studies that report no significant increases in muscle volume or FFM in older adults undergoing short-term ST. We had anticipated that a change in ICW might occur with a high-intensity periodized ST program. BIS has been proven to be valid in HIV-infected individuals and other populations; it is highly likely that BIS can provide accurate measures of ICW in this older population. The fact that we found no change in ICW does not diminish the utility of BIS-measured ICW as a surrogate measure for skeletal muscle mass. Indeed, the use of BIS in future ST studies would allow for more meaningful interpretation of FFM and skeletal muscle measures by DXA and other research methods, because it provides information regarding body water distribution. For example, any increase in FFM detected by DXA could be attributable to an increase in total body water, caused by an expansion of ECW. Furthermore, the capacity to measure ICW noninvasively, as a reflection of BCM, is valuable in its own right because it reveals important information about nutritional and health status, particularly useful for evaluating aging individuals. We affirm that BIS should be more thoroughly evaluated for its ability to document changes in ICW and BCM in ST intervention trials. Furthermore, periodized ST should be studied in larger population samples in comparison with other more traditional ST approaches in order to determine which ST approach is most effective in older women.

Recommendations for Future Research

Based on the findings of the present study and relevant literature, the following recommendations may be made.

1. A more comprehensive evaluation of periodized ST including a comparison with both traditional resistance ST and non-exercising control groups is warranted. This type of comparative study would help to determine the most effective means of ST for the older population. Studies need to focus on which method of ST is most suitable for obtaining the desired results for a specific population.
2. Future studies on periodization should involve longer term ST interventions so that changes in muscle volume and mass can be maximized.
3. Future studies should utilize a multi-method approach to body composition assessment in order to better define the changes that are occurring in the lean tissue compartment.
4. There is a lack of "normal" or expected values for ICW and ECW in older women and men. Normal ICW and ECW values need to be assessed in large study samples of older adults using BIS in order to obtain population-specific reference data.
5. Currently DXA, CT, and MRI are the techniques used to indirectly assess skeletal muscle mass changes in response to ST. All of these techniques are expensive, and require specialized equipment found primarily in research settings. There is a need for a field method that is able to assess specific changes in skeletal muscle mass. Measures of ICW (and thus, BCM) by BIS provide a noninvasive way to estimate skeletal muscle mass changes in field settings. Clearly, additional strength training studies involving the evaluation of ICW changes by BIS (preferably in conjunction with other research methods) need to be conducted.

Appendix A: Informed Consent Form

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
Informed Consent Form

Project Title: A Community-Based Strength Training Program to Increase Strength and Body Cell Mass in Apparently Healthy Postmenopausal Women.

I. The Purpose of this Research Project:

I am being invited to voluntarily participate in the above titled research study to assess the impact of a community-based strength training program on muscle strength and body composition in apparently healthy post-menopausal women. A secondary purpose of the study is to compare the ability of different methods of measuring body composition to detect changes in body composition. Approximately 50 adult post-menopausal women 60 years and older, who are apparently healthy and meet study inclusion/exclusion criteria, who do not have a pacemaker or other internally placed biomedical device, and who have not participated in strength training during the previous six months will be eligible to participate in this study.

II. Procedures:

If I agree to participate in this study, I will complete the following:

1. Come to the Senior Center for an initial screening appointment in order to read and sign an Informed Consent Form, and to complete two questionnaires regarding my health history and habits. At this initial meeting, I will be provided a Medical Clearance Form that I will take to my primary care physician in order to obtain written physician approval for study participation. I understand that I must obtain written approval from my primary care physician before I can continue with this study.
2. Come to the Senior Center for a second screening appointment with my Medical Clearance Form that has been completed by my primary care physician. At this appointment, I will undergo submaximal exercise testing, which will involve my walking on a treadmill while the treadmill's grade is increased every 2 to 3 minutes. Throughout this test, my heart rate, blood pressure, and rate of perceived exertion (my overall feeling) will be evaluated several times. The test will be stopped after 8 - 12 minutes, when I have reached 60% of my age-predicted heart rate maximum. If my response to this test is within normal limits, then I will be given instructions on how to record my dietary intake and what I need to do before reporting for body composition testing at Virginia Tech.

TWICE during the study, at BASELINE (after completion of the two screening appointments, and before I start the strength training program) and at STUDY CONCLUSION (at the end of the strength training program), I will complete the following:

3. Write down everything I eat or drink (and the amount) on two weekdays and one weekend day during the week before I come to the Bone, Osteoporosis, and Nutrition Evaluation (BONE) and Body Composition and energy Metabolism (BCM) Laboratory at Virginia Tech for testing.
4. Come to the BONE and BCM Laboratory at Virginia Tech in the morning after a 10 - 12

hour fast (nothing to eat after ~ 10:00 PM the night before). I will bring my food record with me, and while at the BONE and BCM Laboratory, I will complete the following:

   a. Provide ~60 ml of second void urine just after I arrive at the Lab. This means that I will urinate once at home in the morning so that the urine sample provided is from the second time of urination since midnight.
   b. Have my height and weight measured.
   c. Allow 6 teaspoons of blood to be taken from a vein in my arm with a sterile needle by a Licensed Medical Technician just after I provide the urine sample, and 4 more teaspoons of blood to be taken three hours later, for a total of 10 teaspoons.
   c. Drink a small measured dose of "heavy water" or deuterium oxide. This type of water tastes like regular drinking water, is nontoxic, and is naturally present in all drinking water and my body in small amounts.
   d. Drink a small measured dose of a 3% sodium bromide solution. Sodium bromide is a naturally occurring salt which is colorless, odorless, tastes like table salt, and is nontoxic in the amounts that I will be consuming.
   e. Collect all my urine in a bottle during the 3-hour period between blood draws.
   f. Have my resting energy expenditure (REE) measured by an indirect calorimeter. This involves reclining in a chair for 30 minutes before the measurement, during which time my blood pressure and body temperature will be measured. A ventilated canopy will then be placed over my head and shoulders, and I will breathe normally for 20 minutes while the instrument measures my REE.
   g. Have my body composition measured by bioelectrical impedance analysis (BIA) by three different devices. Four sticky electrodes will be placed on my right hand and foot, and then a small bioelectrical current that I will not be able to detect will be sent through wires attached to the electrodes. The BIA devices will measure the resistance of my body tissues to the flow of the current, and will provide a measurement of my body water, lean mass, and fat mass.
   h. Have my bone, lean, and fat mass measured by an x-ray scanner (called "dual-energy x-ray absorptiometry, or DXA"). This will involve lying on a padded table for 20 minutes while a scanner moves over my body.
   i. Answer questions about my health, ability to function, physical activity, and overall life satisfaction.

5. Have my physical strength assessed by a 1-RM test, which involves lifting the maximum amount of weight I can lift one time. I will complete this at the Senior Center during the third and final sessions of the strength training program.
6. Participate in a strength training program by coming to the Senior Center in Blacksburg, VA on three alternate days per week for approximately 45 minutes over a period of 12 weeks. During my participation in exercise, I understand that I will be expected to complete the physical activities involved in the program UNLESS symptoms such as fatigue, shortness of breath, chest discomfort, or similar occurrences appear. At that point, I understand it is my complete right to decrease or stop exercise, and it is my obligation to inform the program personnel of my symptoms. I understand that I will also be asked to provide information regarding any changes in my medical status, medications, and symptoms every week over the duration of the study.
7. Abstain from beginning any new exercise routine, i.e. maintain my normal activity pattern, throughout the duration of the study.

III. Risks:

My participation in this study may involve risks which are currently unforeseeable. If important information regarding the safety of the testing is discovered, I will be informed of it before continuing participation. I hereby agree to indemnify, defend and hold harmless Virginia Tech and the Commonwealth of Virginia and their officers, agents, and employees from any claims, damages and actions of any kind or nature whether at law or in equity, arising from or caused by my participation in this research study. Should an emergency/injury occur while I am participating in the strength training program at the Senior Center, or while I am at the BONE and BCM Laboratory at Virginia Tech, emergency services will be contacted immediately (Town of Blacksburg or Virginia Tech Rescue Squad, as appropriate depending upon the location of the emergency). During the time that I am participating in this study, I will be responsible for any medical expenses, including any expenses related to emergency service calls placed on my behalf, that I or the university should incur related to my medical treatment. I understand that Virginia Tech will not be responsible for any medical expenses I should require during the course of the study.

Several risks already known are the following:

1. I understand that exposure to radiation will occur during DXA scans for measurement of my bone mineral density. Radiation exposure will occur from the DXA scans because the DXA machine uses x-ray technology. Radiation exposure is measured in milliRads (or mR). My total amount of exposure is 20 mR (whole body = 1 mR, lumbar spine = 7 mR, hip = 7 mR, forearm = 5 mR) during each testing time and my cumulative total exposure is 40 mR if I complete all DXA scans throughout the 12 week study. Because my combined total exposure for the entire study represents 4% of the estimated exposure expected to increase cancer risk in only 0.03% of the population, I understand that this dose is very small, and poses minimal risk compared to radiation doses from dental bite-wing films (334 mR) and enviromental background exposure (100 to 400 mR per year) expected to occur in one 12-month period. The following table lists the radiation limits for an adult research participant according to the National Institutes of Health, Office for Protection from Research Risks (NIH-OPRR), compared to my exposure during this study.

NIH-OPRR Radiation Limits for an Adult Research Participant	**My Exposure During Participation in this Research Study**
Whole Body (single dose) = 3,000 mR	Whole Body (single dose) = 1mR
Whole Body (annual cumulative dose) = 5000 mR	Whole Body (annual cumulative dose) = 2 mR
Lumbar Spine (single dose) = 5,000 mR	Lumbar Spine (single dose) = 7 mR
Lumbar Spine (annual cumulative dose) = 15,000 mR	Lumbar Spine (annual cumulative dose) = 14 mR
Hip (single dose) = 5,000 mR	Hip dose (single dose) = 7 mR
Hip (annual cumulative dose) = 15,000 mR	Hip dose (annual cumulative dose) = 14 mR
Forearm (single dose) = 5,000 mR	Forearm (single dose) = 5 mR
Forearm (annual cumulative dose) = 15,000 mR	Forearm (annual cumulative dose) = 10 mR
	Annual Cumulative Exposure (whole body + lumbar spine + hip + forearm) = 40 mR during 12 week study.

I have been informed of this risk and may choose to not complete any one, combination, or all of these DXA scans. If in the event that any scan is unusable or unreadable, a replacement scan will not be conducted to avoid further exposure. These DXA scans will be conducted in the Bone, Osteoporosis and Nutrition Evaluation (BONE) and Body Composition and energy Metabolism (BCM) Laboratory, Room 229 Wallace Hall, on the Virginia Tech campus by the Director of the BONE Laboratory or Graduate Research Assistant who are both Licensed Radiologic Technologists - Limited in the Commonwealth of Virginia.

2. Deuterium oxide (heavy water) is colorless, odorless, tasteless, present in all drinking water, and is not toxic in the amount given.
3. Sodium bromide is colorless, odorless, tastes like table salt, is found normally in nature, and is not toxic in the amount given.
4. Blood will be drawn using sterile needles by a Licensed Medical Technician. During blood collections, there may be a slight discomfort from the needle puncture of the skin. There is also a chance that a bruise or swelling may occur where the needle is placed in my arm. Should an exposure incident occur, my blood will be tested for HIV, and the results of this test will kept confidential, and will only be shared with myself and the Licensed Medical Technician, should that be necessary.
5. Soreness will occur from strength training due to my untrained physical status. Before I begin the strength training program and before I do the 1 RM test, I will be thoroughly instructed on how to properly and safely operate the weight equipment, and how to breathe while engaging in the strength training exercises. I will be supervised during each strength training session by a certified Health/Fitness Instructor to ensure that I am using proper lifting and breathing techniques.
6. There is a remote possibility during exercise of adverse changes, including abnormal blood pressure, fainting, and disorders of heart rhythm, and very rare instances of heart attack or even death. Every effort will be made to minimize these risks by proper staff assessment of

my condition and by obtaining approval from my primary care physician before enrollment in this study. In addition, all strength training sessions will be supervised by an individual who is American College of Sports Medicine (ACSM) Health/Fitness Instructor Certified who holds current CPR, First Aid, Blood Borne Pathogens, and Aerobics and Fitness Association of America certifications.

IV. Benefits of this Research Project:

There are no guaranteed benefits to participating in this study. However, I will be told about aspects of my body composition and physical strength, which might be useful to me.

V. Extent of Anonymity and Confidentiality:

All information concerning my participation and any results of the various tests done in the study will be kept strictly confidential. I will be assigned a code number, which will be recorded on the consent form, as well as any data collection forms used for the study. I understand that my consent form and a master list of participants' names and code numbers will be kept in a locked filing cabinet separate from my data, which will also be stored in a locked filing cabinet. Only investigators or their students will be allowed access to the data collected in this study. Should results of this study be reported or published, no individual subjects' names will be used. All data will be filed according to a number identification coding system.

VI. Compensation:

I will not be charged for any of the procedures or materials used in this study. No compensation will be provided to me for my participation in this study.

VII. Freedom to Withdraw:

I am free to withdraw from participation in this study without penalty at any time by simply telling or calling one of the staff members or principal investigators listed at the bottom of this page.

VIII. Approval of Research:

This research project has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute and State University, by the Department of Human Nutrition, Foods and Exercise, and the Senior Center of Blacksburg, VA.

XI. Subject's Responsibilities:

I voluntarily agree to participate in this study. I have the following responsibilities:

1. I will come to the Senior Center for an initial screening appointment for 30 minutes to read and sign an Informed Consent Form and to complete two health questionnaires.
2. I will take a Medical Clearance Form to my Primary Care Physician to obtain written approval to participate in this study.
3. I will bring my signed Medical Clearance Form to the Senior Center for a second screening appointment, where I will undergo a submaximal exercise test as described under section II. Procedures. It is expected that these screening procedures will take approximately 1 hour of my time.

3. I will record my dietary intake for two weekdays and one weekend day during the week prior to reporting to the BONE and BCM Laboratory (229 Wallace Hall) at Virginia Tech.
4. Come to the BONE and BCM Laboratory at Virginia Tech in the morning after a 10 - 12 hour fast (nothing to eat after ~ 10:00 PM the night before), having abstained from exercise, and alcohol and caffeine consumption for 24 hours prior. I will bring my food record with me, and during the 3 ½ hours that I will be at the BONE and BCM Laboratory, I will complete the following:
    a. Provide ~60 ml of second void urine just after I arrive at the Lab. This means that I will urinate once at home in the morning so that the urine sample provided is from the second time of urination since midnight.
    b. Have my height and weight measured.
    c. Allow 6 teaspoons of blood to be taken from a vein in my arm with a sterile needle by a Licensed Medical Technician just after I provide the urine sample, and 4 more teaspoons of blood to be taken three hours later, for a total of 10 teaspoons.
    c. Drink a small measured dose of “heavy water” or deuterium oxide.
    d. Drink a small measured dose of a 3% sodium bromide solution.
    e. Collect all my urine in a bottle during the 3-hour period between blood draws.
    f. Have my resting energy expenditure (REE) measured by an indirect calorimeter. This will take approximately 50 minutes.
    g. Have my body composition measured by bioelectrical impedance analysis (BIA) by three different devices.
    h. Have my bone, lean, and fat mass measured by an x-ray scanner (called “dual-energy x-ray absorptiometry, or DXA”). This will involve lying on a padded table for 20 minutes while a scanner moves over my body.
    i. Answer questions about my health, ability to function, physical activity, and overall life satisfaction.
5. Have my physical strength assessed by a 1-RM test, which involves lifting the maximum amount of weight I can lift one time. I will complete this at the Senior Center during the third and final sessions of the strength training program.
6. Participate in a strength training program by coming to the Senior Center in Blacksburg, VA on three alternate days per week for approximately 45 minutes over a period of 12 weeks. During my participation in exercise, I understand that I will be expected to complete the physical activities involved in the program UNLESS symptoms such as fatigue, shortness of breath, chest discomfort, or similar occurrences appear. At that point, I understand it is my complete right to decrease or stop exercise, and it is my obligation to inform the program personnel of my symptoms. I understand that I will also be asked to provide information regarding any changes in my medical status, medications, and symptoms every week over the duration of the study.
7. Abstain from beginning any new exercise routine, i.e. maintain my normal activity pattern, throughout the duration of the study.

X. Subject's Permission:

I have read and understand the informed consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

Printed Name of Participant	Signature of Participant	Date

Identification Number (will be assigned)

Signature of the Investigator Date

Should I have any questions about this research or its conduct, I may contact any of the following individuals:

Carrie P. Earthman, Ph.D., R.D. Investigator	Phone: 231-7421
Kathleen Poole, Ph.D. Investigator	Phone: 231-3402
David M. Moore, Ph.D. Chair, Virginia Tech Institutional Review Board	Phone: 231-4991

Appenidx B:

The Physical Activity Readiness Questionnaire - PAR-Q

PAR Q & YOU

Regular fitness activity is fun and healthy, and increasingly more people are starting to become more active everyday. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. Common sense is your best guide when you answer these questions.

Please read the questions carefully and answer each one honestly: Check YES or NO.

YES NO

☐ ☐ 1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

☐ ☐ 2. Do you feel pain in your chest when you do physical activity?

☐ ☐ 3. In the past month, have you had chest pain when you were not doing physical activity?

☐ ☐ 4. Do you lose your balance because of dizziness or do you ever lose consciousness?

☐ ☐ 5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?

☐ ☐ 6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?

☐ ☐ 7. Do you know of any other reason why you should not do physical activity?

If you answered YES to one or more questions:

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

You may be able to do any activity you want - as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those that are safe for you. Talk with you doctor about the kinds of activities you wish to participate in and follow his/her advice.

Find out which community programs are safe and helpful for you.

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

Start becoming much more physically active - begin slowly and build up gradually. This is the safest and easiest way to go.

Take part in a fitness appraisal - this is an excellent way to determine you basic fitness so that you can plan the best way for you to live actively.

DELAY BECOMING MUCH MORE ACTIVE:

If you are not feeling well because of temporary illness such as a cold or fever - wait until you feel better; or

If you are or may be pregnant - talk to your doctor before you start becoming more active.

Please note: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change you physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

I have read, understood, and completed this questionnaire. Any questions I had were answered to my full satisfaction.

____

Name

____

Signature Date

____

Signature of Parent or Guardian (for participants under the age 18) Witness

Appenidx C: Health Status Questionnaire

Name ____________________________   Date___________________

Please answer the following questions about your health/medical history.

Age_______________   Date of Birth____________

Have you had a physical examination within the last 12 months?

Yes   No

What is the present state of your general health?

Excellent
Good
Fair
Poor

In case of an emergency when you are at the BCM Laboratory for testing, we would appreciate knowing the contact information for your primary care physician.

Physician's Name__________________ Telephone#: ____ - ______

Are you presently taking any medications? (Please list)

____

Current Weight ___________   Height ________

Recent weight loss or gain?

(If so, please circle one, and specify estimated pounds lost or gained)__________

Please list any recent illnesses:

____

Please list any conditions leading to hospitalization during the last 5 years:

____

Please list any allergies that you have, including medications and environmental allergens:

____

When was the last time you had a menstrual period?

____

Have you had a hysterectomy? Yes No

Are you on hormone replacement therapy? Yes No

If so, approximately when did you start hormone replacement therapy?____________________________

Please check the box in front of the medical conditions that apply to you:

Anemia	High blood pressure
Arthritis/Bursitis	History of heart or stroke problems in immediate family
Asthma	Hypoglycemia
Chest pains	Indigestion
Chest discomfort while exercising	Joint pain in ______________________
Diabetes	Leg pain with walking
Difficulty with hearing	Lung disease
Difficulty with vision	Low back condition
Dizziness or balance problems	Obesity (20+ lbs overweight)
Heart condition	Orthopedic problems (please specify:______________)
Hernia	Osteoporosis
High blood cholesterol	Shortness of breath

Smoking history:

Never smoked Currently Smoke Smoked in Past

If you are currently a smoker, please indicate amount smoked per day:

1/2 pack/day ½-1 pack/day 1-2 packs/day > 2 packs/day

Alcohol Consumption: None 1-2 drinks/week >2 drinks/week

What kind of caffeine-containing beverages do you consume on a regular basis?

Coffee
Tea
Cola drinks
Other:______________________________________

Do you take any natural herbal or soy-based supplements? Yes No

If so, please list:____

____

How often do you consume soy foods (soy milk, tofu, tempeh, etc.,)?

___ times per week ___ times per month ___ times per year

Please specify the soy foods you typically consume:

____

Would you classify yourself as a vegetarian? Yes No

If so, please check one:

Vegan (consume no animal products at all)

Lacto-ovo vegetarian (consume milk & eggs)

Other (please specify): _____________________________________

Appendix D: Inclusion and Exclusion Criteria

***Inclusion criteria**:*

Subjects will be included in the study who:

1. are apparently healthy, as assessed by the PAR-Q questionnaire (Appendix B) and Health Status Questionnaire (Appendix C) during screening, and as determined by the individual's primary care physician, evidenced by the primary care physician's Medical Clearance Form (Appendix D).
2. are 60 years of age or older.
3. have not engaged in a strength training regimen for the preceding 6 months.
4. have had a physical examination within the preceding 12 months.

***Exclusion criteria**:*

Subjects will be excluded from the study who:

1. have a medical history and/or current diagnosis of chronic diseases or conditions that preclude maximal exercise (cardiovascular disease, pulmonary disease, diabetes mellitus, chest discomfort during exercising, high blood pressure (>140/90 mm Hg), shortness of breath, or any other medical condition determined to preclude maximal exercise by the primary care physician of the individual.

2. exhibit abnormal responses to submaximal exercise testing. Significant findings leading to exclusion would include: angina upon exertion, hypertensive response to exercise (SBP>240mmHg or DBP>120 mmHg), or if heart rate does not increase with increasing intensity of the submaximal test.

3. have had a menstrual period within 1 year of the start date of the study.

4. ***exhibit two or more of the following characteristics:*** have a total plasma cholesterol >240 mg/dl or a plasma LDL cholesterol of > 160 mg/dl; smoke more than 1/2 PPD; OR are obese, defined as a body mass index (BMI; kg/m^2) above 30 or a waist girth > 100 cm.

5. have undergone major surgery such as any surgery involving major organs or orthopedic surgery within the past 6 months.

6. have a pacemaker or other internal electrical biomedical device.

7. have initiated hormone replacement therapy within the past 3 months.

8. are on any of the following medications: nitrates, digitalis/digitoxin, antiarrhythmic medications, beta blockers, calcium channel blockers, vasodilators, or ACE inhibitors.

Appendix E: Medical Clearance Form

The following individual has expressed interest in participating in a 12-week study involving a strength training program. Apparently healthy, post-menopausal women 60 years and older who meet the study inclusion/exclusion criteria, who have had a physical examination within the last 12 months, and who have physician approval to participate in a strength training exercise program will be asked to participate in this study.

____________________________________	____________________________________
(Name)	(Signature)

____
(Social Security Number)

Studies requiring use of human subjects will be supervised by trained personnel within the Department of Human Nutrition, Foods and Exercise using facilities and procedures designed for this purpose. The strength training program will be conducted in conjunction with the Senior Center in Blacksburg, Virginia using the weight training facilities there. A certified health fitness instructor who holds current CPR and First Aid certifications will supervise all strength training sessions and submaximal exercise testing. The strength training program will involve pyramid training with weight machines 3 alternate days per week for 12 weeks. Pyramid training is lifting heavier weight for the first set, then lighter weight for the remaining sets. The heaviest amount an individual will lift will be 70-80% of the maximal amount of weight she can lift three times consecutively (3 repetition max). Pending physician approval, and prior to enrollment in the study and initiation of the strength training program, all potential study participants will undergo submaximal exercise testing to be further screened for study eligibility. Submaximal exercise testing will require the individual to walk on a treadmill while the treadmill's grade is increased every 2-3 minutes. Heart rate and blood pressure will be monitored during the submaximal test.

MEDICATIONS:
Please list all medications the above individual is taking, including any medications that will affect her heart rate response to exercise and indicate the manner of the effect (raises, lowers, or has no effect on heart rate response):

____
____
____
____

PHYSICIAN'S RECOMMENDATION:

I have reviewed the clinical record/examined the above individual and

__________ do **NOT** find a medical or physical condition that precludes

__________ **do** find a medical or physical condition that precludes

her participation in the proposed study to be conducted under the supervision of qualified personnel in the Department of Human Nutrition, Foods and Exercise at Virginia Tech.

Please identify any **recommendations** or **restrictions** that are appropriate for your patient in this strength training program:

____

____
(Physician's name)

____ _____________________
(Physician's signature) (Date)

For additional information about the study, please contact:

Carrie P. Earthman, PhD, RD (Principal Investigator)
Department of Human Nutrition, Foods and Exercise
253 Wallace Hall
Virginia Tech
Telephone: (540) 231-7421
E-mail: cpearth@vt.edu

Appenidx F: Standardized Protocol for BIS Measures

- Subjects refrained from exercise and avoided alcohol and caffeine consumption for 24 hours prior to testing.

- Subjects voided urine at least 30 minutes prior to testing.

- Subjects were in a fasted condition, and were advised not to consume large amounts of water within 4 hours of the test.

- Subjects rested in a supine position on a nonconductive surface in a room with a normal ambient temperature (~35 degrees Celsius). Bioimpedance measures were taken on the right side of the body, using the right foot and the right hand.

- The subject's skin was cleaned at the electrode sites with an alcohol pad.

- The sensor (proximal) electrodes were placed on (a) the dorsal surface of the wrist so that the upper border of the electrode bisects the head of the ulna, and (b) the dorsal surface of the ankle so that the upper border of the electrode bisects the medial and lateral malleoli.

- The source (distal) electrodes were placed at the base of the second or third metacarpal-phalangeal joints of the hand and foot. It was ensured that at least 5 cm lie between the proximal and distal electrodes.

- The lead wires were attached to the appropriate electrodes. Red leads are attached to the wrist and the ankle, and black leads are attached tot he hand and foot.

- The subject's legs and arms were abducted approximately 45 degrees to each other. There should be no contact between the thighs and between the arms and the trunk.

Appendix G: Raw Data

Subject n=11	Weight (kg)	ICW (L)	Bench Press (lbs)	Bicep Curl (lbs)	Tricep Extension (lbs)	Lat Pulldown (lbs)	Leg Press (lbs)	Leg Extension (lbs)	Row (lbs)
98001									
Baseline	77.5	16.71	20	15	20	60	90	50	
Final	77.9	16.18	40	16	30	52.5	100	60	
Change	0.4	-0.530	5.0	1.0	10.0	-7.5	10.0	10.0	
98002									
Baseline	103.8	24.38	40	15	30	50	90	50	40
Final	103.1	24.16	50	20	37.5	62.5	90	75	87.5
Change	-0.7	-0.220	10.0	5.0	7.5	12.5	0.0	25.0	47.5
98003									
Baseline	70.1	17.83	50	20	40	70	120	50	80
Final	72.1	17.80	50	23	35	70	115	90	70
Change	2.0	-0.030	0.0	3.0	-5.0	0.0	-5.0	40.0	-10.0
98004									
Baseline	76.7	14.14	22.5	15	17.5	45	80	60	52.5
Final	76.9	14.52	30	20	25	65	97.5	85	70
Change	0.2	0.380	7.5	5.0	7.5	20.0	17.5	25.0	17.5
98005									
Baseline	55.0	14.08	30	12	20	60	90	60	60
Final	56.2	14.52	35	15	30	60	110	75	70
Change	1.2	-0.880	5.0	3.0	10.0	0.0	20.0	15.0	10.0
98006									
Baseline	68.7	14.12	10	12	20	40	60	20	50
Final	68.8	14.09	17.5	15	27.5	45	65	72.5	52.5
Change	0.1	-0.030	7.5	3.0	7.5	5.0	5.0	52.5	2.5
98007									
Baseline	50.3	12.35	20	12	20	50	70	50	40
Final	50.8	11.99	35	18	25	50	100	110	72.5
Change	0.5	-0.360	15.0	6.0	5.0	0.0	30.0	60.0	32.5
98008									
Baseline	63.9	13.22	20	15	30	40	60	70	50
Final	64.0	14.03	25	16	30	52.5	80	85	65
Change	0.1	0.810	5.0	1.0	0.0	12.5	20.0	15.0	15.0
98009									
Baseline	79.4	15.25	20	15	20	50	70	80	60
Final	80.0	15.26	40	20	25	60	110	102.5	75
Change	0.6	0.010	20.0	5.0	5.0	10.0	40.0	22.5	15.0
98010									
Baseline	61.5	14.68	20	12	20	50	75	30	60
Final	61.9	14.93	30	15	30	52.5	77.5	60	70
Change	0.4	0.250	10.0	3.0	10.0	2.5	2.5	30.0	10.0
98011									
Baseline	70.8	14.67	32.5	17	30	45	80	50	50
Final	70.9	15.87	45	20	32.5	52.5	90	80	70
Change	0.1	1.200	12.5	12.5	2.5	12.5	10.0	30.0	20.0

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