BODY COMPOSITION AND MUSCULAR STRENGTH IN ELITE COMPETITIVE ATHLETES AND HEALTHY CONTROLS AGED 65 AND OLDER

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Sarah Elizabeth Hunt, M.S

University of Pittsburgh, 2007

Purpose: The purpose of this study is to determine if components of body composition differ between elite competitive older athletes and community-dwelling ambulatory controls and to examine the relationships between the components of body composition and the relationship between the components and strength.

Methods: One-hundred Senior Athletes from the 2005 National Senior Games and 86 healthy controls participated. Body composition was measured by dual-energy x-ray absorptiometry (DXA). The DXA scans provided measures of bone mineral density (BMD), bone mass, mineral free lean mass percentage (MFLP), and fat mass percentage (FMP) including regional measures (trunk, legs and arms) of body composition. Isometric strength of the quadriceps and hamstrings was measured.

Results: One factor ANOVAs (α=.05) were performed to assess regional FMP and regional MFLP. Controls had a significantly higher FMP in every body region than athletes. Athletes had a significantly higher MFLP of the arm and leg than controls. Correlational analyses (α=.05) were also performed to examine the relationship between MFLP and strength, MFLP and BMD, and FMP and BMD. Athletes had a stronger correlation between flexion strength values and MFLP of the leg and Controls showed a stronger correlation between extension strength values and MFLP of the leg. Significant correlations were found for the relationship between MFLP and BMD, with stronger correlations in the athlete group. Significant correlations between BMD and FMP were found in all regions except the trunk for all groups.

Discussion: Our predominant findings were that, as expected, all regional measures of body fat were higher in control subjects than in athletes. This study showed that all regional measures of lean muscle mass were greater in athletes than in control subjects. This indicates that physical activity may help to prevent the decrements associated with the aging process even well in to the 7^{th} decade of life.

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DEDICATION

I would like to dedicate this dissertation to two incredible and influential people in my life, without whom I would not be here today, Alice M. Meadows and Billy L. Coffindaffer, Ph.D.

My grandmother Alice M. Meadows was the first person I told that I was going back to school to get my Ph.D. I remember that night very well; she seemed so excited at the thought of having two of her grandchildren to call "Doctor" (the other being my cousin who had finished her M.D. a few years before). That night was also the last night I spoke with her, since she passed away two days later from complications of surgery. When I was in undergrad and getting my master's my grandma would always call late at night just to say hi or see how things were going. Those calls always seemed to come at the times when I thought I was never going solve a problem, get a paper written, or even just make it through in general. During my work for my doctorate the thing that I would think of most when I thought there was no end in sight and that it was just too tough to continue was how happy she was the night I told her of my plans and how I could not let her down. There are many other reasons, too numerous to list, that I feel that she has helped me become who I am today. However, her undying support and unconditional love is why I would like to dedicate this dissertation in her memory.

Billy L. Coffindaffer became my grandfather when I was eleven. Bill was the first person I knew who had a Ph.D., something at the time I had never even thought of pursuing. As a kid, I was always announcing these grand ideas of what I would be doing next, where I would be going, and who I would become. When I would do this, Bill's response was always an astounding "GREAT" often followed by "you know we expect great things". There was never a question in my mind that he thought, without a shadow of a doubt, that I could accomplished

whatever idea I had just so boldly announced, even if I wasn't so sure I could. So when I blurted out that I would be going to pursue my doctorate, he was right there telling me how he was sure I could do it. I was never more honored than when Bill and my grandmother, Norma, were at graduation and were able to see me receive my hood.

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1.0 INTRODUCTION

It is common knowledge that as we age we start to experience difficulties in performing tasks that in our younger years seemed effortless. Many studies have confirmed what people have known for years, the aging process in itself causes a variety of physiological decrements including, but not limited, to decreases in muscle mass, bone mass, strength, bone density, and cardiovascular function, and increases in visceral fat mass, total body fat, and intramuscular lipid accumulation. [234, 286] With this knowledge, several studies have set out to find the role of exercise in the prevention of such declines associated with aging. Many studies have turned to the Master Athlete as the ideal model of successful aging due to his or her chronic participation in high-intensity exercise.[113] Using the Master Athlete as an ideal model helps separate the modifiable changes associated with aging from the immutable biologic changes.[286]

In the aging population, total body composition needs to be examined in order to assess health risks. With aging, total body fat increases as well as the risks associated with such gains.[23, 24, 27] However, elderly people also have less muscle mass, expanded extracellular fluid volumes, and reduced body cell mass compared to younger adults.[24, 27] This illustrates the importance of both fat and non-fat components in influencing the health of the elderly. Body composition alterations in the elderly are due to a complicated combination of factors, including hormonal changes that regulate metabolism, dietary intake, and nutrient absorption.[19, 91, 268]

With aging, an increase in total and visceral fat mass is often seen. Along with a decline in muscle and bone mass, these changes in fat mass may affect metabolic, cardiovascular, and musculoskeletal function negatively even in the absence of overt disease.[126, 215] A decrease in total fat accumulation and visceral adiposity may be related to an increase in endurance type physical activity in women and men.[58, 129, 153]

The decrements associated with aging often accompany functional loss and frailty in older adults. Sarcopenia, the decline in skeletal muscle mass, is considered a major contributing factor to the loss of functional independence and frailty in these individuals. [264, 266] Young et al. (1984, 1985) showed 25-35% reductions in cross-sectional area of the quadriceps muscle in older men and women as compared with young controls.[342, 343] The apparent loss of muscle mass and strength is strongly associated with aging and may accelerate after 65 years of age.[27, 90] Sarcopenia, however, can be slowed or reversed with high-intensity progressive resistance exercise.[265] Studies on strength trained Master Athletes have shown significantly greater muscle mass, improved architecture, and function when compared with sedentary controls of similar age.[151, 288-290]

Aging is also associated with losses in bone mass and density.[286] Although genetics has been found to be the primary determinant of bone mass in adults in a twin study by Pocock et al.[224], many factors play a role in the attainment of peak bone mass and the rate of loss during middle and old age.[179] Some of these factors include physical activity, body composition, hormonal status, and nutrition.[66, 108, 254] Exercise has been positively associated with higher bone mineral density in populations ranging from adolescents to elderly females.[157, 213, 258]

Exercise seems to play a role in preventing or slowing all of the age-related declines mentioned above. This leads us to question the extent to which we can slow or prevent the decrements associated with aging. In order to answer this question, more research is needed on life-long participation in exercise and its effects on age-related declines in muscle mass and strength, bone mass and density, and increases in body fat as an ideal model for aging. It is also important to examine the relationship between various body composition measures to determine what effect, if any, they have on each other.

1.1 STATEMENT OF THE PROBLEM

With many advances in medicine, humans are living longer than ever before. Because losses of muscle and bone mass, muscle strength, and increases of body fat contribute to the loss of independence and induce frailty in many of the nation's elderly, the quest to find the remedy to combat the ills of aging is increasing in importance. The goal of this study is to examine the role of elite competitive exercise into the 7th and 8th decade on the body composition changes and strength losses associated with aging. The results of this study should suggest future research questions and exercise interventions that will increase the quality of life for the growing elderly population.

1.2 OBJECTIVE OF THE STUDY

Body composition changes with aging, specifically those related to changes in fat mass, fat distribution and muscle mass, are common among the general population, even though body weight may remain unchanged. [89] However, few have looked at the effect of elite competitive participation in exercise into the 7th and 8th decade on these parameters. The purpose of this study is to determine if various components of body composition differ between elite competitive older athletes and community-dwelling ambulatory controls and to examine the relationships between the components of body composition and strength. Specifically, to examine the relationship between the muscle mass and strength, regional body fat distribution and strength, and regional body fat distribution and muscle mass, bone mineral density and bone mass in community-dwelling ambulatory controls and elite competitive older athletes.

1.3 SPECIFIC AIMS AND HYPOTHESES

Specific Aim 1. To determine the difference in regional adiposity between male and female elite competitive athletes age 65 years and older and community-dwelling ambulatory controls of the same age.

Hypothesis 1. It is hypothesized that regional adiposity will differ between elite competitive athletes age 65 years and older and community-dwelling ambulatory controls.

Hypothesis 1a. It is hypothesized that female elite competitive athletes aged 65 years and older will have lower percentage of abdominal, leg and arm adiposity than will female community-dwelling ambulatory controls.

Hypothesis 1b. It is hypothesized that male elite competitive athletes aged 65 years and older will have lower percentage of abdominal, leg and arm adiposity than will male community-dwelling ambulatory controls.

Specific Aim 2 To determine the difference between regional mineral free lean mass between male and female elite competitive athletes age 65 years and older and community-dwelling ambulatory controls of the same age.

Hypothesis 2a It is hypothesized that mineral free lean mass of the arm and leg will be greater in female athletes than in female controls age 65 years and older.

Hypothesis 2b It is hypothesized that mineral free lean mass of the arm and leg will be greater in male athletes than in male controls age 65 years and older.

Specific Aim 3. To determine the relationship between thigh mineral free lean mass and thigh muscle strength in a sample of athletes; in a sample of controls; and in a combined sample of athletes and controls.

Hypothesis 3. It is hypothesized that thigh mineral free lean mass will have positive correlation with thigh muscle strength in all samples.

Specific Aim 4. To determine the relationship between mineral free lean mass of the arm and leg and bone mineral density in a sample of athletes; in a sample of controls; and in a combined sample of athletes and controls.

Hypothesis 4. It is hypothesized that regional mineral free lean mass will have a positive correlation with bone mineral density in all samples.

Specific Aim 5. To determine the relationship between regional fat mass and bone mineral density in a sample of athletes; in a sample of controls; and in a combined sample of athletes and controls.

Hypothesis 5a. It is hypothesized that abdominal fat mass and bone mineral density will have a positive correlation in all samples.

Hypothesis 5b. It is hypothesized that leg fat mass and bone mineral density will have a positive correlation in all samples.

Hypothesis 5c. It is hypothesized that arm fat mass and bone mineral density will have a positive correlation in all samples.

1.4 DELIMITATIONS OF THE STUDY

Subjects will be included in the study if they meet the following criteria:

- Free of chronic obstructive pulmonary disease, myocardial infarction, or coronary artery disease
- No history of cerebral vascular accident or a history of transient ischemic attacks
- Free of joint replacements, rheumatoid arthritis, gout, bilateral hip replacement, lumbar spine surgery or osteoarthritis severe enough to limit activity
- Does not use a cane or walker
- No history of osteoporosis for which the subject has received treatment
- Does not currently use antidepressant drugs or any drugs that may interfere with neurological, musculoskeletal, or cognitive function
- No history of insulin dependent diabetes mellitus, or neurological or rheumatologic disorders that might interfere with sensory input.
- No recent history of fractures, ligament reconstruction, or sprain within the past 12 months
- Free of any other disease, injury, or disorder that may affect strength or balance
- Individuals who have a life long history of competitive activity defined as 20 years or longer
- Subjects who are not on medications that can prevent bone loss (e.g., oral or intravenous bisphosphonates, calcitonin, SERMs, and parathyroid hormone) or cause bone loss (glucocorticoids for greater than 3 months over the last year, certain anticonvulsants, anabolic steroids)
- Free of diseases known to affect bone mineral metabolism (hyperthyroidism, hyperparathyroidism, end stage renal or liver disease)
- No history of cancer within the past 5 years, though subjects with a more recent history of relatively benign skin cancers such as basal cell or squamous cell carcinoma are not excluded

1.5 LIMITATIONS OF THE STUDY

The research study was limited by all of the following:

1. All subjects for this research were volunteers; no attempt was made to control the sample for self-selection.
2. No attempt was made to control for genetics as a determinant of bone mineral density, body composition or body fat distribution.
3. No attempt was made to control for dietary intake as a factor in body composition.
4. No attempt was made to control for calcium intake.
5. All subjects entering the study were assumed to comply to the best of their ability with the methods of testing.
6. No attempt was made to control for growth hormone or testosterone use.
7. Testing took place during two consecutive summer months.
8. The researcher assumed that all subjects answered questions about participation in exercise honestly.
9. The subjects were not recruited from the same geographical area.
10. Control subjects could participate in recreational exercise. However, they were not participants of the Senior Olympics.

1.6 DEFINITION OF TERMS

Abdominal Adiposity: Fat (adipose tissue) that is centrally distributed between the thorax and pelvis and that induces greater health risk.

Bone Mineral Density: The mineral content in a given volume of bone, used as a measure of bony health and in the diagnosis of osteoporosis.

DXA: Dual energy X-ray absorptiometry is a means of measuring bone mineral density (BMD). Two X-ray beams with differing energy levels are aimed at the patient's bones. When soft tissue absorption is subtracted out, the BMD can be determined from the absorption of each beam by

bone. DXA is the most widely used and most thoroughly studied bone density measurement technology.

Fat mass: The absolute amount or mass of body fat.

Fat free mass: The mass of the body that is not fat, including muscle, bone, skin, and organs

Growth Hormone: An anabolic agent that stimulates fat metabolism and promotes muscle growth and hypertrophy by facilitation of amino acid transport into the cells.

Kyphosis: Posterior convex angulation of the spine.

Muscular strength: The ability of a muscle to exert force.

Osteoporosis: A disease characterized by low bone mineral density and microarchitectural deterioration of bone tissue leading to enhanced bone fragility and a consequent in fracture risk.

Sarcopenia: The loss of muscle mass associated with aging.

Torque: The moment of a force; the measure of a force's tendency to produce torsion and rotation about an axis, equal to the vector product of the radius vector from the axis of rotation to the point of application of the force and the force vector.

2.0 REVIEW OF LITERATURE

Exercise has been touted as an effective intervention to reduce or prevent a number of functional declines associated with aging.[1] Exercise has been shown to reduce risk factors associated with disease states, improve health status and contribute to an increase in life expectancy.[1] Exercise is also important in combating the negative effects of age-related sarcopenia.[113] While the master athlete has been proposed as the ideal model of aging due to their chronic participation in high intensity exercise, the influence of chronic exercise on body composition, muscle mass, and muscle strength has not been extensively studied.[37, 113]

In this chapter, components of body composition, total body and regional measures, and the effects of exercise on each component will be discussed. The chapter will also include a discussion of muscular strength and how it is affected by exercise. The methodology, including equipment and procedure background, will also be included.

2.1 BODY COMPOSITION

Body composition has been shown to change dramatically with increasing age.[23, 162, 164, 271] Aging is associated with an increase in fat mass which is positively correlated with metabolic syndrome, which is defined by a cluster of risk factors that include obesity, hypertension, hypoglycemia, and dyslipidemia.[96] According to several studies, body weight increases until approximately 60 years of age, followed by a period of marked decline in weight in more than 60 percent of the population.[36, 43, 259, 282, 333] Longitudinal studies have confirmed that the weight gain is characterized by a greater percentage of fat than lean tissue. The risks associated with increases in body fat are more widely recognized. Aging is also associated with declines in

muscle and bone mass, expanded extra cellular fluid volumes, and reduced body cell mass.[23] According to Allen et al. and Pierson et al., lean mass peaks in the third and fourth decade of life, followed by a steady decline with advancing age.[9, 220] The loss of muscle mass is associated with weakness, disability, and morbidity.[25, 84, 126]

Health of the elderly person is best assessed by looking at all components of body composition. This is especially important due to the conflicting literature regarding the sources of major disability. Frailty is a term that is applied to elderly people who are at increased risk of mortality due to multiple problems with cognitive abilities, physical functioning, nutritional status, endocrine status, and quality of life.[99] Some of the literature points to the loss in lean mass as the major predictor of functional decline and frailty, whereas others point to excess fat mass as the most important predictor.[57, 301, 324, 326] According to Villareal et al., obesity was a major cause of physical dysfunction in community dwelling elderly. However, the frailty of these obese elderly was also associated with a low amount of fat free mass, such as muscle, and poor muscle quality.[323]

2.1.1 BODY FAT

According to Villareal et al., obesity is defined as an unhealthy excess of body fat, which increases the risk of medical illness and premature mortality.[322] While the prevalence of obesity has increased in all age groups in the last 25 years, the number of elderly obese has increased markedly because of both the increase in the number of older people and the increase in the number of older obese.[81, 114, 159] In the age group 60-69 years of age, the prevalence of obesity increased from 14.7% in 1991 to 22.9% in 2000 and in the age group of greater than 70 years of age, the prevalence increased from 11.4% to 15.5%.[195, 196]

Body mass index (BMI) is a measure used to classify medical risk by weight status in most populations. This is usually due to the fact that the technology needed to assess body fat percentage is not readily available. Also, it requires a knowledge base to perform and interpret. BMI is a measure of the relationship between height and weight and correlates with body fat percentage in the young and middle age adults.[211, 214, 280, 332] . In the elderly, however, BMI may

not be the best measure to use. Older adults experience changes in body composition, and loss of height due to compression of the vertebral bodies and kyphosis, that alter the relationship between BMI and body fat percentage.[299] This indicates that for any given BMI value, changes in body composition would tend to underestimate fatness, whereas the loss of height would tend to overestimate fatness.[299]

Total fat mass increases with aging, with maximal fat mass usually being reached at approximately 60-70 years of age.[27, 90] An important determinant of body fat mass at any age is the relationship between energy intake and expenditure.[322] If energy expenditure decreases and/or energy intake increases, the result is an increase in body fat. Many studies have suggested that energy intake does not change or may even decrease with age.[92, 110] This would lead us to believe that a decrease in total energy expenditure is a major factor in the gradual increase in body fat with advancing age.

Total energy expenditure is comprised of many components including: resting metabolic rate (RMR), the thermic effect of food, and amount of physical activity. Aging shows decreases in all of these components. RMR is shown to decrease by 2-3% every decade after the age of 20 years due partly to the decrease in fat free mass as we age.[315] The thermic effect of food only contributes about 10% of total energy expenditure. However, it has been shown to decrease by 20% between young and older men.[70, 275] For most individuals, physical activity also decreases with increasing age. According to Elia et al., it has been estimated that the decrease in physical activity accounts for about one-half of the age-associated decrease in total energy expenditure that occurs with aging.[70, 275]

Hormonal changes should also be considered when looking at the accumulation of fat mass with aging. Hormonal alterations include a decrease in growth hormone, reduced responsiveness to thyroid hormone, decrease in serum testosterone, and resistance to leptin. All of the factors contribute to the increase in fat, the reduction of fat-free mass and an energy imbalance.[51, 183, 197, 274]

Excess body fat and obesity are often associated with a myriad of health problems that lead to considerable morbidity, impaired quality of life, and premature death.[322] However, many of the studies conducted on obesity-related complications were conducted on middle-aged adults, not elderly adults. According to a study by Daviglus et al., excess weight gain in the young and middle-age years may translate to medical complications such as hypertension, diabetes, cardiovascular disease, and osteoarthritis, and increased Medicare expenditures that occur during old age.[56]

2.1.1.1 REGIONAL BODY FAT

Along with increased accumulation of total fat mass, aging is associated with a redistribution of body fat.[322] Many studies have reported a positive association between age and visceral adipose tissue.[154, 344] The viscera is defined as the region with borders at approximately T10-T11 and L5-S1 intervertebral spaces.[341] Although the positive association of age and visceral fat is independent of gender, the age-related increase is greater in men than in women.[154] In women, the accumulation of visceral adipose tissue increases rapidly after menopause to a rate similar to that of men.[154]

The health complications associated with increased visceral adipose tissue are vast. A centrally located fat pattern is related to the development of diabetes, heart disease, and mortality.[34, 78, 119, 279] Central adiposity has also been implicated in the development of blood lipid risk factors of cardiovascular disease[44, 83, 123, 216] and hypertension.[78, 321] All of these relationships with increased visceral adipose tissue endure even after accounting for the effects of increased total fat mass.[166]

In particular, the risk factors for cardiovascular disease are more highly correlated with visceral fat than other fat distribution variables.[38, 216] According to a study performed by Fujimoto using Japanese-American men, patients diagnosised with heart disease have relatively large intra abdominal fat stores.[87]

Metabolic syndrome, which is defined by a combination of risk factors including obesity, hypertension, hyperglycemia, and dyslipidemia, identifies individuals at increased risk of type 2 diabetes and cardiovascular disease.[102, 134] Metabolic syndrome has been associated with general obesity; however, it is now understood that distribution of body fat is an important determinant of metabolic abnormalities and is possibly more important than overall excess weight measured by BMI.[328] Visceral fat accumulation is strongly associated with metabolic disturbances and insulin resistance.[226, 241] In a 2003 study performed by Nguyen-Duy et al., visceral adipose tissue was found to be a significant predictor of lipid profile independent of abdominal subcutaneous adipose tissue[202], which serves to strengthen the results of other studies in showing that visceral adiposity is a strong marker of metabolic risk.[60, 227] In another study by Goodpastor et al., visceral abdominal adipose tissue and intramuscular adipose tissue clearly differentiated those with metabolic syndrome, particularly among the non-obese.[95] These results lead us to believe that metabolic syndrome can be present in older men and women with normal weight and relatively low total body fat due to the amount of intraabdominal and intramuscular adipose tissue.[95] In this same study, the associations of subcutaneous adipose tissue and metabolic syndrome were much less robust or nonexistent.[95] Greater subcutaneous adipose tissue in the thighs of obese men and women was actually associated with a lower prevalence of metabolic syndrome,[95] which is consistent with other studies.[316]

The association of excess visceral adipose tissue and increased risk of metabolic syndrome and cardiovascular disease has many possible explanations. According to Bergman et al., visceral fat is thought to release fatty acids into the portal circulation, where they may cause insulin resistance in the liver and muscle.[30] Ravussin et al. stated that the ability to store excess fat in adipose tissue is impaired leading to the ectopic storage of fat into nonadipose tissue such as muscle and liver.[240]

2.1.1.2 EFFECT OF EXERCISE ON BODY FAT

It has been well established that in adults, physical activity results in decreases in fat stores. The inverse relationship between physical activity and body fatness is well documented.[20, 62] These findings were further supported in a study by Hughes et al., in which

higher levels of physical activity were effective in decreasing body weight and body fat in an older (mean age 60.7years) population of men and women.[125] Another study of middle aged women showed that the more aerobic physical activity they engage in and the greater the intensity and/or duration of that activity, the less body fat they have.[313] A three year longitudinal study on elderly individuals revealed that leisure time physical activity did not prevent the decline in muscle mass and the increase in body fat; however, a higher level of physical activity was associated with higher muscle mass and less total and abdominal fat.[235] No studies, however, have been found that look at the effect of elite competitive activity, including high levels of competitive activity into the 7th and 8th decade, on body fat accumulation and distribution.

Regional body fat also seems to decrease with increases in physical activity, however, it is much less understood and researched. One study reported an association between the lack of physical activity and an increase in abdominal adipose tissue.[262] Several studies suggest that exercise may produce a preferential reduction in abdominal adipose tissue.[61, 137, 139, 262, 263] In a study performed with older men and women, physical activity was inversely related with abdominal adipose tissue, even after controlling for age and gender.[253]

2.1.2 MINERAL FREE LEAN MASS

Aging is often associated with sarcopenia, a gradual reduction of skeletal muscle mass and a subsequent loss in strength.[25, 27, 41, 170] According to Lexell et al., the average reduction in muscle area between 20 and 80 years of age was 40%, and the reduction began as early as 25 years of age.[172] Lexell also discovered that by the age of 50, only approximately 10% of muscle area was lost with an acceleration in loss there after.[172] (Figure 1) Two later studies confirmed the results of Lexell and his colleagues, reporting a decline in muscle area of 35-40% between the ages of 20 to 80 years.[73, 80] Flynn et al., using total body potassium as an index of fat free mass, showed that men experience a more rapid loss in muscle mass between the ages of 41 and 60, with women experiencing rapid loss after the age of 60 years.[82]

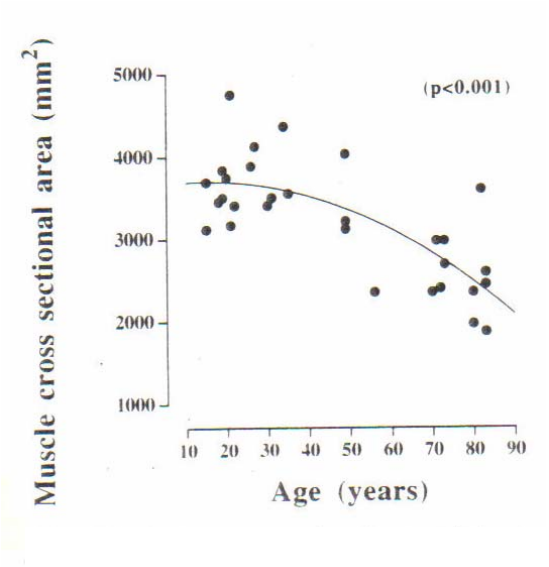

Figure 1 Relationship between age and muscle cross-sectional area. Lexell et al. 1988

Muscle atrophy has been shown to result from gradual and selective loss of muscle fibers.[171] Lexell et al. showed a 23% decrease in the number of muscle fibers in the vastus lateralis muscle of older male cadavers as compared to young male cadavers.[171] The decline is more apparent in type II, fast twitch muscle fibers.[167, 230] Larsson documented this decline in type II muscle fibers at 60% in sedentary young men to below 30% after the age of 80.[167, 230] In addition to the decline in muscle mass, many studies have found increases of fat and connective tissue within the older muscle.[84, 212, 251] Overend et al., in particular, found increases in non-muscle tissue of 59% in the quadriceps and 127% in the hamstrings.[212] With this increase in age-related infiltration of fat and connective tissue, the reduction in muscle contractile tissue is greater than the actual reduction in muscle volume and muscle cross-sectional area.[170] According to Proctor et al., the infiltration of fat and connective tissue reduce the contractile tissue volume available for locomotive and metabolic functions and act as a "friction brake" to slow contractile velocity.[230]

2.1.2.1 EFFECT OF EXERCISE ON MINERAL FREE LEAN MASS

Endurance exercise results in relatively small increases in the cross-sectional area of slow twitch muscle fibers.[6] However resistance training shows increases in muscle mass by both increases in size and number of myofibrils in both fast-twitch and slow-twitch muscle fibers.[144] In older men and women, muscles adapt to resistance training with marked myofibril hypertrophy. [233, 287] One study reported similar gains in myofibril size in younger and older men following the same resistance training program.[107] While resistance training results in marked increases in muscle mass in both genders, the response seems to be blunted in older women.[130] In one six month resistance training study, relative myofibril hypertrophy was 36% in men and only 7% in women.[21] However no studies in the literature have looked at the effect of elite competitive participation in endurance exercise on the lean muscle mass in both elderly men and women.

2.1.3 BONE MINERAL DENSITY

Bone Mineral Density (BMD) is the measure frequently used to assess bone and accounts for approximately 70% of bone strength.[273] Aging is associated with significant losses in bone mineral density in both men and women.[255] Figure 2 is a compilation of numerous cross-sectional and longitudinal studies using areal bone mineral density. This figure illustrates the overall pattern of bone loss in both sexes.[148] Menopause in women is associated with a rapid loss of trabecular bone.[148] Trabecular bone is present in the vertebrae, pelvis, and ultra distal forearm. The loss of bone mineral density of trabecular bone is the primary cause of fragility in arrangement and architecture of the spires of trabecular bone.[45] Following menopause there is a less dramatic loss of cortical bone.[45] Cortical bone is found in the long bones of the body and as a thin rim around the vertebrae and other sites of trabecular bone. Men have a similar pattern of slow, age-related bone loss as women, however, they lack the equivalent of menopause and therefore do not exhibit this rapid phase of bone loss. [148]

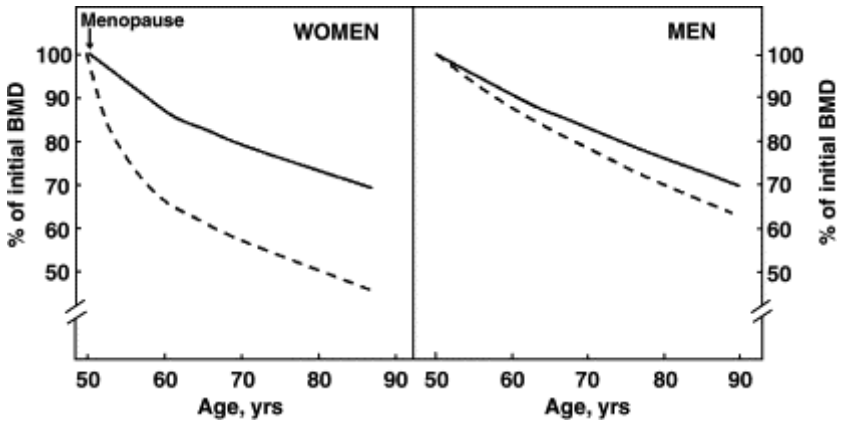

Figure 2 Patterns of age-related bone loss in women and in men. Dashed lines represent trabecular bone and solid lines cortical bone.

Peak bone mass occurs sometime between 18 and 30 years of age.[45] Bone density naturally begins to decline after the third decade of life at a rate of 0.3% of bone per year in both men and women.[3, 4, 29, 94, 285] Women accelerate this net bone loss about 10 fold for approximately 5 to 7 years beginning with the decrease in estrogen associated with menopause.[182, 256, 257, 281] In women, 7 years after menopause, bone loss slows to approximately 1% of bone per year.[3, 4, 29, 94] Although women experience an accelerated rate of bone loss during and for years after menopause, constant bone loss affects both men and women over the age of 70 years.[285] While accelerated bone loss is a large problem associated with aging and often the dominant effect in postmenopausal osteoporosis, the main problem in older men and women is likely a decrease in synthesis of new bone in conjunction with either stable or accelerated bone loss.[285]

Extreme losses in bone mineral density can result in osteoporosis, which is defined as a disease of the skeleton characterized by low bone mineral density and micro-architectural deterioration of bone tissue that results in an increased susceptibility to fracture.[5] Osteoporosis is a large public health problem that is responsible for more than 1.5 million fractures every year.[17] According to Bennett et al., thirty percent of women who suffer hip fractures related to osteoporosis die with in 1 year of injury, and another 25% remain permanently disabled.[29]

Many factors affect bone mineral density including genetics, gender, race, nutritional factors, lifestyle factors, hormones, chronic diseases and medication, and body composition.[11, 26, 42, 59, 120, 121, 165, 169, 201, 210, 231, 236, 242, 244-246, 249, 277, 295, 303, 305, 307, 314, 325] Genetics may be the most important factor in determining an increased risk for osteoporosis.[285] Gender and race are also crucial, as males have greater bone mass than females and that African-Americans and Hispanics have greater bone mass than Caucasians of the same age.[28, 69, 97, 124, 147, 204, 284] However, many other factors play an important role in determining bone health. Nutritional factors such as low dietary intake of calcium, phosphorous, and vitamin D are associated with age-related bone loss.[276] Lifestyle factors such as lack of physical activity precipitate bone loss. Physical activity has a protective effect on bone mineral density.[115, 201, 231, 296, 304] Other important factors that contribute to decreased bone mass include late menarche and early menopause, caffeine ingestion, alcohol use and cigarette smoking.[10, 16, 52, 55, 138, 150, 229, 278]

Obesity is also associated with higher bone mass.[285] Although the protective effects of obesity on osteoporosis have been shown, it is not well understood exactly how obesity protects against osteoporosis.[239, 311] Obesity related bone protective effects may be due to increased weight bearing, increased aromatization of androgen to estrogen in adipose tissue, lowered levels of sex hormone binding globulin, or a direct increased bone formation induced by high circulating levels of insulin.[86, 149, 245, 247, 248, 267, 293]

According to Tabensky et al., individual peak bone mass and volumetric bone mineral density (bone size and amount of bone) affect age-related bone loss.[309] This study conducted in women and their daughters concluded that reduced peak bone size and reduced peak volumetric bone mineral density during growth established the clinical relevance of bone loss during aging.[309] Furthermore it suggested that in women with reduced peak bone size and reduced volumetric bone mineral density, age-related bone loss will be poorly tolerated and result in events such as non-traumatic vertebral fractures.[309]

2.1.3.1 REGIONAL BONE MINERAL DENSITY

Bone mineral density is assessed in regional sections of the body. Regional measures of bone mineral density are often taken at the lumber spine, femoral neck, and the wrist. Bone Mineral Density is of particular interest in the lumbar spine and femoral neck because these two regions are sites of major bone fractures.[111, 145, 283] Colles' fractures, a common term to refer to distal radius fractures, are also common and incidence increases in women after menopause, however there is no increase in Colles' fractures for men with age until after the age of 80 years.[191] Patterns of bone loss differ for the lumbar spine, femoral neck, and femoral shaft in women.[232] For example many studies have reported that bone loss at the femoral neck begins in the mid-20s and continues throughout life.[18, 175, 192] However, in a study by Slemenda et al., the bone loss in the femoral neck did not correspond with bone loss at the spine or forearm in women during the same years.[292] In men, little research has been done on the rate of regional bone loss. One relatively small cross-sectional study found that in men there were no age-related decreases in bone mineral density at the lumbar spine, trochanter, ultra-distal forearm, radius, ulna, or head, but the decreases in bone mineral density were substantial with age at the pelvis and proximal femur.[76]

2.1.3.2 EFFECTS OF EXERCISE ON BONE MINERAL DENSITY

Exercise can be categorized based upon aerobic level and amount of force borne by the body; for example aerobic, weight bearing exercise; aerobic non-weight bearing exercise; and resistance training (ie: high muscle load activity). Most bone mineral density studies focus on weight bearing exercise, such as running, where the participant's skeleton supports the entire mass of the body during the exercise, and non weight bearing exercise, such as swimming, where the body mass is supported by the water.

Because accumulation of bone mass occurs primarily in childhood and adolescence, many studies have investigated the effect of weight bearing exercise in children.[35, 127, 176] Regular participation in weight bearing activity has been associated with higher bone mineral density in children and higher peak bone mass in the young adult.[98, 294, 331] It has also been shown that physical activity during childhood is associated with higher bone mineral density in adolescence and young adulthood.[50, 331] However, few studies have gone so far as to say that weight bearing

physical activity during adolescence maximizes the peak bone density achieved in adulthood.[100, 206, 331] Welten et al. also reported that weight bearing physical activity in childhood is more influential than calcium intake in reaching the highest peak adult bone mass.[331] Additionally, Hui et al. stated that peak bone mass accounts for at least half of the variation in bone mass in the elderly.[128]

Exercise modulates bone mineral density in adults. A cross-sectional study of female athletes aged 18-69 years, demonstrated that lumbar spine and femoral neck bone mineral density, but not total body bone mineral density, declined with age but at a lesser rate than that of the general population.[270] Another study found that 40-65 year old ex-athletes had higher lumbar and femoral bone mineral density than their age matched controls.[72] Although data on males in this area are limited, a few cross-sectional studies have shown the positive effect of exercise on bone mineral density in adult males.[178, 209, 269, 340] Longitudinal data would provide the clearest answer to the effect of exercise on bone mineral density, however these types of studies are lacking.

Cross-sectional studies of athletes from different sports compared with non-athlete controls show that weight bearing sports are generally more osteogenic than non weight bearing activities.[68, 116] In a study comparing athletes in three sports, Judo, Karate (high impact weight bearing sports) and water polo (non weight bearing sport) to non-athlete controls, Andreoli et al. found that although the athletes as a whole had better bone mineral density than the controls. The athletes in weight bearing sports, Judo and Karate, had significantly higher bone mineral density than that of the athletes who played water polo.[12] Also, in studies of athletes, researchers have found that skeletal adaptations in regional bone density seem to be site specific due to the loading requirements of the specific sport or activity.[39, 141] For example, a study with female volleyball and basketball players showed higher bone mineral density of the calcaneus and the lumbar spine in the athletes compared with non-athletes controls.[261] This is not only true when comparing bone density across populations, but is true of the loading differences within the individual. Among athletes and sedentary individuals alike, studies have found that the dominant arm of an individual has higher bone mineral density than that of the non-dominant arm.[222, 252]

2.1.4 DXA

Dual energy x-ray absorptiometry (DXA) has been shown to be an effective measure of body composition and is considered a valid and reliable reference measure.[71, 174, 335] DXA shows a three-dimensional model of body composition and takes into account bone free lean mass, fat mass, and bone mass.[2, 329] DXA provides accurate information regarding bone mineral content, areal bone density, and has been suggested as a criterion method for measuring percent fat.[152, 185] DXA has been shown to give accurate measures of whole body as well as regional bone mineral density, percent fat, and lean muscle mass with a small precision error which is comparable or smaller than those achieved with other types of noninvasive methods.[118, 185]

2.2 MUSCLE STRENGTH

Muscle strength is defined as the ability of a muscle to exert force.[336] Many factors determine muscle strength including type of muscle fiber, size of the muscle, and length and speed of the muscle at contraction.[88] Fast twitch muscle fibers show a faster time to peak tension than slow twitch fibers. Recent research has shown considerable evidence that fast twitch fibers produce a greater magnitude of contraction force than slow twitch, however there is significant controversy over this suggestion.[88, 228] The basic premise regarding muscle size is that larger muscles are stronger than smaller muscles.[88] Muscle mass, the cross-sectional area of the muscle, is often a better determinant of muscle size than the more clinically used muscle circumference. Circumference of the muscle often overestimates muscle size because fat, fluid, bone, skin, vasculature and other tissues are included. Therefore, muscle mass is a more accurate measurement of how much muscle is available to produce strength.[88] As the cross-sectional area of the muscle increases, so does the amount of contractile proteins, actin and myosin, which ultimately results in greater force production.[88] Another factor affecting muscle strength is muscle length. Maximum force is generated near its resting length. If the muscle length changes, either shorter or longer, the force is reduced.[188]

Gender also has an affect on muscle strength.[88] Men have significantly higher absolute and relative strength than women.[46, 143, 173, 177, 221, 291] Until recently, the consensus has been that men and women have similar muscle quality (peak torque per unit of muscle mass)[194, 243]; however, a 1999 study reported that men have higher muscle quality than women, for both arm and leg muscles.[177]

The human aging process also has a profound effect on muscle strength. Many cross-sectional studies of limb muscles in healthy young, middle aged, and older men and women, utilizing both dynamic and isometric testing methods, show an age-related decline in muscle strength. [65, 225, 317] Some data indicate that strength peaks in the third decade and remains relatively unchanged or slightly decreases to the fifth decade.[132] The age-related decreases in strength are on average 20-40% with even greater losses, approximately 50% or more, reported for individuals in their 9th decade.[168, 199, 200, 342, 343] The relative losses in muscle strength appear to be similar for both men and women.[64] Few longitudinal studies have been performed; however, they have reported larger losses of strength than the cross-sectional studies.[22, 47] Longitudinal studies have reported annual decline rates ranging from 1.4 to 5.4% in both men and women[13-15, 22, 237, 338] No studies have been conducted that compare the strength of elite senior athletes who have been competitively active for the majority of their lives with healthy community dwelling seniors.

2.2.1 RELATIONSHIP OF MUSCLE MASS AND MUSCLE STRENGTH

Muscle mass has a high correlation with muscle strength[177] leading some to conclude that the loss in muscle strength is due entirely to the loss in muscle mass.[318] There is conflicting literature on the association of the changes of muscle mass and muscle strength. In one longitudinal study, muscle mass changes only accounted for 5% of the variance in knee strength.[126] A significant association between the change in muscle strength and mass with exercise or detraining is rarely observed.[104, 306] Disproportionate gains in strength and muscle mass, with large gains in strength but small increases in lean muscle mass, have been shown in intervention studies.[85] This may indicate that other neuromuscular changes may mediate muscle

strength decreases.[126] However, some studies suggest that muscle mass explains most of the variance in muscle strength.[63, 193, 243]

2.2.2 RELATIONSHIP OF BONE MINERAL DENSITY AND MUSCLE STRENGTH

The data on the relationship of bone mineral density and muscle strength is conflicting. Some studies have documented positive correlations between muscle strength and bone mineral density.[32, 33, 155, 203, 223, 320, 327] Studies by Hyakutake et al. and Madsen et al. demonstrated a relationship between muscle strength and the bones in which they act upon in non-athletes.[133, 180] The association between muscle strength and bone mineral density seems to be more prominent among sedentary individuals and those with low to moderate levels of physical training, while in highly trained individuals there is little or no relationship between muscle strength and bone mineral density.[7, 8, 205, 207, 208, 272, 308] Also, significant correlation between isometric strength of the quadriceps muscle and bone mineral density in both young adult women and pre- and post-menopausal women on hormone replacement therapy has been found, whereas no correlation between muscle strength and bone mineral density was found in men.[250] Several other studies reported muscle strength to be a predictor of bone mineral density independent of body weight in women and men.[93, 109, 180, 204, 297, 298] A recent study demonstrated a positive relationship between quadriceps muscle strength and bone mineral density of all measured sites except the forearm.[67] No studies have reported data on lifelong master athletes.

2.2.3 EFFECT OF EXERCISE ON MUSCLE STRENGTH

Different types of exercise affect muscle strength in different ways. Resistance trained muscles exert considerably more force because of both increased muscle size and increased muscle fiber recruitment.[144] This increase in muscle size is due to the increase in size and number of myofibrils in both the fast and slow twitch muscle fibers. Many resistance training intervention studies have shown the changes in strength are similar in both young and old individuals when presented with the same progressive resistance training program[106, 140, 330] One study found that older subjects significantly increased the amount of maximum force generated

by 174% +/- 31% following high intensity isotonic training.[77] Many strength training studies in older adults typically show gains in strength beyond what would be anticipated by the increases in muscle mass.[131, 135, 310, 312] These disproportionate increases may be explained by an increase in motor unit activation.[103, 105, 198]

Endurance training has also been shown to increase muscular strength. Significant improvements in lower limb strength after participation in aerobic exercise training programs have been reported in many studies.[31, 49, 112] This was supported by a study on older adults, where relative improvements of 1-RM knee extensors and flexors strength were 12% and 19% respectively following a 12 week aerobic exercise program.[142]

2.2.4 ISOMETRIC STRENGTH TEST

Strength is defined as the ability of a muscle to develop tension and exert force on a bony lever.[156] Strength is often assessed using an isometric contraction. An isometric contraction involves a maximal voluntary contraction performed at a specified joint angle against an unyielding resistance[337] The amount of tension developed in a muscle is determined by the number of bridges formed between the actin and myosin filaments as they slide past each other during a contraction. Theoretically, according to Murray et al., in an isometric contraction there is sufficient time for the maximum number of cross-bridges to be formed allowing for the maximum tension to develop.[200] Position of the knee during the isometric contraction is very important. A study by Murray et al. showed that position had little effect on the average strength for knee flexor muscles, but for extensor muscles the average isometric strength values at the 30 degree position were significantly lower than the values at 45 and 60 degrees.

2.3 NATIONAL SENIOR GAMES (IE: THE SENIOR OLYMPICS)

The National Senior Games began in 1985 with the first games taking place in St. Louis, Missouri. In St. Louis, 2,500 senior athletes from 33 states participated in the first "Senior Olympics". In 1987, an agreement was reached with United States Olympic Committee based on their objection to the use of the term Olympic in the organization's corporate name and the name was changed to the U.S. National Senior Sports Organization. The designation of "Senior Olympics" is still allowed to be used in the original states. The National Senior Games Association is a not-for-profit organization dedicated to motivating active adults to lead a healthy lifestyle through the senior games movement. The Summer Games event has grown to one of the largest multi-sport events in the world. The 2005 Summer Games were held in Pittsburgh, Pennsylvania where 10,500 athletes participated.

Athletes qualifying for the National Senior games must be 50 years of age on or before December 31st of the year before the Summer Games. All athletes competing in individual competitions are divided into five year age categories (i.e. 50-54, 54-59, 60-64 etc). All athletes must qualify at "Qualifying Games" held in each state. Each event has different numbers of qualifiers they will accept, however, each athlete must meet the minimum qualifying performance set by the National Senior Games Association.

3.0 METHODOLOGY

3.1 SUBJECTS

One hundred male and female master athletes ≥ 65 years of age were recruited from the Summer 2005 National Senior Games (i.e. the Senior Olympics) held at the University of Pittsburgh from June 3-20, 2005. The National Senior Games occur biannually and encompass athletes from all states except Alaska. Over 250,000 individuals participate in one of 19 sports at the community level. The top five finishers in each age category in each sport move on to compete at the state level, resulting in 12,000 medalists that qualify to compete at the National Games. Subjects were recruited from the following sports 1) running [events with distances ≥ 400 meters, *n*=43], 2) cycling [all events, *n*=16], and 3) swimming [all events, *n*=41]. During the following summer, 2006, a control group of 86 sedentary men and women ≥ 65 years of age were recruited from the University of Pittsburgh Claude D. Pepper Older Americans Independence Center. All subjects completed the same protocol. All participation was voluntary. We excluded master athletes and controls who were on medications that can prevent bone loss (e.g., bisphosphonates, hormone replacement therapy, SERMs, and parathyroid hormone) or cause bone loss (glucocorticoids, certain anticonvulsants).

All procedures were approved by the University of Pittsburgh Institutional Review Board committee prior to data collection. Each subject was required to be present for one study visit lasting approximately 2 ½ to 3 hours. Subjects were prescreened over the telephone and then consented for the study at the General Clinical Research Center (GCRC) in UPMC Montefiore University Hospital prior to any study procedures.

3.2 SUBJECTS

Subjects for this investigation included 186 individuals aged 65 and older. Subject descriptive data are presented in Tables 1 and 2.

Table 1 Control Demographics

	Age (yr)	Height (in)	Weight (lbs)	Body Fat (%)
Males *(n=52)*	74.15 ± 5.05	68.06 ± 2.33	180.29 ± 22.04	25.07 ± 5.67
Females *(n=34)*	77.09 ± 5.47	62.97 ± 2.68	167.03 ± 30.23	38.77 ± 5.93
Total *(n=86)*	75.31 ± 5.38	66.05 ± 3.51	175.05 ± 26.24	30.20 ± 8.80

Table 2 Athlete Demographics

	Age (yr)	Height (in)	Weight (lbs)	Body Fat (%)
Males *(n=61)*	73.10 ± 6.86	68.30 ± 2.43	170.52 ± 25.63	21.65 ± 5.74
Females *(n=39)*	72.03 ± 6.31	63.28 ± 2.50	142.10 ± 27.66	30.68 ± 7.55
Total *(n=100)*	72.68 ± 6.64	66.34 ± 3.47	159.44 ± 29.76	25.15 ± 7.83

3.2.1 INCLUSION/EXCLUSION CRITERIA

3.2.1.1 SENIOR ATHLETE GROUP

We excluded any master athletes who had a history of the following:

- Medications that can prevent bone loss (e.g., oral or intravenous bisphosphonates, calcitonin, SERMs, and parathyroid hormone) or cause bone loss (glucocorticoids for greater than 3 months over the last year, certain anticonvulsants, anabolic steroids);
- Diseases known to affect bone mineral metabolism (hyperthyroidism, hyperparathyroidism, end stage renal or liver disease);

- A history of cancer within the past 5 years, though subjects with a more recent history of relatively benign skin cancers such as basal cell or squamous cell carcinoma are not excluded;
- Bilateral hip replacement or lumbar spine surgery;
- Master athletes who participate in the triathlon or two separate impact categories.

Subjects were included in the study if they met the following criteria:

- Male and female master athletes ages $\geq$ 65 years who are entered in the following events at the Summer 2005 Senior Olympics and who participate in only one of these impact categories: **1)** high-impact sports (running [including events $\geq$ 400 meters, n=40]); **2)** medium-impact sports (cycling [including all events, n=40]); and **3)** low-impact sports (swimming [including all events, n=40]).
- We attempted to recruit subjects so that the three groups will have similar age and gender composition to facilitate a matching of subjects across groups.

3.2.1.2 CONTROL GROUP

We excluded any control subjects who had a history of the following:

- Medications that can prevent bone loss (e.g., oral or intravenous bisphosphonates, calcitonin, SERMs, and parathyroid hormone) or cause bone loss (glucocorticoids for greater than 3 months over the last year, certain anticonvulsants, anabolic steroids);
- Diseases known to affect bone mineral metabolism (hyperthyroidism, hyperparathyroidism, end stage renal or liver disease);
- A history of cancer within the past 5 years, though subjects with a more recent history of relatively benign skin cancers such as basal cell or squamous cell carcinoma are not excluded;
- Bilateral hip replacement or lumbar spine surgery;

Subjects were included in the study if they met the following criteria:

- Male and female healthy community dwelling seniors ages $\geq$ 65 years;
- Do not participate as a competitive master athletes.

3.3 METHODS

This was a cross-sectional study to determine various components of body composition and muscle strength between life-long athletes and sedentary controls over the age of 65. All data were collected at the General Clinical Research Center (GCRC) at Montefiore University Hospital.

3.3.1 PRE SCREENING

All subjects were screened by telephone prior to acceptance into the study. A waiver to document the informed consent for the telephone screening questionnaire was requested from the University of Pittsburgh IRB. This request was made due to the fact that screening questions present no more than minimal risk of harm to the subjects and involve no procedure for which written consent is normally required outside of the research context. The telephone screening included questions on age, medications, current health problems, and impact-level of sporting events. Subjects were then informed if they qualified for the study and were scheduled accordingly.

3.3.2 BODY COMPOSITION

Body composition was measured by dual-energy x-ray absorptiometry (DXA) using a Hologic QDR-4500A (Bedford, MA). DXA provides state-of-the-art accuracy and precision. A licensed DXA technician performed all of the data collection and analysis procedures. The DXA scans provided measures of bone mineral density, bone mass, mineral free lean mass, and fat mass. Regional measures (trunk, legs and arms) of body composition were provided. Regional measures of body fat (in grams) and lean tissue (in grams) measures were converted to percent of total body by dividing the measure by the total grams of the body, as measured by DXA. Each scan lasted approximately 1-5 minutes and was a noninvasive, low-radiation procedure. Quality control was assured with a daily measurement of a spine phantom of defined hydroxyapetite composition.

3.3.3 LOWER EXTREMITY MUSCLE STRENGTH ASSESSMENT

Figure 3 Custom designed aluminum chair

Muscular strength was measured with a tension/compression load cell (Lebow Model 3132, Columbus, OH) We measured isometric strength of the quadriceps and hamstrings on the subject's left side. The left side was chosen because that is the side on which hip bone density was measured. The load cell was attached to an adjustable bar, which was attached to a metal bar secured to a custom designed aluminum chair. (Figure 3) This allowed for adjustments to be made for leg length differences of the subjects. The load cell was calibrated daily using 10lb and 35lb weights. All calibration equations have been saved and will be used to analyze all data.

Subjects were placed in a comfortable seated position on the chair, and secured using a seatbelt positioned at the hips to minimize extraneous body movements. The hip was positioned in 90º of flexion. The knee was positioned in 45º of flexion. The adjustable bar to which the load cell was attached was positioned just proximal to the malleoli. The distance from the knee to the adjustable bar was recorded in order to calculate torque. The subjects were asked to position their arms either crossed at the chest level or resting on their lap in order to avoid bracing or pulling on the chair. The correct positioning of a subject in the chair is illustrated in Figure 4.

Figure 4 Subject performing hamstring strength assessment.

The gravity effect torque was calculated based on the subject's leg weight at this angle. Subjects performed 3 repetitions of maximal isometric knee extension lasting 5 seconds each. Thirty seconds of rest were provided between contractions. Similarly, subjects performed three repetitions, each lasting 5 seconds, of maximal isometric knee flexion. Thirty seconds of rest were provided between contractions. Torque was calculated as the product of the force in the load cell times the distance from the knee to the adjustable bar. Peak torque and peak torque to body weight ratio was recorded. Isometric peak torque has an intraclass correlation coefficient of greater than 0.89.[40]

Subjects were instructed to continue breathing during the tests and to not hold their breath in order to prevent the subjects from doing the Valsalva maneuver during the tests. The subjects were also instructed that they could stop the test at any time. During the test, subjects were instructed to begin and were encouraged to "push" for the extension trials and to "pull" for the flexion trials. The test adminstrator repeated the word push/pull each second for a total of five

seconds. The subject was then instructed to relax at the conclusion of each trial. This entire procedure was repeated for a total of three trials of extension and three trials of flexion. The instructions and encouragement were consistant for all of the subjects, both athletes and controls. The order of exercises was counterbalanced for all subjects to ensure acuracy.

3.3.4 MISCELLANEOUS

This study was a part of a larger study named "The Effect of High Impact Exercise on Skeletal Integrity in Master Athletes", with Susan Greenspan, MD as the Principal Investigator. This study examined bone mineral density, lower extremity muscle strength, biochemical markers of bone turnover, measures of bone and mineral metabolism, and gonadal status in 104 master athletes who participated in the 2005 Summer Olympic Games in Pittsburgh and sedentary controls from the Greater Pittsburgh Area. The specific aims of this study were as follows:

To determine the differences among high-impact sports (running) versus medium-impact sports (cycling) or low impact sports (swimming) in:

1) bone mass in the spine, hip, forearm, and heel,
2) lower extremity strength,
3) biochemical markers of bone turnover,
4) indices of bone and mineral metabolism or gonadal status.

3.4 STATISTICS

This is a cross-sectional study to determine various components of body composition and muscle strength between lifelong athletes and sedentary controls over the age of 65. All statistical analyses were performed using SPSS 13.0 Statistical Software (Lead Technologies Inc., Chicago, IL). Initial analysis began with calculating descriptive statistics, including measures of central tendency (means, medians, other percentiles) and dispersion (standard deviations, ranges) for controls and senior athletes. Significance was determined at a p-value of 0.05.

To test hypothesis 1, three separate, two factor ANOVA (Gender X Group) on arm, leg and abdominal adiposity values were performed to determine differences between groups.

To test hypothesis 2, two separate, two factor ANOVA (Gender X Group) on arm and leg mineral free lean mass were performed to determine differences between groups.

To test hypothesis 3, two correlational analysis for each group were performed on quadriceps strength and thigh mineral free lean mass, and hamstring strength and thigh mineral free lean mass.

To test hypothesis 4, three correlational analyses for each group were performed on regional mineral free lean mass and bone mineral density (arm mineral free lean mass and wrist bone mineral density; leg mineral free lean mass and hip bone mineral density; trunk mineral free lean mass and lumbar spine bone mineral density)

To test hypothesis 5, six correlational analysis for each group were performed on regional fat mass and bone mineral density (arm fat mass and wrist bone mineral density; leg fat mass and hip bone mineral density; trunk fat mass and lumbar spine bone mineral density; arm fat mass and total bone mineral density; leg fat mass and total bone mineral density; trunk fat mass and total bone mineral density)

3.5 CALCULATIONS

Because the participants in the study vary greatly in height and weight, several calculations needed to be made in order to compare individuals. Strength data, reported in Nm, were normalized to body weight and height by dividing the calculated torque by the person's body weight and height. Regional measures of body fat (in grams) and lean tissue (in grams) measures were converted to percent of total body by dividing the measure by the total grams of the body, as measured by DXA. This allowed for comparisons between subjects on all measures.

4.0 RESULTS

Dual-energy x-ray absorptiometry was utilized to examine the body composition of male and female elite senior athletes and healthy community dwelling controls. Specifically, measures of fat mass and mineral free lean mass were compared. Measures of bone density were also obtained. Similar group and gender comparisons on the bone density data were performed by other members of our research team and are presented elsewhere.[302, 319] The relationships between the measures of mineral free lean mass and thigh muscle strength, body fat and thigh muscle strength, mineral free lean mass and bone mineral density, and body fat and bone mineral density were also examined.

4.1 REGIONAL ADIPOSITY

Two-factor analyses of variance (group X gender) were performed to test the differences in regional adiposity between group and gender. There were no significant gender by group interactions for percent body fat in the trunk and the leg. The interaction was significant for percent body fat in the arm, but it was ordinal in nature. In other words, both female and male athletes had lower percentage of body fat than their control counterparts. (ANOVA tables located in Appendix A.1) Therefore, to directly address the question of whether significant differences were present between athletes and controls within each gender, six one factor analyses of variance (group) were performed. For both females and males, controls had a significantly higher body fat percentage in every body region examined than did athletes. The findings are presented in the following table.

Table 3 Comparison of Regional Body Fat for each gender between Athletes and Controls

	Variables	Athletes	Controls	*P*-value
Females	% Body fat Left Arm	1.81 ± .57	2.21 ± .48	$p = .003$*
	% Body fat Trunk	14.08 ± 4.71	18.67 ± 4.07	$p < .001$*
	% Body fat Left Leg	5.82 ± 1.38	7.02 ± 1.50	$p = .001$*
Males	% Body fat Left Arm	1.17 ± .33	1.31 ± .32	$p = .033$*
	% Body fat Trunk	11.25 ± 4.07	13.56 ± 3.65	$p = .003$*
	% Body fat Left Leg	3.17 ± .94	3.79 ± 1.12	$p = .002$*

* denotes significance at $p < .05$

4.2 REGIONAL MINERAL FREE LEAN MASS

Two separate 2 factor (Gender X Group) analyses of variance (ANOVA) were used to compare regional measures of mineral free lean mass (MFL) between subjects. In the arm and leg, mineral free lean mass is predominately comprised of muscle tissue. Mineral free lean mass for the abdomen is comprised of both muscle tissue and internal organs. Similar comparisons were not made of abdominal mineral free lean mass because of the confounding factor of organ tissue in the measurement.

There were no significant gender by group interactions for percent mineral free lean mass of the arm or leg.(ANOVA tables located in Appendix A.2) Therefore, to directly address the question of whether significant differences were present between athletes and controls within each gender, four one factor analyses of variance were performed. In both males and females, athletes had a significantly higher percentage of mineral free lean tissue of the arm and leg than controls. The findings are presented in the following table.

Table 4 Comparison of Mineral Free Lean Mass for each gender between Athletes and Controls

	Variables	Athletes	Controls	*P*-value
Females	% MFL Left Arm	3.20 ± .51	2.83 ± .47	$p = .003$*
	% MFL Left Leg	10.72 ± 1.46	9.59 ± .96	$p = .001$*
Males	% MFL Left Arm	4.33 ± .45	4.05 ± .50	$p = .002$*
	% MFL Left Leg	12.38 ± 1.25	11.39 ± 1.16	$p < .001$*

* denotes significance at $p < .05$

4.3 RELATIONSHIP BETWEEN MINERAL FREE LEAN MASS OF THE LEFT LEG AND STRENGTH

Three separate one-tailed correlational analyses were performed to determine the relationship between % mineral free lean tissue of the left leg and measures of thigh muscle strength in athletes, controls and a combined sample of athletes and controls. The findings are presented in the following three tables. All of the correlations were statistically significant. The relationship between extension strength and mineral free lean mass was stronger in the control group, while the relationship between flexion strength and mineral free lean mass was stronger in the athletes. Normalizations of the strength data to body weight and height resulted in stronger relationships than did the raw torque values.

Table 5 Correlational analysis on MFL and strength measures for a combined sample of athletes and controls

	% MFL in Left Leg	
	r value	***p-value***
Flexion Peak Torque Nm	.411	p < .001*
Flexion Peak Torque BW*Hgt	.489	p < .001*
Extension Peak Torque Nm	.517	p < .001*
Extension Peak Torque BW*Hgt	.603	p < .001*

Table 6 Correlational analysis on MFL and strength measures for a sample of athletes only

	% MFL in Left Leg	
	r value	***p-value***
Flexion Peak Torque Nm	.348	p < .001*
Flexion Peak Torque BW*Hgt	.472	p < .001*
Extension Peak Torque Nm	.365	p < .001*
Extension Peak Torque BW*Hgt	.509	p < .001*

Table 7 Correlational analysis on MFL and strength measures in a sample of controls only

	% MFL in Left Leg	
	r value	***p-value***
Flexion Peak Torque Nm	.258	p = .013*
Flexion Peak Torque BW*Hgt	.264	p = .011*
Extension Peak Torque Nm	.586	p < .001*
Extension Peak Torque BW*Hgt	.615	p < .001*

4.4 RELATIONSHIP BETWEEN REGIONAL MINERAL FREE LEAN MASS AND REGIONAL BONE MINERAL DENSITY

Two separate one-tailed correlational analyses were performed to determine the relationship between regional % mineral free lean tissue and its corresponding regional bone mineral density in athletes, controls, and a combined sample of athletes and controls.

In a combined sample of athletes and controls a significant correlation ($r = .248$, $p = .001$) was found between bone mineral density of the total hip and the % mineral free lean tissue of the left leg. A significant correlation ($r = .640$, $p < .001$) was also found between bone mineral density of the total radius and the % mineral free lean tissue of the left arm. (Results summarized in figures 5 & 6)

When this relationship is examined in athletes alone, a significant correlation ($r = .196$, $p = .030$) was found between bone mineral density of the total hip and the % mineral free lean tissue of the left leg. A significant correlation ($r = .548$, $p < .001$) was also found between bone mineral density of the total radius and the % mineral free lean tissue of the left arm. (Results summarized in figures 5 & 6)

When the data of the controls alone were studied, a significant correlation ($r = .375$, $p = .001$) was found between bone mineral density of the total hip and the % mineral free lean tissue of the left leg. A significant correlation ($r = .745$, $p < .001$) was also found between bone mineral density of the total radius and the % mineral free lean tissue of the left arm. (Results summarized in figures 5 & 6)

The relationships between bone mineral density of the hip and percent mineral free lean tissue, and between bone mineral density of the wrist and percent mineral free lean mass of the arm were strongest in the control group.

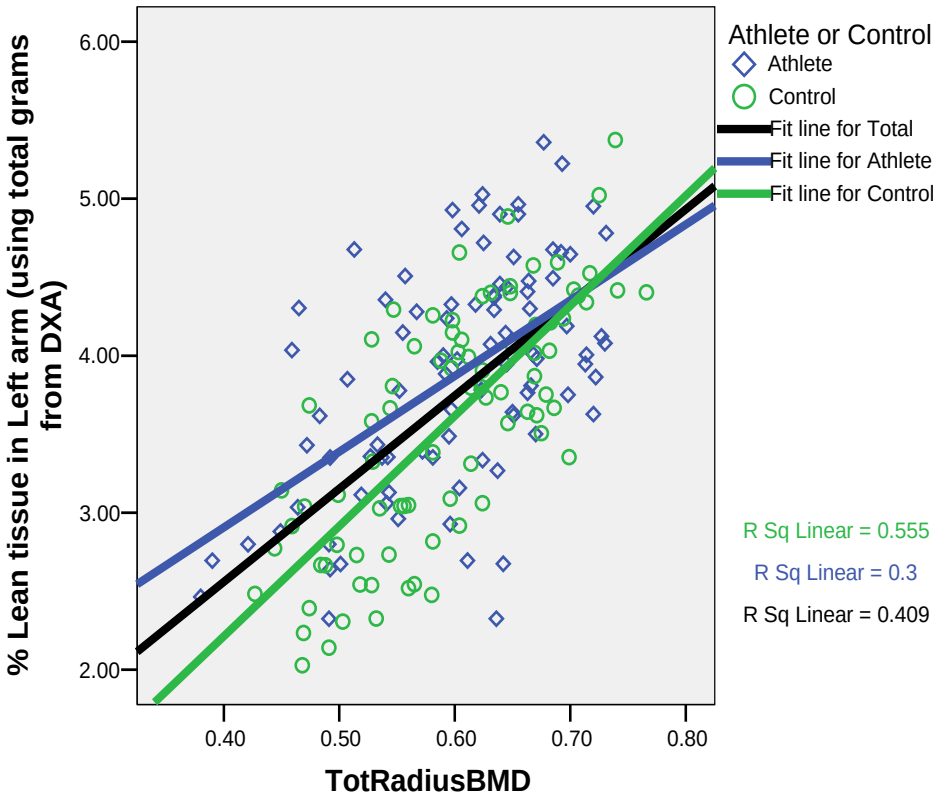

Figure 5 Scatterplot for % MFL of the left arm and BMD of the total radius

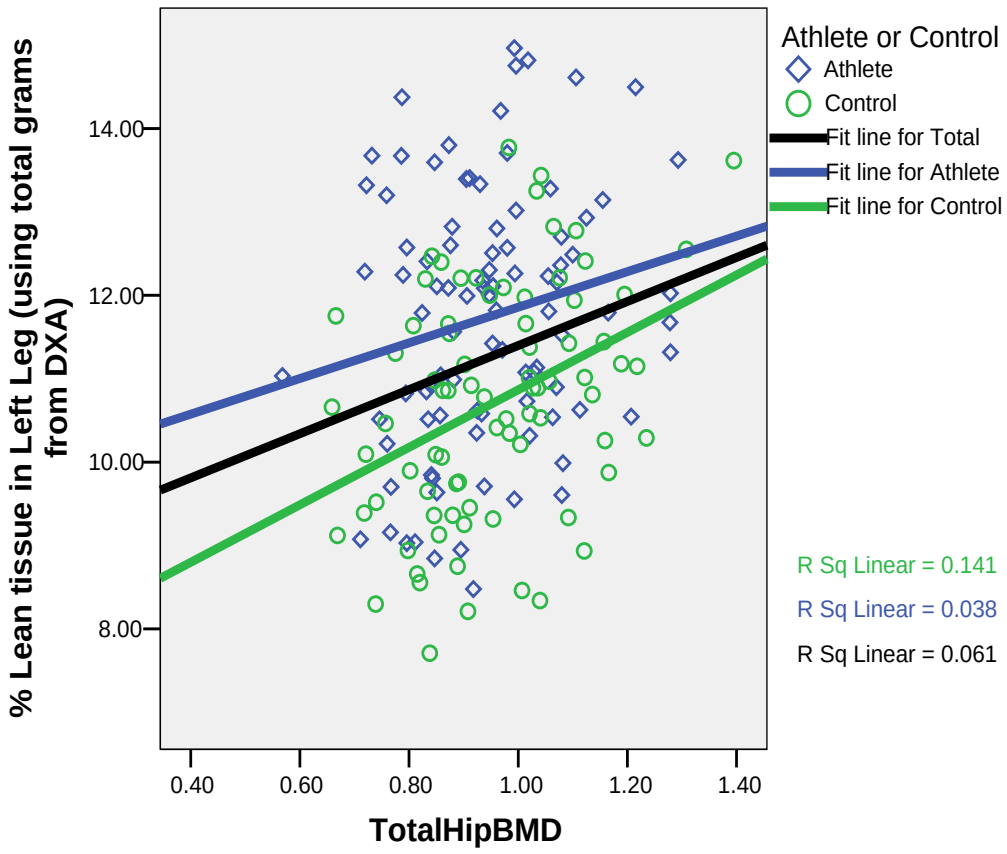

Figure 6 Scatterplot for %MFL of the left leg and BMD of the total hip

4.5 RELATIONSHIP BETWEEN REGIONAL FAT MASS AND REGIONAL BONE MINERAL DENSITY

Six separate one-tailed correlational analyses were performed to determine the relationship between regional % body fat and its corresponding regional bone mineral density in athletes, controls and a combined sample of athletes and controls. Specifically, radius BMD and arm percent body fat, spine BMD and trunk percent body fat, hip BMD and leg percent body fat were compared.

In a combined sample of athletes and controls, a significant negative correlation ($r = -.508$, $p < .001$) was found between bone mineral density of the total radius and the % body fat of the left arm. No correlation ($r = .000$, $p = .498$) was found between bone mineral density of the total spine and the % body fat of the trunk. A significant negative correlation ($r = -.386$, $p < .001$) was found between bone mineral density of the total hip and the % body fat of the left leg. (Results summarized in figures 7, 8 & 9)

When only the athletes are studied, a significant negative correlation ($r = -.407$, $p < .001$) was found between bone mineral density of the total radius and the % body fat of the left arm. No significant correlation ($r = .028$, $p = .397$) was found between bone mineral density of the total spine and the % body fat of the trunk. A significant negative correlation ($r = -.338$, $p < .001$) was found between bone mineral density of the total hip and the % body fat of the left leg. (Results summarized in figures 7, 8 & 9)

When this relationship is examined in control subjects alone, a significant negative correlation ($r = -.615$, $p < .001$) was found between bone mineral density of the total radius and the % body fat of the left arm. No significant correlation ($r = .164$, $p = .070$) was found between bone mineral density of the total spine and the % body fat of the trunk. A significant negative correlation ($r = -.466$, $p < .001$) was found between bone mineral density of the total hip and the % body fat of the left leg. (Results summarized in figures 7, 8 & 9)

The relationships between bone mineral density of the total radius and the percent body fat of the left arm, and the bone mineral density of the total hip and percent body fat of the left leg were strongest in the control group. However, no significant correlations were found between bone mineral density of the total spine and percent body fat of the trunk in any group.

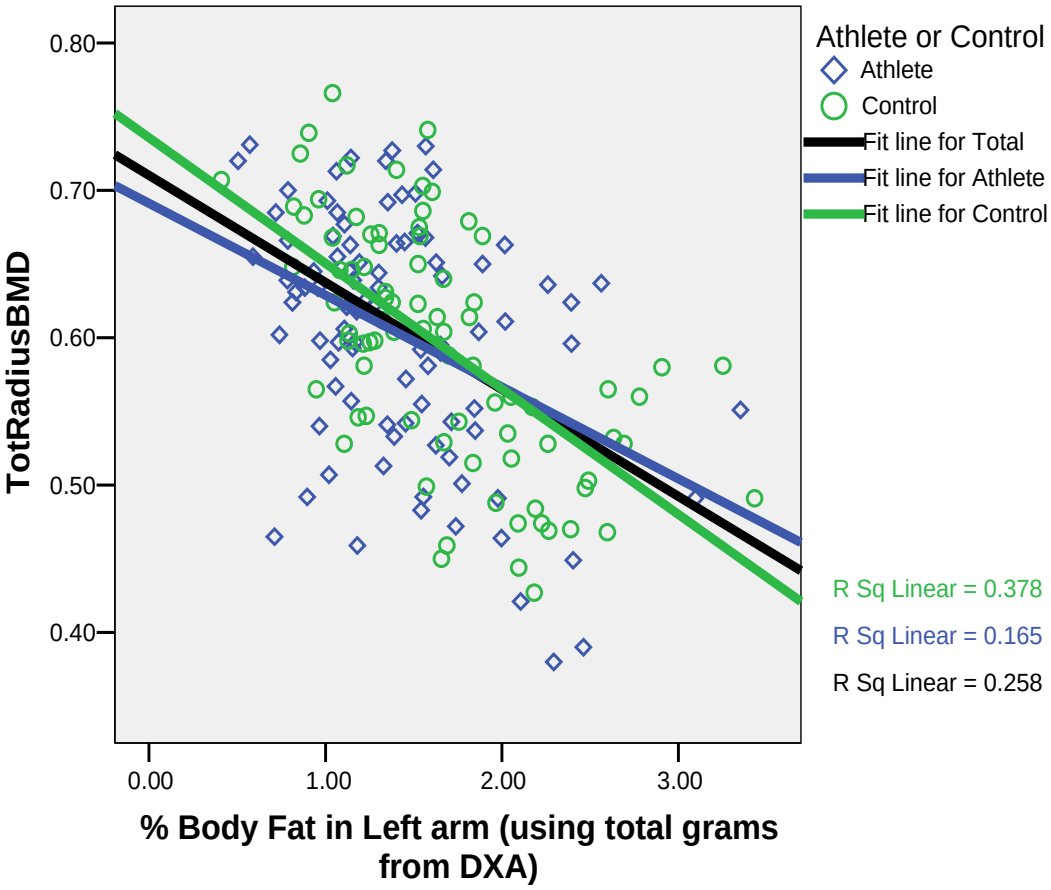

Figure 7 Scatterplot for % body fat of the left arm and BMD of the total radius

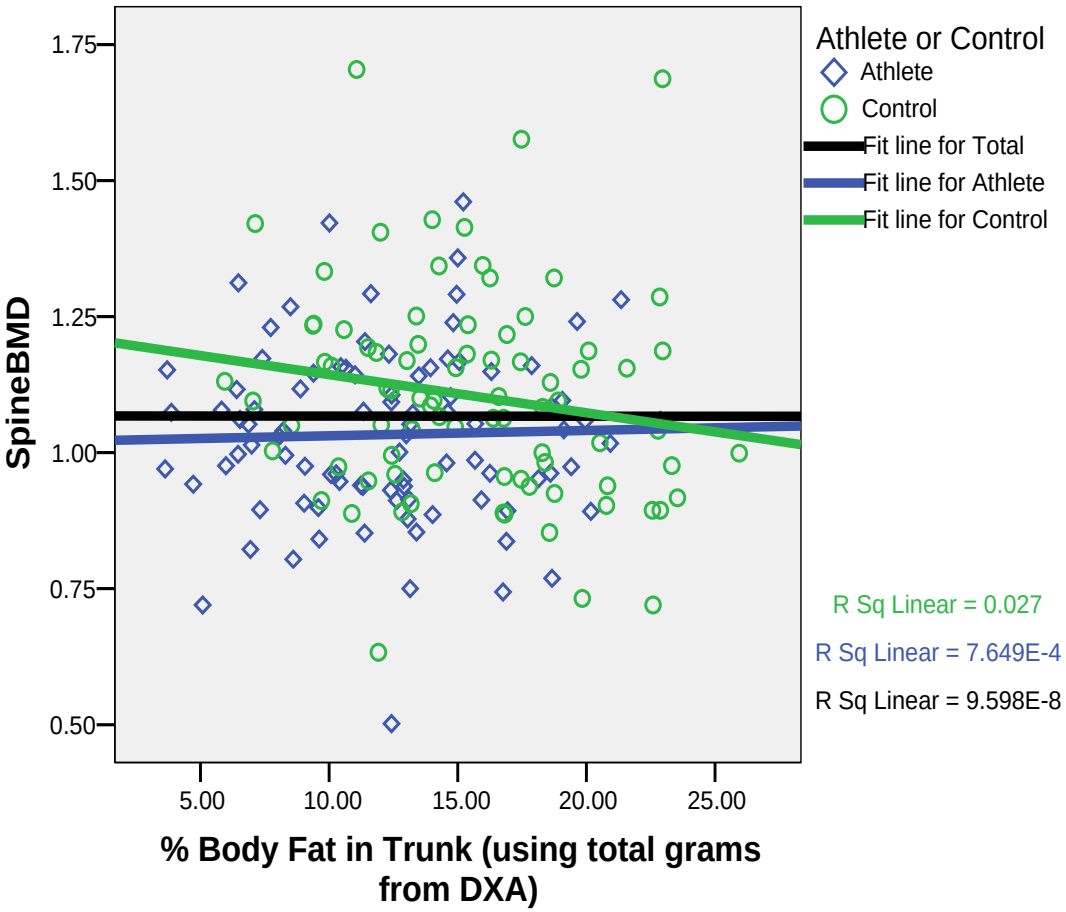

Figure 8 Scatterplot for % body fat of the trunk and BMD of the total spine

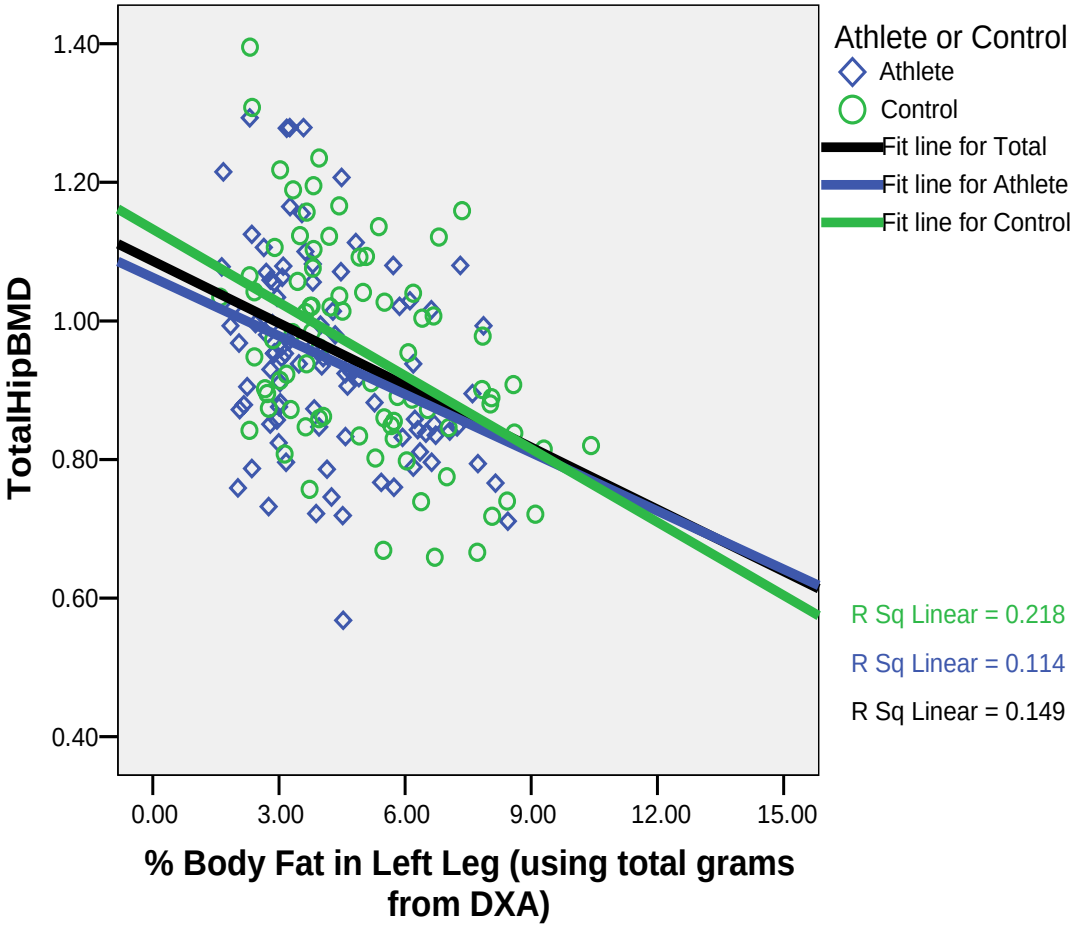

Figure 9 Scatterplot for % body fat of the left leg and BMD of the total hip

5.0 DISCUSSION

The purpose of this cross-sectional study was to determine the difference between various components of body composition in elite competitive older athletes and community-dwelling ambulatory controls and to examine the interrelationships between the components of body composition, and between these components and strength; specifically, to examine the relationship between the muscle mass and strength, regional body fat distribution and strength, and regional body fat distribution and muscle mass, bone mineral density and bone mass in community-dwelling ambulatory controls and elite competitive older athletes. Although many studies have examined the relationship between body composition parameters and age in older subjects, none have compared clinical normal community dwelling elderly aged 65 and older and what is often referred to as the ideal model of aging, the elite competitive athletes aged 65 and older.[27, 90, 146] Our predominant findings were that, as expected, all regional measures of body fat were significantly higher in control subjects than in athletes. This study also showed that all regional measures of lean muscle mass were significantly greater in athletes than in control subjects.

5.1 BODY FAT

Our study showed that all regional measures of body fat were significantly less in athletes than in control subjects. This indirectly corroborates previous studies that reported decreases in total and abdominal fat with physical activity.[20, 62, 124, 253] Protective effects of physical activity on the prevention of weight gain in middle-aged subjects has been widely reported and are often attributed to the increase in energy expenditure with physical activity.[101, 163, 260, 334] Previous studies have shown an increase in total and abdominal fat with aging.[27, 90, 154, 344] Most studies attribute the gain in total and abdominal fat with aging to a decrease in resting metabolic rate, thermic effect on food and decrease in physical activity.[70, 275, 315]

Our study also showed that women in both the athlete and control groups had a significantly higher percentage of body fat in the arm, trunk and leg than did males. This is contrary to most data that show men have a higher percentage of abdominal fat than women, however it does support the data from the same studies that state that men have less overall body fat than women.[238]

Studies that examined the body fat of college-aged competitive athletes showed ranges of body fat for runners, cyclist and swimmers (presented in Table 8). No data were found for college-aged female cyclists. As expected, the body fat for our elderly athletes was much higher for all three sports.

Table 8 Body fat values for college-aged athletes compared with elderly athletes of the current study

College-aged Athletes	**Runners**	**Cyclists**	**Swimmers**
Males	3.0 – 15.0%[181]	10.5 – 13.7%[79, 218, 339]	5.0 – 12.3%[79, 218, 300]
Females	13.6 – 14.2%[190]	*No Data Available*	16.1 – 17.1%[190, 219]
Elite Master Athletes from current study	**Runners**	**Cyclists**	**Swimmers**
Males	19.6%	22.4%	24.1%
Females	28.9%	26.4%	34.2%

For the purpose of this discussion, we examined the data in five year age categories. Unlike previous studies[160, 161], we did not see a significant difference between age categories in either controls or athletes in the arm or leg body fat regions. However, we did see a significant difference in body fat of the trunk, in controls only, between age categories. The findings of these analyses are presented in the figures 10 – 12. The graphs illustrate a slight trend in the controls, although not significant, of body fat percentage of the arm and leg that increases with age. The control group we recruited were healthy, relatively active individuals and may not best represent the general population of elderly; therefore, if a more sedentary control group were used we may see a more significant trend. However the significant difference for trunk body fat

percentage for controls and not for athletes helps to support the findings of previous studies that show an age-related increasing of body fat.[160, 161] This finding is perhaps the most important considering that abdominal fat, in particular, has been linked to increased risk for multiple chronic disease conditions, such as heart disease and metabolic syndrome. [34, 78, 119, 279, 226, 241]

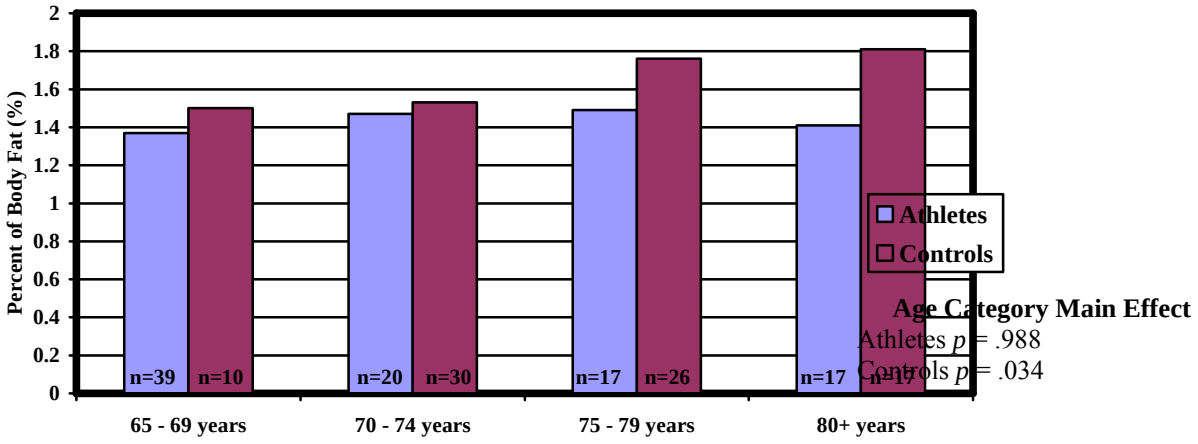

Figure 10 Left Arm Body Fat Percentage by Age Category

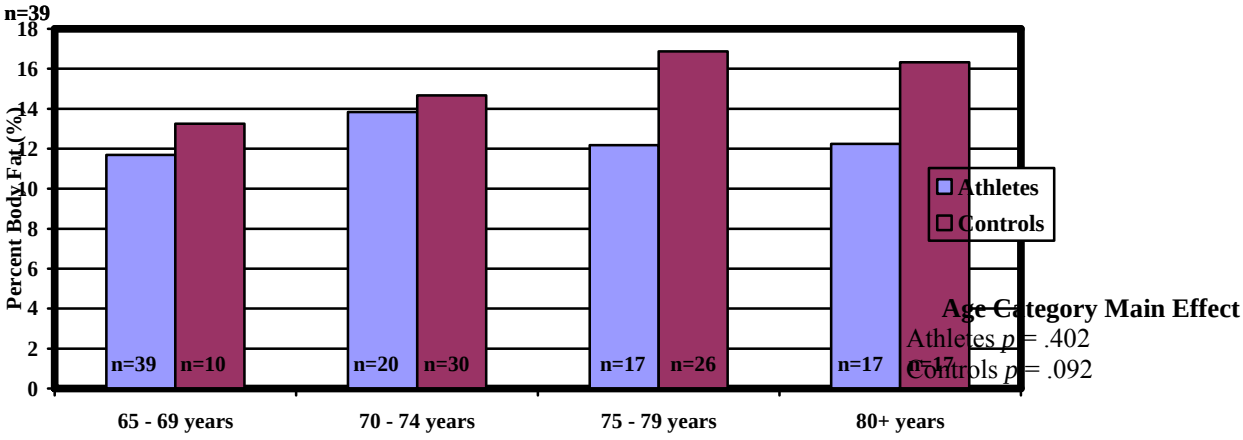

Figure 11 Trunk Body Fat Percentage by Age Category

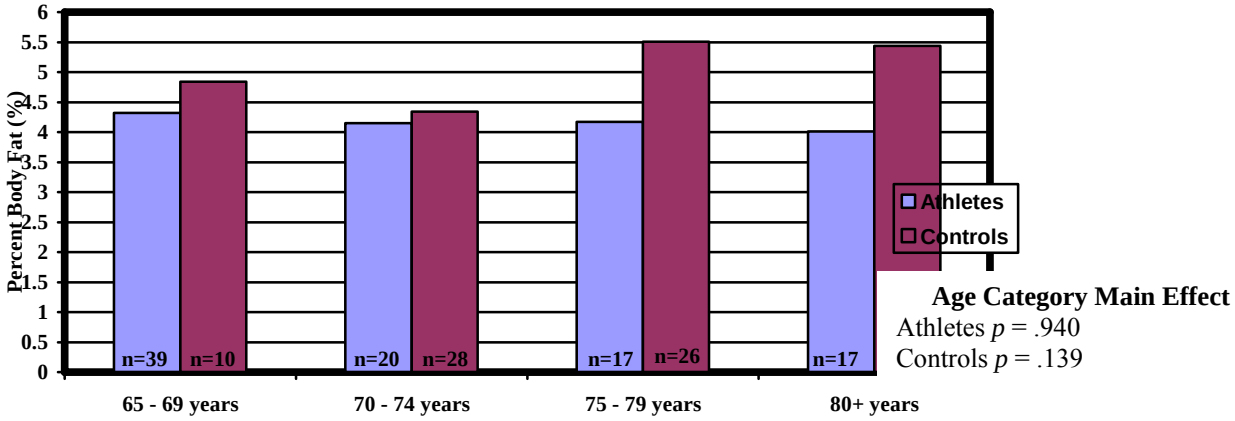

Figure 12 Left Leg Body Fat Percentage by Age Category

5.2 MUSCLE MASS

Mineral free lean mass of the arm and leg was significantly higher in both male and female athletes when compared to healthy controls. This is consistent with previous studies that showed higher mineral free lean mass with greater physical activity. [73-75, 122, 225, 266] Endurance type activity shows increases in cross-sectional area and resistance type activity has shown increases in size and number of myofibrils all leading to greater mineral free lean mass.[6, 145] In our elite athlete group, the runners and cyclists in this study were endurance athletes, while swimmers in any event were included in the study. It is unknown what resistance training, if any, was regularly performed by our subjects.

In a study by Penn et al., they found the lean muscle mass to of male distance runners with mean age of 27.9 to be 73.5% and the mineral-free lean mass of controls (subjects completed less than 4 hours of recreational activity per week) with a mean age of 27.8 to be 72.7.[217] Whereas, a study by Hetland et al. reported the mineral-free lean mass in males with a mean age of 32 years to be as much as 89.4% in recreational runners (mean 60 km per week), 91.6% in elite runners (mean 118 km per week) and 86.2% in control subjects.[217] The subjects from this study, as expected, had a lower percent mineral-free lean mass than that of the younger subjects from the Hetland study; but surprisingly, the male runners in our study had higher

mineral free lean percentages than that of the younger participants in the Penn study. Because the subjects in the Penn study were much younger, the discrepancy in mineral free lean percentages may be due to maturation issues. The results for this study are presented in table 9.

Table 9 Mineral Free Lean Mass Percentage for Participants of the Current Study

	Runners	Cyclists	Swimmers	Controls
Males	76.8%	74.5%	72.7%	71.3%
Females	67.9%	70.5%	63.4%	53.3%

With many complications associated with sarcopenia, many studies have also looked at the decrease in mineral free lean mass with age. For the purposes of this discussion, we examined the data in five year age categories in relation to percent mineral free lean mass of the arm and leg (i.e. percent muscle). Interestingly, there were significant differences in percentage of mineral free lean mass of the arm and leg between age categories of controls while there were no significant differences among age categories for athletes (figure 13-14). We also found significant correlations between age and percentage of mineral free lean mass of the leg and arm in controls only. In our review of the data it was interesting to note that we found a significant negative correlation between age and percent mineral free lean mass of the leg and arm only in the control subjects. This indicates that the athletes do not experience the same relationship between age and muscle mass decline. This leads us to speculate that indeed intense levels of physical activity may help combat the age-related decline in mineral free lean mass. This is especially important considering that physical activity may directly or indirectly help combat a major cause of frailty in the elderly.

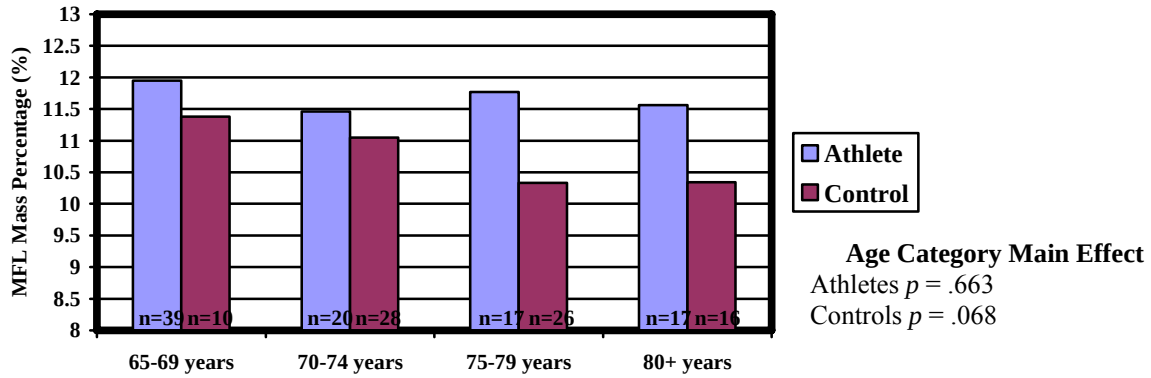

Figure 13 Left Leg MFL Mass Percentage by Age Category

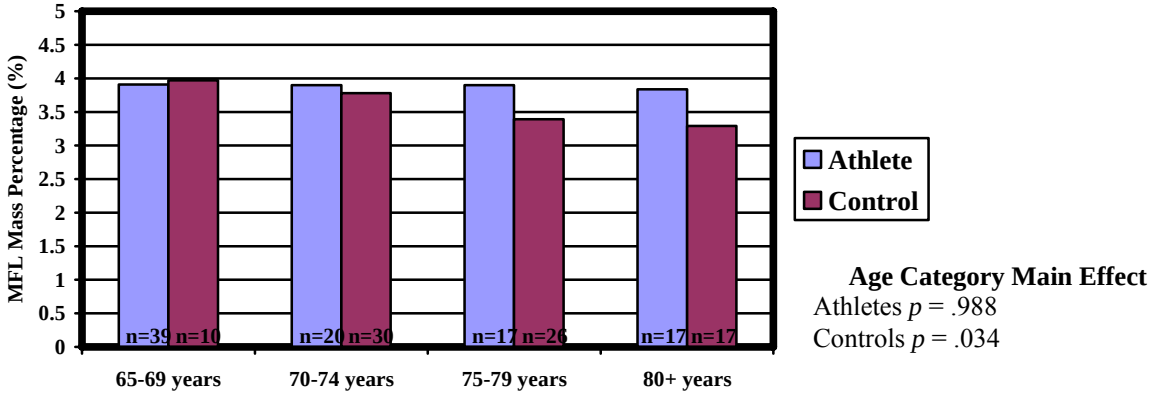

Figure 14 Left Arm MFL Mass Percentage by Age Category

This study also found men had a higher percentage of mineral free lean mass than did women for both the arm and leg in both athletes and controls. This is consistent with previous studies that found women to have less mineral free lean mass than men in both overall and regional measures.[90, 136]

These findings point to the speculation that athletics and exercise play more of a role than genetics when it comes to the common age-related declines in muscular strength and muscle mass, and increases in fat mass. If genetics were the predominant factor in these age-related decrements then we would see a parallel decline in muscle strength and muscle mass and a

parallel increase in fat mass with age in both groups. However this is not the case, our data shows age-related trends in only the control subjects.

5.3 RELATIONSHIP BETWEEN MUSCLE STRENGTH AND MINERAL FREE LEAN MASS

Age-related declines in strength have been well documented in the literature, stating average losses between 20-40%, even upwards of 50% into the 9th decade.[63, 64, 225, 317] Previous studies have reported a high correlation between muscle mass and muscle strength, however, Frontera et al. reported disproportionate gains in strength and leg muscle mass, indicating that other neuromuscular changes may mediate strength decreases. In a study conducted simultaneously with the current investigation, McCroy et al. found a significant difference in all strength values between athletes and controls, however, they found no significant effect for age in either groups.[189] Our study showed significant correlations between leg muscle mass and muscle strength in all samples. Although all relationships were significant, we saw stronger relationships between leg muscle mass and extension torque. This may be due to the fact that quadriceps are often larger in cross-sectional area because they are made up of four muscles whereas hamstrings have only three.

When we separated the athlete and control groups, we saw stronger correlations for the extension values and muscle mass in the controls; however, when looking at flexion values we experienced stronger correlations in the athletes. This may be due to a balanced training regimen focusing on the hamstrings in the athletes.

5.4 RELATIONSHIP BETWEEN BONE MINERAL DENISTY AND OTHER BODY COMPOSTION PARAMETERS

Previous studies have indicated that bone mineral mass is closely related to other body composition variables.[11, 48, 158, 245, 249] However, results of previous studies are not in agreement on whether fat tissue mass or lean tissue mass is the major determinant of bone mineral mass in women.[11, 48, 245, 249] One study has suggested that in men the predominant relationship is with lean muscle mass and bone mineral density and in women, the predominant relationship is with fat mass and bone mineral density.[249]

Studies have elucidated many other aspects that may be related to bone mineral density such as genetics, gender, race, nutritional factors, lifestyle factors, hormones, chronic diseases and medication as well as body composition.[11, 26, 42, 59, 120, 121, 165, 169, 201, 210, 231, 236, 242, 244-246, 249, 277, 295, 303, 305, 307, 314, 325] In the context of this dissertation, the most interesting factor when discussing bone mineral density and muscle mass may be physical activity. It has been shown that lack of physical activity decreases bone density and that physical activity has a protective effect on bone mineral density. [115, 201, 231, 296, 304]

In our study, we examined the athletes and controls separately and then combined independent of gender. We found significant relationships in all samples between bone mineral density of the radius and hip and mineral free lean mass of the arm and leg, showing when lean muscle mass increases so does bone mineral density. Even though all relationships were significant, there was a stronger relationship in all samples between the bone mineral density of the hip and mineral free lean mass of the leg. This may be due to the influence of mechanical loading on the joint. Since weight-bearing activity has been shown to be more osteogenic than non weight bearing activity[54], it would lead us to believe that given the loads and impact that the hip bears it would have higher bone mineral density. The increase in mineral free lean mass would also increase the weight load on the joint contributing to the weight bearing effect. Also, since increased muscle mass is associated with increased muscle strength, this would result in a stronger pull on the bone from the muscle attachment points, therefore increasing the load on the bone, resulting in more stress and further contributing to the osteogenic effects. This

corroborates the 1990 study by Heinrich et al., which showed that higher muscle mass, which is correlated to muscular strength, and thus reflects higher contractile forces exerted on the skeleton, and lead to increased bone mass.[117]

In regard to body fat, the relationships were quite different than we initially expected. In all samples we found significant negative relationships between bone mineral density of the radius and % body fat of the arm, and bone mineral density of the hip and % body fat of the leg. However, no relationship was found between bone mineral density of the spine and trunk fat percentage. The absence of this relationship may be affected by possible measurement error due to the fact that the presence of large amounts of abdominal tissue could affect the accuracy of the findings. In order to more accurately assess bone mineral density of the spine in subjects with a large abdominal mass, it may be best to use a lateral scan of the spine. These data indicate that lean muscle mass may be a better determinant of bone mineral density in the elderly population.

The negative relationships found between regional body fat and regional bone mineral density is particularly interesting considering that previous studies, including the larger study of which this dissertation is a part, indicate that weight and BMI are strong determinants of bone mineral density.[53, 184, 186, 187, 302] This may indicate that the weight bearing mechanical loading and the pull on the bone produced by the attached muscles contributes more to the bone density than does an individual component of body composition. This is an area that would require further research in order to show a causal relationship.

5.5 LIMITATIONS OF THE STUDY

Because the data are cross-sectional, cause and effect cannot be determined. Even though we excluded subjects for certain prescribed drugs and diseases that could affect bone density, we did not exclude for all medications that could adversely affect any other measure of body composition. Therefore, factors other than aging may well have been responsible for the differences reported.

In this study, all of the subjects were volunteers and were not recruited from the same geographical location. The athletes were recruited from the 2005 National Senior Games and, therefore, were originally from a wide array of locations across the United States. The control group was recruited from the University of Pittsburgh Claude D. Pepper Older Americans Independence Center, and therefore, primarily from the Pittsburgh metro area. This could affect the results due to differences in climate, access to health care, quality of health care, and access to physical activity programs and facilities. Also, since these subjects were all volunteers and were in good health, they may not be representative of the general older population.

In this study, despite our best efforts, the control group was significantly older than the athletes. This may serve to further exaggerate the differences found between groups. In an effort to minimize the exaggeration, we did analyze and report data in separate 5 year age categories.

5.6 FUTURE DIRECTIONS

Future research is needed to further substantiate the results of this study. In order to show a causal relationship between exercise and the prevention of common age-related declines a longitudinal study would need to be preformed. This would help to prove the benefits of exercise and aging. Also in order to determine the exact frequency, intensity and type of exercise needed several intervention studies would need to be performed.

During the current investigation we also collected data regarding the life long activity of the control subjects. This data will be used to further address the role activity plays on body composition components.

[APPENDIX A]

APPENDIX A – Statistical Tables

A.1 REGIONAL MEASURES OF BODY FAT

ANOVA % Body Fat in Left arm

Tests of Between-Subjects Effects

Dependent Variable: % Body Fat in Left arm (using total grams from DXA)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power(a)
Corrected Model	27.479(b)	3	9.160	52.465	.000	157.394	1.000
Intercept	440.059	1	440.059	2520.586	.000	2520.586	1.000
Gender	24.685	1	24.685	141.391	.000	141.391	1.000
Group	2.999	1	2.999	17.180	.000	17.180	.985
Gender * Group	.736	1	.736	4.213	.042	4.213	.532
Error	30.029	172	.175				
Total	470.591	176					
Corrected Total	57.508	175					

a Computed using alpha = .05

b R Squared = .478 (Adjusted R Squared = .469)

ANOVA % Body Fat in Trunk

Tests of Between-Subjects Effects

Dependent Variable: % Body Fat in Trunk (using total grams from DXA)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power(a)
Corrected Model	1138.070(b)	3	379.357	22.626	.000	67.879	1.000
Intercept	34445.789	1	34445.789	2054.490	.000	2054.490	1.000
Gender	658.247	1	658.247	39.261	.000	39.261	1.000
Group	495.390	1	495.390	29.547	.000	29.547	1.000
Gender * Group	54.229	1	54.229	3.234	.074	3.234	.432
Error	2883.769	172	16.766				
Total	37762.955	176					
Corrected Total	4021.839	175					

a Computed using alpha = .05

b R Squared = .283 (Adjusted R Squared = .270)

ANOVA % Body Fat in Left Leg

Tests of Between-Subjects Effects

Dependent Variable: % Body Fat in Left Leg (using total grams from DXA)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power(a)
Corrected Model	377.936(b)	3	125.979	87.943	.000	263.830	1.000
Intercept	3975.433	1	3975.433	2775.172	.000	2775.172	1.000
Gender	350.021	1	350.021	244.343	.000	244.343	1.000
Group	33.383	1	33.383	23.304	.000	23.304	.998
Gender * Group	3.250	1	3.250	2.269	.134	2.269	.322
Error	242.092	169	1.432				
Total	4232.400	173					
Corrected Total	620.028	172					

a Computed using alpha = .05

b R Squared = .610 (Adjusted R Squared = .603)

A.2 REGIONAL MEASURES OF MINERAL FREE LEAN TISSUE

ANOVA % Mineral Free Lean Tissue in Left Arm

Tests of Between-Subjects Effects

Dependent Variable: % Lean tissue in Left arm (using total grams from DXA)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power(a)
Corrected Model	62.126(b)	3	20.709	89.943	.000	269.830	1.000
Intercept	2158.058	1	2158.058	9372.994	.000	9372.994	1.000
Gender	57.727	1	57.727	250.723	.000	250.723	1.000
Group	4.454	1	4.454	19.343	.000	19.343	.992
Gender * Group	.075	1	.075	.326	.569	.326	.088
Error	39.602	172	.230				
Total	2569.710	176					
Corrected Total	101.728	175					

a Computed using alpha = .05

b R Squared = .611 (Adjusted R Squared = .604)

ANOVA % Mineral Free Lean Tissue in Left Leg

Tests of Between-Subjects Effects

Dependent Variable: % Lean tissue in Left Leg (using total grams from DXA)

Source	Type III Sum of Squares	df	Mean Square	F	Sig.	Noncent. Parameter	Observed Power(a)
Corrected Model	167.205(b)	3	55.735	36.976	.000	110.928	1.000
Intercept	19694.930	1	19694.930	13066.174	.000	13066.174	1.000
Gender	121.917	1	121.917	80.883	.000	80.883	1.000
Group	45.721	1	45.721	30.332	.000	30.332	1.000
Gender * Group	.206	1	.206	.137	.712	.137	.066
Error	254.737	169	1.507				
Total	22375.870	173					
Corrected Total	421.942	172					

a Computed using alpha = .05

b R Squared = .396 (Adjusted R Squared = .386)

A.3 CORRELATION TABLES FOR MINERAL FREE LEAN AND BMD

Correlation for Combined Sample

		% Lean tissue in Left arm (using total grams from DXA)	% Lean tissue in Left Leg (using total grams from DXA)	TotalHipBMD	TotRadiusBMD
% Lean tissue in Left arm (using total grams from DXA)	Pearson Correlation	1	.795(**)	.362(**)	.640(**)
	Sig. (1-tailed)		.000	.000	.000
	N	176	173	176	175
% Lean tissue in Left Leg (using total grams from DXA)	Pearson Correlation	.795(**)	1	.248(**)	.454(**)
	Sig. (1-tailed)	.000		.001	.000
	N	173	173	173	172
TotalHipBMD	Pearson Correlation	.362(**)	.248(**)	1	.649(**)
	Sig. (1-tailed)	.000	.001		.000
	N	176	173	185	184
TotRadiusBMD	Pearson Correlation	.640(**)	.454(**)	.649(**)	1
	Sig. (1-tailed)	.000	.000	.000	
	N	175	172	184	184

** Correlation is significant at the 0.01 level (1-tailed).

Correlation Tables for Athlete and Control Samples

Athlete or Control			% Lean tissue in Left arm (using total grams from DXA)	% Lean tissue in Left Leg (using total grams from DXA)	TotalHipBMD	TotRadiusBMD
Athlete	% Lean tissue in Left arm (using total grams from DXA)	Pearson Correlation	1	.737(**)	.277(**)	.548(**)
		Sig. (1-tailed)		.000	.004	.000
		N	93	93	93	92
	% Lean tissue in Left Leg (using total grams from DXA)	Pearson Correlation	.737(**)	1	.196(*)	.388(**)
		Sig. (1-tailed)	.000		.030	.000
		N	93	93	93	92
	TotalHipBMD	Pearson Correlation	.277(**)	.196(*)	1	.638(**)
		Sig. (1-tailed)	.004	.030		.000
		N	93	93	99	98
	TotRadiusBMD	Pearson Correlation	.548(**)	.388(**)	.638(**)	1
		Sig. (1-tailed)	.000	.000	.000	
		N	92	92	98	98
Control	% Lean tissue in Left arm (using total grams from DXA)	Pearson Correlation	1	.854(**)	.473(**)	.745(**)
		Sig. (1-tailed)		.000	.000	.000
		N	83	80	83	83
	% Lean tissue in Left Leg (using total grams from DXA)	Pearson Correlation	.854(**)	1	.375(**)	.564(**)
		Sig. (1-tailed)	.000		.000	.000
		N	80	80	80	80
	TotalHipBMD	Pearson Correlation	.473(**)	.375(**)	1	.667(**)
		Sig. (1-tailed)	.000	.000		.000
		N	83	80	86	86
	TotRadiusBMD	Pearson Correlation	.745(**)	.564(**)	.667(**)	1
		Sig. (1-tailed)	.000	.000	.000	
		N	83	80	86	86

** Correlation is significant at the 0.01 level (1-tailed).

* Correlation is significant at the 0.05 level (1-tailed).

A.4 CORRELATION TABLES FOR BODY FAT AND BMD

Correlation for Combined Sample

Correlations

		% Body Fat in Left arm (using total grams from DXA)	% Body Fat in Trunk (using total grams from DXA)	% Body Fat in Left Leg (using total grams from DXA)	Spine BMD	TotalHip BMD	TotRadius BMD
% Body Fat in Left arm (using total grams from DXA)	Pearson Correlation	1	.751(**)	.778(**)	-.182(**)	-.290(**)	-.508(**)
	Sig. (1-tailed)		.000	.000	.008	.000	.000
	N	176	176	173	175	176	175
% Body Fat in Trunk (using total grams from DXA)	Pearson Correlation	.751(**)	1	.633(**)	.000	-.111	-.338(**)
	Sig. (1-tailed)	.000		.000	.498	.071	.000
	N	176	176	173	175	176	175
% Body Fat in Left Leg (using total grams from DXA)	Pearson Correlation	.778(**)	.633(**)	1	-.259(**)	-.386(**)	-.600(**)
	Sig. (1-tailed)	.000	.000		.000	.000	.000
	N	173	173	173	172	173	172
SpineBMD	Pearson Correlation	-.182(**)	.000	-.259(**)	1	.663(**)	.541(**)
	Sig. (1-tailed)	.008	.498	.000		.000	.000
	N	175	175	172	184	184	183
TotalHipBMD	Pearson Correlation	-.290(**)	-.111	-.386(**)	.663(**)	1	.649(**)
	Sig. (1-tailed)	.000	.071	.000	.000		.000
	N	176	176	173	184	185	184
TotRadiusBMD	Pearson Correlation	-.508(**)	-.338(**)	-.600(**)	.541(**)	.649(**)	1
	Sig. (1-tailed)	.000	.000	.000	.000	.000	
	N	175	175	172	183	184	184

** Correlation is significant at the 0.01 level (1-tailed).

Correlation for Athlete and Control Samples

Athlete or Control			% Body Fat in Left arm (using total grams from DXA)	% Body Fat in Trunk (using total grams from DXA)	% Body Fat in Left Leg (using total grams from DXA)	Spine BMD	TotalHip BMD	TotRadius BMD
Athlete	% Body Fat in Left arm (using total grams from DXA)	Pearson Correlation	1	.776(**)	.731(**)	-.061	-.231(*)	-.407(**)
		Sig. (1-tailed)		.000	.000	.283	.013	.000
		N	93	93	93	92	93	92
	% Body Fat in Trunk (using total grams from DXA)	Pearson Correlation	.776(**)	1	.588(**)	.028	-.065	-.210(*)
		Sig. (1-tailed)	.000		.000	.397	.266	.022
		N	93	93	93	92	93	92
	% Body Fat in Left Leg (using total grams from DXA)	Pearson Correlation	.731(**)	.588(**)	1	-.195(*)	-.338(**)	-.514(**)
		Sig. (1-tailed)	.000	.000		.031	.000	.000
		N	93	93	93	92	93	92
	SpineBMD	Pearson Correlation	-.061	.028	-.195(*)	1	.659(**)	.506(**)
		Sig. (1-tailed)	.283	.397	.031		.000	.000
		N	92	92	92	98	98	97
	TotalHipBMD	Pearson Correlation	-.231(*)	-.065	-.338(**)	.659(**)	1	.638(**)
		Sig. (1-tailed)	.013	.266	.000	.000		.000
		N	93	93	93	98	99	98
	TotRadiusBMD	Pearson Correlation	-.407(**)	-.210(*)	-.514(**)	.506(**)	.638(**)	1
		Sig. (1-tailed)	.000	.022	.000	.000	.000	
		N	92	92	92	97	98	98
Control	% Body Fat in Left arm (using total grams from DXA)	Pearson Correlation	1	.703(**)	.802(**)	-.375(**)	-.368(**)	-.615(**)
		Sig. (1-tailed)		.000	.000	.000	.000	.000
		N	83	83	80	83	83	83
	% Body Fat in Trunk (using total grams from DXA)	Pearson Correlation	.703(**)	1	.637(**)	-.164	-.189(*)	-.486(**)

	Sig. (1-tailed)	.000		.000	.070	.043	.000
	N	83	83	80	83	83	83
% Body Fat in Left Leg (using total grams from DXA)	Pearson Correlation	.802(**)	.637(**)	1	-.421(**)	-.466(**)	-.697(**)
	Sig. (1-tailed)	.000	.000		.000	.000	.000
	N	80	80	80	80	80	80
SpineBMD	Pearson Correlation	-.375(**)	-.164	-.421(**)	1	.674(**)	.619(**)
	Sig. (1-tailed)	.000	.070	.000		.000	.000
	N	83	83	80	86	86	86
TotalHipBMD	Pearson Correlation	-.368(**)	-.189(*)	-.466(**)	.674(**)	1	.667(**)
	Sig. (1-tailed)	.000	.043	.000	.000		.000
	N	83	83	80	86	86	86
TotRadiusBMD	Pearson Correlation	-.615(**)	-.486(**)	-.697(**)	.619(**)	.667(**)	1
	Sig. (1-tailed)	.000	.000	.000	.000	.000	
	N	83	83	80	86	86	86

** Correlation is significant at the 0.01 level (1-tailed).

* Correlation is significant at the 0.05 level (1-tailed).

[APPENDIX B]

APPENDIX B – Informed Consent

CONSENT TO ACT AS A PARTICIPANT IN A RESEARCH STUDY

TITLE: The Effect of High Impact Exercise on Skeletal Integrity in Master Athletes

PRINCIPAL INVESTIGATOR:

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Pittsburgh, PA 15213

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SOURCE(S) OF SUPPORT:

Aventis/Procter & Gamble Pharmaceuticals (Alliance for Better Bone Health)

Osteoporosis Prevention and Treatment Center

Gift Fund (Private Donor Bequest)

Why is this research being done?

The purpose of this research study is to see if high-impact sports (running) in master athletes will produce greater bone mass in the spine, hip, and heel than medium-impact sports (cycling) or low-impact sports (swimming), and to see how that compares with bone mass in men and women of similar age who are not master athletes. Bone mass (also known as bone density) is a measure of bone strength.

Who is being asked to take part in this research study?

You are being asked to participate in this study because you are a senior master athlete participating in one of these sports, or a non-athlete age 65 or older living in the Pittsburgh area. Up to 600 subjects will be screened in order to find 230 eligible male and female participants ages 65 and older who are either master athletes or community dwelling non-athletes.

What procedures will be performed for research purposes?

If you decide to take part in this research study, you will undergo the following procedures that are not part of your standard medical care:

Screening Procedures: Procedure to determine if you are eligible to take part in a research study are called "screening procedures." For this research study, the screening procedures will include:

1. Questions about your health, medications, age, demographics, and exercise/sports category (impact level and Senior Olympic competition event). These questions will take about 5-10 minutes and will be done immediately following the informed consent process or by telephone screening.

If you qualify to take part in this research study you will be scheduled for an appointment for the remaining tests, which will be performed at the General Clinical Research Center (GCRC) at Montefiore Hospital at the University of Pittsburgh Medical Center (UPMC) and will involve one study visit which will take approximately 2-3 hours of your time.

Study Procedures: The following study procedures will be attempted at your GCRC visit (approx. 2-3 hours):

1. A nurse practitioner, physician assistant, registered nurse, or phlebotomist will draw blood upon your arrival to determine your indicators of bone change, bone mineral metabolism and for general health measures (takes less than 5 minutes).
2. Dual-energy X-ray absorptiometry (DXA) of the hip, spine, forearm, and total body. You will be asked to lie still on a padded table for approximately 20 minutes while the arm of the DXA machine (a special low-radiation X-ray machine) passes over those body regions to measure the thickness of your bones and your body composition.
3. A urine sample will be taken for markers of bone turnover (takes less than 5 minutes). Bone is in a constant state of change as new bone is made and old bone is broken down. We can measure this turnover indirectly by measuring the protein breakdown products of bone in urine.
4. Height and weight (takes less than 5 minutes)
5. Food Frequency (dietary calcium intake) Questionnaire (approx. 20 minutes)
6. Quality of Life Questionnaire (approx. 10 minutes)
8. Heel ultrasound, a procedure which measures bone thickness by sound waves. For this procedure, you will be asked to remove your shoes and socks and roll up one pant leg. The technologist will apply clear gel to each side of your heel and place your foot in the unit, which sits on the floor. When the technologist starts the test, sound waves will move through your heel, measuring the thickness of the bone. This procedure requires a few minutes. Afterward, the gel will be wiped from your heel and the machine will be cleaned thoroughly. This procedure takes less than 5 minutes.
9. Strength Test: You will be asked to sit in the chair used with the strength measurement device so that we may secure your body with cloth straps to eliminate any unnecessary motion. We will secure your left leg to the device using a cloth strap. You will extend your left leg as hard as you can for five seconds, immediately after which you will rest for thirty seconds then repeat this action three times. You will then be asked to bend your knee at your maximal effort level. Again, you will perform three five-second contractions with thirty seconds of rest between each. You will be instructed to keep breathing during the test and to not hold your breath. No encouragement or coaching will be given during the test, only reminders to keep breathing. You will also be able to stop the test at any time if you feel you can't continue. This procedure takes less than 10 minutes.

10. Injury and Fitness/Leisure Activity Questionnaire: Following the strength testing, you will be asked questions about any major or recent musculoskeletal injuries and about your participation in physical activities over the last year and during previous stages of your life. This questionnaire will take approximately 10-15 minutes to complete.

What are the possible risks, side effects, and discomforts of this research study?

Risks of the Blood Tests

Some common risks may include pain, bleeding, and the possibility of bruising at the site of the blood draw or the feeling of lightheadedness (occurs in 1-25%, or 1-25 people out of 100), and rarely, infection at the site of the blood draw (occurs in less than 1%, or less than 1 out of 100 people). A maximum of up to 70 ml (approximately 14 teaspoons) of blood will be drawn for the study procedures listed above.

Risks of Radiation Exposure

Participation in this research study will involve exposure to radiation from the DXA studies (spine, hip, wrist and whole body). If the research subject completes all of these studies, as outlined in this protocol, the total radiation dose to your spine will be about 10 mrems (a mrem is a unit of radiation dose); to your hip will be about 10 mrems; and to your wrist will be about 5 mrems. The whole body DXA scan will result in a whole body radiation dose of about 1 mrem. For comparison, these radiation doses are a very small fraction of the maximum annual single organ radiation dose (50,000 mrems) and maximum annual whole body radiation dose (5000 mrems) permitted by Federal regulation to adult radiation workers. There is no minimum level of radiation exposure that is recognized as being totally free of the risk of causing genetic mutations (abnormal cells) or cancer. However, the risk associated with the amount of radiation exposure research subjects will receive from participation in this research study is considered to be low and comparable to everyday risks.

Heel Ultrasound

There is no known risk from ultrasound testing.

Strength Testing

We do not anticipate any injuries and the risks of participation are small. However, it is possible as with any experiment that harmful effects may occur. If an injury does occur, the investigators listed on the front page of this form will administer immediate and appropriate first aid care.

Because this is a muscle contracting exercise, the occurrence of slight muscle soreness is possible. This mild soreness typically develops 2-3 days after the experiment and may last approximately 2-3 days.

What are possible benefits from taking part in this study?

There may be no direct benefit to your participation in this study. This study is being performed to advance medical knowledge in general and is not specifically intended to diagnose or treat any illness you may have. However, one benefit is that you will learn your bone mineral density.

What treatments or procedures are available if I decide not to take part in this research study?

DXA scans of various body regions (e.g., the spine, hip, wrist) are available outside of study participation for the diagnosis and evaluation of osteopenia/osteoporosis (thinning and weakening of bones). You may choose not to participate and discuss how to get a DXA scan with your physician.

Will my insurance provider or I be charged for the cost of any procedures performed as part of this research study?

Neither you nor your insurer will be billed for study procedures. The study procedures (DXA, blood and urine tests, heel ultrasound, questionnaires, strength testing) will be paid for by the study sponsor.

Will I be paid if I take part in this research study?

You will be provided with a parking sticker for Montefiore Hospital.

Who will pay if I am injured as a result of taking part in this study?

University of Pittsburgh researchers and their associates who provide services at UPMC recognize the importance of your voluntary participation in their research studies. These individuals and their staffs will make reasonable effort to minimize, control, and treat any injuries that may arise as a result of this research. If you believe that you are injured as a result of the research procedures being performed, please contact immediately the Principal Investigator or one of the co-investigators listed on the first page of this form. Emergency medical treatment for injuries solely and directly related to your participation in this research study will be provided to you by the hospitals of UPMC. It is possible that UPMC may bill your insurance provider for the costs of this emergency treatment, but none of these costs will be charged directly to you. If your research-related injury requires medical care beyond this emergency treatment, you will be responsible for the costs of this follow-up care unless otherwise specifically stated below. There is no plan for monetary compensation. You do not, however, waive any legal rights by signing this form.

Who will know about my participation in this research study?

This research study will result in identifiable information that will be placed into your medical records held at the Osteoporosis Prevention and Treatment Center under lock and key. The nature of the identifiable information resulting from your participation in this research study that will be recorded in your medical record includes DXA scan reports, brief history per screening/eligibility questions, medications, lab values, heel ultrasound results, and progress notes which were performed for research purposes and information related to any adverse events you may experience related to the study procedures.

This research study will result in identifiable information that will be placed into your medical records held at UPMC Presbyterian [Medical ARchival System (MARS)]. The nature of the identifiable information resulting from your participation in this research study that will be recorded in MARS includes lab values and information related to any adverse events you may experience related to the study procedures.

Who will have access to identifiable information related to my participation in this research study?

In addition to the investigators listed on the first page of this authorization (consent) form and their research staff, the following individuals will or may have access to identifiable information, which may include your identifiable medical information, related to your participation in this research study:

Authorized representatives of the University of Pittsburgh Research Conduct and Compliance Office may review your identifiable research information, which may include your identifiable medical information, for the purpose of monitoring the appropriate conduct of this research study.

In unusual cases, the investigators may be required to release identifiable information, which may include your identifiable medical information, related to your participation in this research study in response to an order from a court of law. If the investigators learn that you or someone with whom you are involved is in serious danger or potential harm, they will need to inform, as required by Pennsylvania law, the appropriate agencies.

Authorized representatives of the UPMC hospitals and affiliated health care providers may have access to identifiable information, which may include your identifiable medical information, related to your participation in this research study for the purpose of (1) fulfilling orders, made by the investigators, for hospital and health care services (e.g., laboratory tests, diagnostic procedures) associated with research study

participation; (2) addressing correct payment for tests and procedures ordered by the investigators; and/or (3) for internal hospital operations (i.e. quality assurance).

For how long will the investigators be permitted to use and disclose identifiable information related to my participation in this research study?

The investigators may continue to use and disclose, for the purposes described above, identifiable information (which may include your identifiable medical information) related to your participation in this research study for a minimum of five years after final reporting or publication of a project.

May I have access to my medical information that results from my participation in this research study?

In accordance with the UPMC Notices of Privacy Practices document that you have been provided, you are permitted access to information (including information resulting from your participation in this research study) contained within your medical records filed with your health care provider.

Is my participation in this research study voluntary?

Your participation in this research study, to include the use and disclosure of your identifiable information for the purposes described above, is completely voluntary. Note, however, that if you do not provide your consent for the use and disclosure of your identifiable information for the purposes described above, you will not be allowed to participate in the research study. Whether or not your provide your consent for participation in this research study will have no effect on your current or future relationship with the University of Pittsburgh. Whether or not you provide your consent for participation in this research study will have no

effect on your current or future medical care at a UPMC hospital of affiliated health care provider or your current or future relationship with a health care insurance provider.

May I withdraw, at a future date, my consent for participation in this research study?

You may withdraw, at any time, your consent for participation in this research study, to include the use and disclosure of your identifiable information for the purposes described above. Note, however, that if you withdraw your consent for the use and disclosure of your identifiable medical record information for the purposes described above, you will also be withdrawn, in general, from further participation in this research study. Any identifiable research or medical information recorded for, or resulting from, your participation in this research study prior to the date that you formally withdrew your consent may continue to be used and disclosed by the investigators for the purposes described above.

To formally withdraw your consent for participation in this research study you should provide a written and dated notice of this decision to the principal investigator of this research study at the address listed on the first page of this form.

Your decision to withdraw your consent for participation in this research study will have no effect on your current or future relationship with the University of Pittsburgh. Your decision to withdraw your consent for participation in this research study will have no effect on your current or future medical care at a UPMC hospital or affiliated health care provider or your current or future relationship with a health care insurance provider.

If I agree to take part in this research study, can I be removed from the study without my consent?

You should also be aware that you may be asked to leave the research study by the study doctor or sponsors, without your consent if you need other treatment, if you do not follow the investigators' instructions, if you have a study-related injury, or for another reason. You might

also be removed for the study for other medical or administrative reasons (e.g., because the research is not found to be beneficial or the study resources are no longer available). We will notify you should this arise and advise you of available alternatives that may be of benefit at the time.

If you leave the study, the doctor may ask to examine you and do some final tests. This could be important for your safety if you withdraw because of adverse effects.

* *

VOLUNTARY CONSENT

All of the above had been explained to me and all of my current questions have been answered. I understand that I am encouraged to ask questions about any aspect of this research study during the course of this study, and that such future questions will be answered by the researchers listed on the first page of this form.

Any questions which I have about my rights as a research participant will be answered by the Human Subject Protection Advocate of the IRB Office, University of Pittsburgh (1-866-212-2668).

By signing this form, I agree to participate in this research study. A copy of this consent form will be given to me.

I agree to be contacted in the future about new studies related to bone health (Check and initial your answer on the appropriate line below):

YES _____ NO_____

_____	_____
Participant's Signature	Date

CERTIFICATION OF INFORMED CONSENT

_____	_____
Printed Name of Person Obtaining Consent	Role in Research Study
_____	_____
Signature of Person Obtaining Consent	Date

* *

GENETIC ASSESSMENT ADDENDUM

In addition to the other blood tests for this study, we would also like to draw an additional 10 ml sample (approx. 2 teaspoons) for genetic testing. We will examine the DNA (deoxyribonucleic acid) from the sample to study the genes that are thought to influence bone strength and density (also known as bone mass) and bone mineral metabolism (the process by which new bone is made and old bone is broken down, as bone is in a constant state of change). The goal of these exploratory research studies is to find genetic markers (genes associated with a particular trait) that will identify persons at high risk of low bone mass or osteoporosis (very low bone mass). We will test to see if there are any differences in two particular genes, the vitamin D receptor gene and the androgen receptor gene, which have both been shown to be involved in bone metabolism.

The use of your sample will be confined to research focused on the study of genes related to osteoporosis, low bone mass or bone related changes. The factors that we are looking at will be examined as a group and will not be examined as individual subjects.

The frozen samples are stored in a locked storage room at Montefiore Hospital, and the principal investigator assume overall responsibility for the control of this storage area, which is monitored by a security alarm service. The information linking the assigned code numbers for the stores samples to the corresponding subjects' identities will be kept in a separate secure area at the Osteoporosis Prevention and Treatment Center. Samples, with the assigned codes but not the associated subject information, will be sent to Dr. Ferrell's Laboratory in the Department of Human Genetics at the University of Pittsburgh for assay.

Results of these studies are for research purposes only and since they are not expected to benefit you directly or to alter your treatment course, these results will not be placed in your

medical record database and will not be made available to you, members of your family, your personal physician, or other third parties except as specified below.

Study Procedures: An additional 10 ml blood sample will be drawn at the time of your GCRC visit for this genetic testing at the same time the blood is drawn for the main study on the Effect of High Impact Exercise on Skeletal Integrity in Master Athletes.

RISKS

Two teaspoons of blood will be drawn for DNA analysis. Some common risks may include pain, bleeding, and the possibility of bruising at the site of the blood draw or the feeling of lightheadedness (occurs in 1-25%, or 1-25 people out of 100), and rarely, infection at the site of the blood draw (occurs in less than 1%, or less than 1 out of 100 people). The risk of DNA testing is the possibility of a loss of confidentiality. The DNA tests that will be done on your sample have no known relationship to health. Knowledge of your genetic research data could potentially impact your future insurability, employability, or reproduction plans; or have a negative impact on family relationships; and/or result in shame or embarrassment.

BENEFITS

There will be no direct benefit to you from the analysis of these samples. Indirect benefits may include the possible advancement of medical knowledge so scientists can find more effective and safer treatments for osteoporosis. A future benefit might be helping to discover new treatments that will supplement currently available treatments.

NEW INFORMATION

You will be promptly notified if any new information develops during the conduct of this research study that may cause you to change your mind about continuing to participate.

COSTS AND PAYMENTS

Neither you nor your insurer will be billed for the genetic testing. This study procedure will be paid for by the study sponsor(s).

* *

VOLUNTARY CONSENT FOR GENETIC TESTING

I agree to have blood drawn and stored as described above for genetic testing (Check and initial your answer on the appropriate line below)

YES _____ NO_____

I understand that if I decline to have this blood testing performed, I can still participate in the main research study on the Effect of High Impact Exercise on Skeletal Integrity in Master Athletes. I agree that authorized persons may have access to my personal medical records, provided that confidentiality on the information is maintained.

By signing this form, I agree to participate in the genotype testing. A copy of this consent form will be given to me.

_____	_____
Participant's Signature	Date

CERTIFICATION OF INFORMED CONSENT

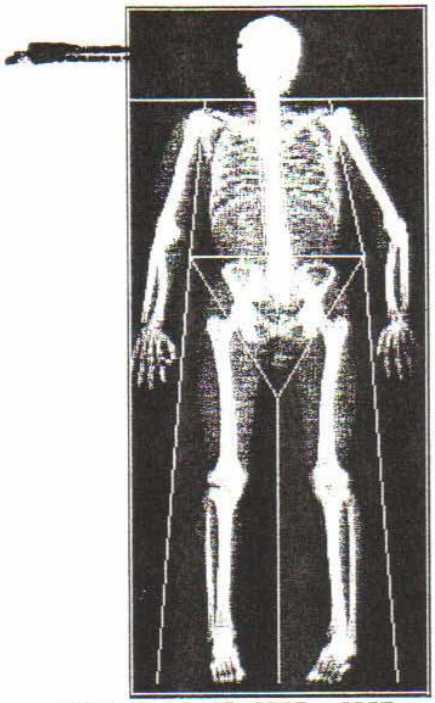
I certify that I have explained the nature and purpose, the potential benefits, and possible risks associated with participation in this research study to the above individual. Any questions the individual has about this study have been answered, and we will always be available to address future questions as they arise.

_____	_____
Printed Name of Person Obtaining Consent	Role in Research Study
_____	_____
Signature of Person Obtaining Consent	Date

[APPENDIX C]

APPENDIX C – Example of a DXA scan

Montefiore Hospital



oJun 9 13:42 2005 [327 x 150]
Hologic QDR-4500A (S/N 45830)
Whole Body Fan Beam V8.26a:3*

A0609050S Thu Jun 9 13:20 2005
Name: [redacted]
Comment: C
I.D.: 0845 Sex: M
S.S.#: - - Ethnic: W
ZIP Code: Height:6' 0"
Operator: DM Weight: 163
BirthDate: 04/14/39 Age: 66
Physician: SENIOR GAMES
Image not for diagnostic use

TOTAL BMC and BMD CV is < 1.0%
C.F. 1.028 0.999 1.000

Region	Area (cm2)	BMC (grams)	BMD (gms/cm2)
L Arm	270.49	233.49	0.863
R Arm	279.69	254.36	0.909
L Ribs	133.24	88.46	0.664
R Ribs	126.84	96.72	0.763
T Spine	130.84	119.44	0.913
L Spine	56.42	63.52	1.126
Pelvis	288.89	311.79	1.079
L Leg	438.54	538.15	1.227
R Leg	440.54	581.88	1.321
SubTot	2165.49	2287.81	1.056
Head	265.68	652.49	2.456
TOTAL	2431.17	2940.31	1.209

HOLOGIC

Montefiore Hospital

[redacted]
Hologic QDR-4500A (S/N 45830)
Whole Body Fan Beam V8.26a:3*
oJun 9 13:42 2005

TBAR1823 - 1
F.S. 68.00% 0(10.00)%

A0609050S Thu Jun 9 13:20 2005
Name: [redacted]
Comment: C
I.D.: 0845 Sex: M
S.S.#: - - Ethnic: W
ZIP Code: Height:6' 0"
Operator: DM Weight: 163
BirthDate: 04/14/39 Age: 66
Physician: SENIOR GAMES

Region	BMC (grams)	Fat (grams)	Lean (grams)	Lean+BMC (grams)	Total (grams)	% Fat (%)
L Arm	233.5	427.2	3575.9	3809.4	4236.6	10.1
R Arm	254.4	569.6	3730.2	3984.5	4554.1	12.5
Trunk	679.9	2893.0	30818.5	31498.4	34391.3	8.4
L Leg	538.2	1533.6	10630.4	11168.6	12702.2	12.1
R Leg	581.9	1661.0	11090.8	11672.7	13333.7	12.5
SubTot	2287.8	7084.4	59845.8	62133.6	69218.0	10.2
~ Head	652.5	1099.7	3830.7	4483.2	5582.9	19.7
TOTAL	2940.3	8184.1	63676.4	66616.7	74800.8	10.9

~assumes 17.0% brain fat
LBM 73.2% water

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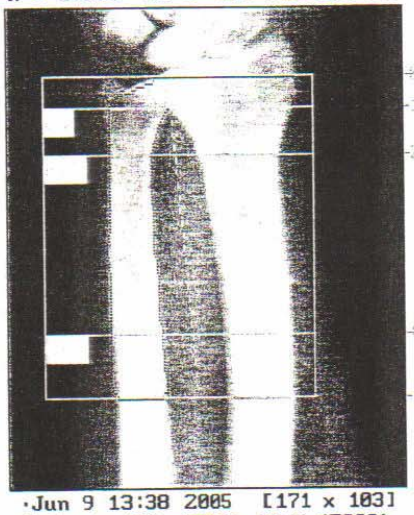
[redacted]

k = 1.179 d0 = 63.4(1.000)[4]



·Jun 9 13:38 2005 [171 x 103]
Hologic QDR-4500A (S/N 45830)
Left Forearm V8.26a:3

A0609050V Thu Jun 9 13:35 2005
Name: [redacted]
Comment: C
I.D.: 0845 Sex: M
S.S.#: - - Ethnic: W
ZIP Code: Height:6' 0"
Operator: DM Weight: 163
BirthDate: 04/14/39 Age: 66
Physician: SENIOR GAMES
Forearm Length: 28.0 cm
Image not for diagnostic use

TOTAL BMD CV IS LESS THAN 1.0%
C.F. 1.028 0.999 1.000

RADIUS	Area (cm2)	BMC (grams)	BMD (gms/cm2)
UD	4.09	2.37	0.581
MID	10.63	7.99	0.752
1/3	3.57	3.01	0.843
TOTAL	18.29	13.38	0.731

HOLOGIC

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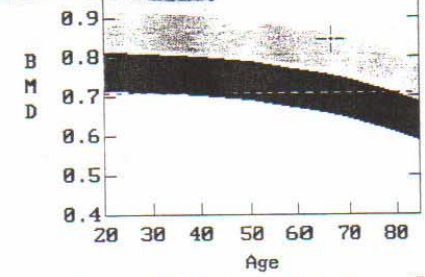
a L.Forearm
Reference Database •

[redacted]



BMD(Radius[L] 1/3) = 0.843 g/cm^2

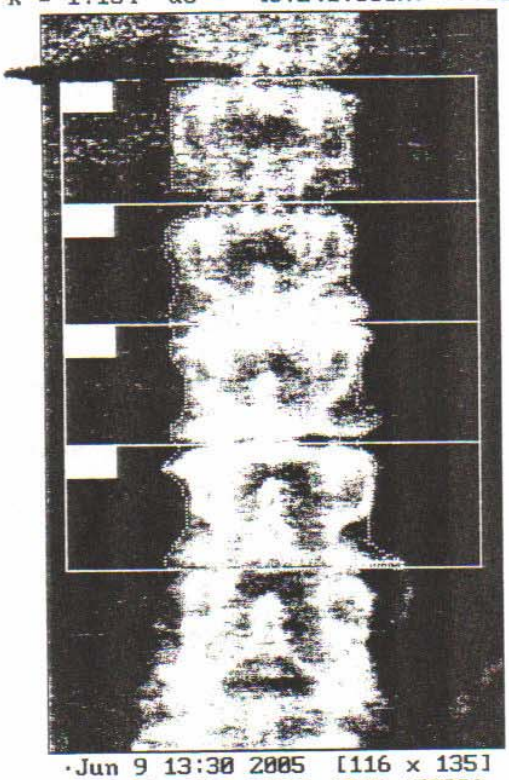
Region	BMD	T	Z
1/3	0.843	+0.49 103% (20.0)	+1.61 111%
MID	0.752	+0.83 106% (20.0)	+1.59 113%
UD	0.581	+0.55 106% (20.0)	+1.68 121%
TOTAL	0.731	+0.85 106% (20.0)	+1.87 115%

• Age and sex matched
T = peak BMD matched
Z = age matched PS 10/25/91

A0609050V Thu Jun 9 13:35 2005
Name: [redacted]
Comment: C
I.D.: 0845 Sex: M
S.S.#: - - Ethnic: W
ZIP Code: Height:6' 0"
Operator: DM Weight: 163
BirthDate: 04/14/39 Age: 66
Physician: SENIOR GAMES

HOLOGIC

k = 1.134 d0 = 45.2(1.000H) 7.032 e Hospital



·Jun 9 13:30 2005 [116 x 135]
Hologic QDR-4500A (S/N 45830)
Lumbar Spine V8.26f:3

A0609050T Thu Jun 9 13:24 2005
Name: [redacted] C
Comment:
I.D.: 0845 Sex: M
S.S.#: - - Ethnic: W
ZIP Code: Height:6' 0"
Operator: DM Weight: 163
BirthDate: 04/14/39 Age: 66
Physician: SENIOR GAMES
Image not for diagnostic use

TOTAL BMD CV FOR L1 - L4 1.0%

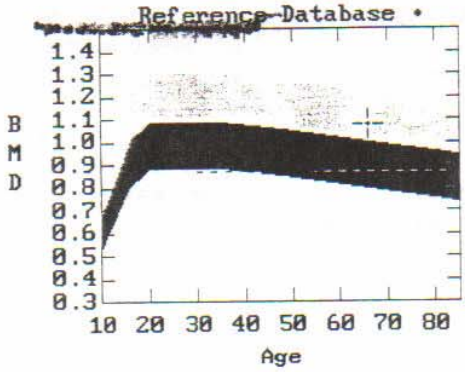
C.F. 1.028 0.999 1.000

Region	Est.Area (cm^2)	Est.BMC (grams)	BMD (gms/cm^2)
L1	16.12	12.56	0.780
L2	16.93	18.49	1.092
L3	17.71	21.39	1.207
L4	19.74	23.26	1.179
TOTAL	70.50	75.70	1.074

HOLOGIC

Montefiore Hospital

f Lumbar Spine
Reference Database •



BMD(L1-L4) = 1.074 g/cm^2

Region	BMD	T(30.0)		Z	
L1	0.780	-2.08	77%	-1.38	84%
L2	1.092	-0.02	100%	+0.77	108%
L3	1.207	+0.95	109%	+1.74	119%
L4	1.179	+0.31	103%	+1.13	112%
L1-L4	1.074	-0.16	98%	+0.63	107%

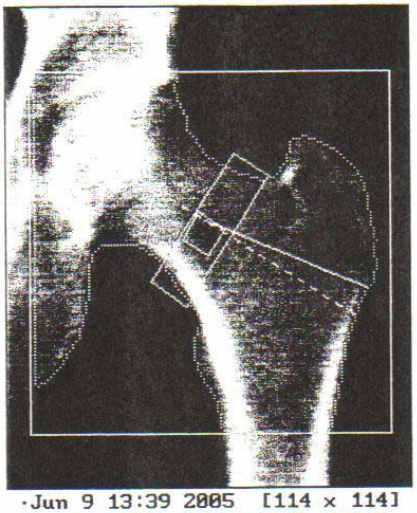
• Age and sex matched
T = peak BMD matched
Z = age matched TK 11/04/91

A0609050T Thu Jun 9 13:24 2005
Name: [redacted] C
Comment:
I.D.: 0845 Sex: M
S.S.#: - - Ethnic: W
ZIP Code: Height:6' 0"
Operator: DM Weight: 163
BirthDate: 04/14/39 Age: 66
Physician: SENIOR GAMES

HOLOGIC

Montefiore Hospital

[redacted] k = 1.141 d0 = 49.7(1.000H) 5.611



·Jun 9 13:39 2005 [114 x 114]
Hologic QDR-4500A (S/N 45830)
Left Hip V8.26f:3

A0609050U Thu Jun 9 13:31 2005
Name: [redacted]
Comment: C
I.D.: 0845 Sex: M
S.S.#: - - Ethnic: W
ZIP Code: Height:6' 0"
Operator: DM Weight: 163
BirthDate: 04/14/39 Age: 66
Physician: SENIOR GAMES
Image not for diagnostic use

TOTAL BMD CV 1.0%
C.F. 1.028 0.999 1.000

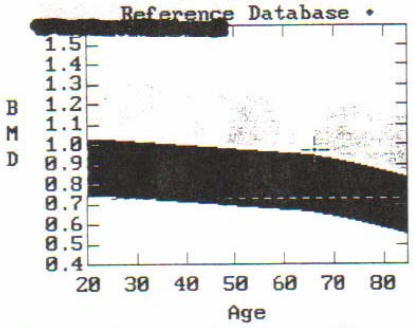
Region	Est.Area (cm^2)	Est.BMC (grams)	BMD (gms/cm^2)
Neck	5.76	4.84	0.840
Troch	14.03	10.21	0.728
Inter	24.26	27.59	1.137
TOTAL	44.05	42.64	0.968
Ward's	1.10	0.71	0.651

Midline (110,132)-(204, 72)
Neck -49 x 15 at [23, 4]
Troch 11 x 55 at [0, 0]
Ward's -11 x 11 at [2, 3]

HOLOGIC

Montefiore Hospital

f Left Hip
Reference Database •



BMD(Total[L]) = 0.968 g/cm^2

Region	BMD	T	Z
Neck	0.840	-0.66 90% (25.0)	+0.40 107%
Troch	0.728	-0.39 94% (25.0)	-0.06 99%
Inter	1.137	-0.32 95% (25.0)	+0.15 102%
TOTAL	0.968	-0.43 94% (25.0)	+0.11 102%
Ward's	0.651	-0.95 83% (25.0)	+0.82 122%

• Age and sex matched
T = peak BMD matched
Z = age matched NHA 02/01/97

A0609050U Thu Jun 9 13:31 2005
Name: [redacted]
Comment: C
I.D.: 0845 Sex: M
S.S.#: - - Ethnic: W
ZIP Code: Height:6' 0"
Operator: DM Weight: 163
BirthDate: 04/14/39 Age: 66
Physician: SENIOR GAMES

HOLOGIC

[APPENDIX D]

APPENDIX D – IRB Letter

University of Pittsburgh
Institutional Review Board

3500 Fifth Avenue
Ground Level
Pittsburgh, PA 15213
(412) 383-1480
(412) 383-1508 (fax)

MEMORANDUM

TO: Susan L. Greenspan, M.D.

FROM: Christopher Ryan, PhD, Vice Chair

DATE: December 12, 2006

SUBJECT: IRB #0503023: The Effect of High Impact Exercise on Skeletal Integrity in Master Athletes

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Your renewal of the above-referenced proposal has received expedited review and approval by the Institutional Review Board under 45 CFR 46.110 (9).

Please include the following information in the upper right-hand corner of all pages of the consent form:

Approval Date: December 12, 2006
Renewal Date: December 11, 2007
University of Pittsburgh
Institutional Review Board
IRB #0503023

Please note that it is the investigator's responsibility to report to the IRB any unanticipated problems involving risks to subjects or others [see 45 CFR 46.103(b)(5) and 21 CFR 56.108(b)]. The IRB Reference Manual (Chapter 3, Section 3.3) describes the reporting requirements for unanticipated problems which include, but are not limited to, adverse events. If you have any questions about this process, please contact the Adverse Event Coordinator at 412-383-1504.

The protocol and consent forms, along with a brief progress report must be resubmitted at least **one month prior** to the renewal date noted above as required by FWA00006790 (University of Pittsburgh), FWA00006735 (University of Pittsburgh Medical Center), FWA00000600 (Children's Hospital of Pittsburgh), FWA00003567 (Magee-Womens Health Corporation), FWA00003338 (University of Pittsburgh Medical Center Cancer Institute).

Please be advised that your research study may be audited periodically by the University of Pittsburgh Research Conduct and Compliance Office.

CR:kh

BIBLIOGRAPHY

1. American College of Sports Medicine Position Stand. Exercise and physical activity for older adults. *Med Sci Sports Exerc.* Jun 1998;30(6):992-1008.

2. Clinical Guidelines on the identification, evaluation, and treatment of overweight and obesity in adults. In: Health NIo, ed.: NIH Publication No. 98-4083, Washington DC; 1998.

3. Intake of dietary calcium to reduce the incidence of osteoporosis. Council on Scientific Affairs, American Medical Association. *Arch Fam Med.* Sep-Oct 1997;6(5):495-499.

4. Osteoporosis prevention, diagnosis, and therapy. *Jama.* Feb 14 2001;285(6):785-795.

5. Who are candidates for prevention and treatment for osteoporosis? *Osteoporos Int.* 1997;7(1):1-6.

6. Abernethy PJ, Thayer R, Taylor AW. Acute and chronic responses of skeletal muscle to endurance and sprint exercise. A review. *Sports Med.* Dec 1990;10(6):365-389.

7. Alfredson H, Nordstrom P, Lorentzon R. Bone mass in female volleyball players: a comparison of total and regional bone mass in female volleyball players and nonactive females. *Calcif Tissue Int.* Apr 1997;60(4):338-342.

8. Alfredson H, Nordstrom P, Lorentzon R. Total and regional bone mass in female soccer players. *Calcif Tissue Int.* Dec 1996;59(6):438-442.

9. Allen T, Andersen E, Langham W. Total body potassium and gross body composition in relation to age. *J Gerontol.* 1960;15:348-357.

10. Aloia JF, Cohn SH, Vaswani A, et al. Risk factors for postmenopausal osteoporosis. *Am J Med.* Jan 1985;78(1):95-100.

11. Aloia JF, Vaswani A, Ma R, et al. To what extent is bone mass determined by fat-free or fat mass? *Am J Clin Nutr.* May 1995;61(5):1110-1114.

12. Andreoli A, Monteleone M, Van Loan M, et al. Effects of different sports on bone density and muscle mass in highly trained athletes. *Med Sci Sports Exerc.* Apr 2001;33(4):507-511.

13. Aniansson A, Grimby G, Hedberg M. Compensatory muscle fiber hypertrophy in elderly men. *J Appl Physiol.* Sep 1992;73(3):812-816.

14. Aniansson A, Hedberg M, Henning GB, et al. Muscle morphology, enzymatic activity, and muscle strength in elderly men: a follow-up study. *Muscle Nerve.* Sep 1986;9(7):585-591.

15. Aniansson A, Sperling L, Rundgren A, et al. Muscle function in 75-year-old men and women. A longitudinal study. *Scand J Rehabil Med Suppl.* 1983;9:92-102.

16. Armamento-Villareal R, Villareal DT, Avioli LV, et al. Estrogen status and heredity are major determinants of premenopausal bone mass. *J Clin Invest.* Dec 1992;90(6):2464-2471.

17. Bailey K, Combs MC, Rogers LJ, et al. Measuring up. Could this simple nursing intervention help prevent osteoporosis? *AWHONN Lifelines.* Apr-May 2000;4(2):41-44.

18. Bainbridge KE, Sowers MF, Crutchfield M, et al. Natural history of bone loss over 6 years among premenopausal and early postmenopausal women. *Am J Epidemiol.* Sep 1 2002;156(5):410-417.

19. Balagopal P, Proctor DN, Nair K. Sarcopenia and hormonal changes. *Endocrine.* 1997;7:57-60.

20. Ballor DL, Keesey RE. A meta-analysis of the factors affecting exercise-induced changes in body mass, fat mass and fat-free mass in males and females. *Int J Obes.* Nov 1991;15(11):717-726.

21. Bamman MM, Hill VJ, Adams GR, et al. Gender differences in resistance-training-induced myofiber hypertrophy among older adults. *J Gerontol A Biol Sci Med Sci.* Feb 2003;58(2):108-116.

22. Bassey EJ, Harries UJ. Normal values for handgrip strength in 920 men and women aged over 65 years, and longitudinal changes over 4 years in 620 survivors. *Clin Sci (Lond).* Mar 1993;84(3):331-337.

23. Baumgartner RN. Body composition in healthy aging. *Ann N Y Acad Sci.* May 2000;904:437-448.

24. Baumgartner RN. Body composition in the elderly: a critical review of needs and methods. *Prog. Food & Nutr. Sci.* 1993;17:223-260.

25. Baumgartner RN, Koehler KM, Gallagher D, et al. Epidemiology of sarcopenia among the elderly in New Mexico. *Am J Epidemiol.* 1998;147:755-763.

26. Baumgartner RN, Stauber PM, Koehler KM, et al. Associations of fat and muscle masses with bone mineral in elderly men and women. *Am J Clin Nutr.* Mar 1996;63(3):365-372.

27. Baumgartner RN, Stauber PM, McHugh D, et al. Cross-sectional age differences in body composition in persons 60+ years of age. *J Gerontol A Biol Sci Med Sci.* Nov 1995;50(6):M307-316.

28. Bell NH, Gordon L, Stevens J, et al. Demonstration that bone mineral density of the lumbar spine, trochanter, and femoral neck is higher in black than in white young men. *Calcif Tissue Int.* Jan 1995;56(1):11-13.

29. Bennett P. How nurses can help fight fragile bones. *Nurs Stand.* Jun 21-28 1995;9(39):20-21.

30. Bergman RN, Van Citters GW, Mittelman SD, et al. Central role of the adipocyte in the metabolic syndrome. *J Investig Med.* Jan 2001;49(1):119-126.

31. Bernard S, Whittom F, Leblanc P, et al. Aerobic and strength training in patients with chronic obstructive pulmonary disease. *Am J Respir Crit Care Med.* Mar 1999;159(3):896-901.

32. Beverly MC, Rider TA, Evans MJ, et al. Local bone mineral response to brief exercise that stresses the skeleton. *Bmj.* Jul 22 1989;299(6693):233-235.

33. Bevier WC, Wiswell RA, Pyka G, et al. Relationship of body composition, muscle strength, and aerobic capacity to bone mineral density in older men and women. *J Bone Miner Res.* Jun 1989;4(3):421-432.

34. Bjorntorp P. Classification of obese patients and complications related to the distribution of surplus fat. *Nutrition.* Mar-Apr 1990;6(2):131-137.

35. Bonjour JP, Theintz G, Buchs B, et al. Critical years and stages of puberty for spinal and femoral bone mass accumulation during adolescence. *J Clin Endocrinol Metab.* Sep 1991;73(3):555-563.

36. Borkan G, Norris A. Fat redistribution and the changing body dimensions of the adult male. *Hum Biol.* 1977;49:495-514.

37. Bortz WMt, Bortz WM, 2nd. How fast do we age? Exercise performance over time as a biomarker. *J Gerontol A Biol Sci Med Sci.* Sep 1996;51(5):M223-225.

38. Bouchard C, Bray GA, Hubbard VS. Basic and clinical aspects of regional fat distribution. *Am J Clin Nutr.* Nov 1990;52(5):946-950.

39. Bourrin S, Palle S, Pupier R, et al. Effect of physical training on bone adaptation in three zones of the rat tibia. *J Bone Miner Res.* Nov 1995;10(11):1745-1752.

40. Callaghan MJ, McCarthy CJ, Al-Omar A, et al. The reproducibility of multi-joint isokinetic and isometric assessments in a healthy and patient population. *Clin Biomech (Bristol, Avon).* Nov 2000;15(9):678-683.

41. Castillo EM, Goodman-Gruen D, Kritz-Silverstein D, et al. Sarcopenia in elderly men and women: the Rancho Bernardo study. *Am J Prev Med.* Oct 2003;25(3):226-231.

42. Chapuy MC, Arlot ME, Duboeuf F, et al. Vitamin D3 and calcium to prevent hip fractures in the elderly women. *N Engl J Med.* Dec 3 1992;327(23):1637-1642.

43. Chumlea W, Garry PJ, Hunt W, et al. Distribution of serial changes in stature and weight in a healthy elderly population. *Hum Biol.* 1988;60:917-925.

44. Chumlea WC, Baumgartner RN, Garry PJ, et al. Fat distribution and blood lipids in a sample of healthy elderly people. *Int J Obes Relat Metab Disord.* Feb 1992;16(2):125-133.

45. Chumlea WC, Guo SS. Body mass and bone mineral quality. *Curr Opin Rheumatol.* Jul 1999;11(4):307-311.

46. Cioni R, Giannini F, Paradiso C, et al. Sex differences in surface EMG interference pattern power spectrum. *J Appl Physiol.* Nov 1994;77(5):2163-2168.

47. Clement FJ. Longitudinal and cross-sectional assessments of age changes in physical strength as related to sex, social class, and mental ability. *J Gerontol.* Jul 1974;29(4):423-429.

48. Compston JE, Bhambhani M, Laskey MA, et al. Body composition and bone mass in post-menopausal women. *Clin Endocrinol (Oxf).* Nov 1992;37(5):426-431.

49. Cononie CC, Graves JE, Pollock ML, et al. Effect of exercise training on blood pressure in 70- to 79-yr-old men and women. *Med Sci Sports Exerc.* Apr 1991;23(4):505-511.

50. Cooper C, Cawley M, Bhalla A, et al. Childhood growth, physical activity, and peak bone mass in women. *J Bone Miner Res.* Jun 1995;10(6):940-947.

51. Corpas E, Harman SM, Blackman MR. Human growth hormone and human aging. *Endocr Rev.* Feb 1993;14(1):20-39.

52. Cummings SR, Nevitt MC, Browner WS, et al. Risk factors for hip fracture in white women. Study of Osteoporotic Fractures Research Group. *N Engl J Med.* Mar 23 1995;332(12):767-773.

53. Cundy TF, Evans M, Roberts H, et al. Reduced bone density in women using depot medroxyprogesterone acetate for contraception. . *Br Med J (Clin Res Ed).* 1991;13(6):303.

54. Daly RM, Bass SL. Lifetime sport and leisure activity participation is associated with greater bone size, quality and strength in older men. *Osteoporos Int.* 2006;17(8):1258-1267.

55. Daniell HW. Osteoporosis of the slender smoker. Vertebral compression fractures and loss of metacarpal cortex in relation to postmenopausal cigarette smoking and lack of obesity. *Arch Intern Med.* Mar 1976;136(3):298-304.

56. Daviglus ML, Stamler J, Pirzada A, et al. Favorable cardiovascular risk profile in young women and long-term risk of cardiovascular and all-cause mortality. *Jama.* Oct 6 2004;292(13):1588-1592.

57. Davison K, Ford E, Cogswell M, et al. Percentage of body fat and BMI are associated with mobility limitations in people aged 70 and older from NHANESIII. *J Am Geriatr Soc.* 2002;50:1802-1809.

58. Davy KP, Evans SL, Stevenson ET, et al. Adiposity and regional body fat distribution in physically active young and middle-aged women. *Int J Obes Relat Metab Disord.* Aug 1996;20(8):777-783.

59. Dawson-Hughes B, Harris SS, Krall EA, et al. Effect of calcium and vitamin D supplementation on bone density in men and women 65 years of age or older. *N Engl J Med.* Sep 4 1997;337(10):670-676.

60. Despres JP, Moorjani S, Lupien PJ, et al. Regional distribution of body fat, plasma lipoproteins, and cardiovascular disease. *Arteriosclerosis.* Jul-Aug 1990;10(4):497-511.

61. Despres JP, Tremblay A, Nadeau A, et al. Physical training and changes in regional adipose tissue distribution. *Acta Med Scand Suppl.* 1988;723:205-212.

62. DiPietro L. Physical activity, body weight, and adiposity: an epidemiologic perspective. *Exerc Sport Sci Rev.* 1995;23:275-303.

63. Doherty TJ. The influence of aging and sex on skeletal muscle mass and strength. *Curr Opin Clin Nutr Metab Care.* Nov 2001;4(6):503-508.

64. Doherty TJ. Invited review: Aging and sarcopenia. *J Appl Physiol.* Oct 2003;95(4):1717-1727.

65. Doherty TJ, Vandervoort AA, Brown WF. Effects of ageing on the motor unit: a brief review. *Can J Appl Physiol.* Dec 1993;18(4):331-358.

66. Drinkwater BL. Exercise in the prevention of osteoporosis. *Osteoporos Int.* 1993;3 Suppl 1:169-171.

67. Duncan CS, Blimkie CJ, Cowell CT, et al. Bone mineral density in adolescent female athletes: relationship to exercise type and muscle strength. *Med Sci Sports Exerc.* Feb 2002;34(2):286-294.

68. Dyson K, Blimkie CJ, Davison KS, et al. Gymnastic training and bone density in pre-adolescent females. *Med Sci Sports Exerc.* Apr 1997;29(4):443-450.

69. Edelstein SL, Barrett-Connor E. Relation between body size and bone mineral density in elderly men and women. *Am J Epidemiol.* Aug 1 1993;138(3):160-169.

70. Elia M, Ritz P, Stubbs RJ. Total energy expenditure in the elderly. *Eur J Clin Nutr.* Jun 2000;54 Suppl 3:S92-103.

71. Erselcan T, Candan F, Saruhan S, et al. Comparison of body composition analysis methods in clinical routine. *Ann Nutr Metab.* 2000;44(5-6):243-248.

72. Etherington J, Harris PA, Nandra D, et al. The effect of weight-bearing exercise on bone mineral density: a study of female ex-elite athletes and the general population. *J Bone Miner Res.* Sep 1996;11(9):1333-1338.

73. Evans WJ. Effects of exercise on body composition and functional capacity of the elderly. *J Gerontol A Biol Sci Med Sci.* Nov 1995;50 Spec No:147-150.

74. Evans WJ. Exercise, nutrition, and aging. *Clin Geriatr Med.* Nov 1995;11(4):725-734.

75. Evans WJ, Cyr-Campbell D. Nutrition, exercise, and healthy aging. *J Am Diet Assoc.* Jun 1997;97(6):632-638.

76. Fatayerji D, Cooper AM, Eastell R. Total body and regional bone mineral density in men: effect of age. *Osteoporos Int.* 1999;10(1):59-65.

77. Fiatarone MA, Marks EC, Ryan ND, et al. High-intensity strength training in nonagenarians. Effects on skeletal muscle. *Jama.* Jun 13 1990;263(22):3029-3034.

78. Filipovsky J, Ducimetiere P, Darne B, et al. Abdominal body mass distribution and elevated blood pressure are associated with increased risk of death from cardiovascular diseases and cancer in middle-aged men. The results of a 15- to 20-year follow-up in the Paris prospective study I. *Int J Obes Relat Metab Disord.* Apr 1993;17(4):197-203.

79. Fleck SJ. Body composition of elite American athletes. *Am J Sports Med.* Nov-Dec 1983;11(6):398-403.

80. Fleg JL, Lakatta EG. Role of muscle loss in the age-associated reduction in VO2 max. *J Appl Physiol.* Sep 1988;65(3):1147-1151.

81. Flegal KM, Carroll MD, Kuczmarski RJ, et al. Overweight and obesity in the United States: prevalence and trends, 1960-1994. *Int J Obes Relat Metab Disord.* Jan 1998;22(1):39-47.

82. Flynn MA, Nolph GB, Baker AS, et al. Aging in humans: a continuous 20-year study of physiologic and dietary parameters. *J Am Coll Nutr.* Dec 1992;11(6):660-672.

83. Freedman DS, Jacobsen SJ, Barboriak JJ, et al. Body fat distribution and male/female differences in lipids and lipoproteins. *Circulation.* May 1990;81(5):1498-1506.

84. Frontera WR, Hughes VA, Lutz K, et al. A cross-sectional study of muscle strength and mass in 45 to 78 year old men and women. *J Appl Physiol.* 1991;71:644-650.

85. Frontera WR, Meredith CN, O'Reilly KP, et al. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. *J Appl Physiol.* Mar 1988;64(3):1038-1044.

86. Frumar AM, Meldrum DR, Geola F, et al. Relationship of fasting urinary calcium to circulating estrogen and body weight in postmenopausal women. *J Clin Endocrinol Metab.* Jan 1980;50(1):70-75.

87. Fujimoto WY, Leonetti DL, Bergstrom RW, et al. Cigarette smoking, adiposity, non-insulin-dependent diabetes, and coronary heart disease in Japanese-American men. *Am J Med.* Dec 1990;89(6):761-771.

88. Gaines JM, Talbot LA. Isokinetic strength testing in research and practice. *Biol Res Nurs.* Jul 1999;1(1):57-64.

89. Gallagher D, Ruts E, Visser M, et al. Weight stability masks sarcopenia in elderly men and women. *Am J Physiol Endocrinol Metab.* Aug 2000;279(2):E366-375.

90. Gallagher D, Visser M, De Meersman RE, et al. Appendicular skeletal muscle mass: effects of age, gender, and ethnicity. *J Appl Physiol.* Jul 1997;83(1):229-239.

91. Gariballa S, Sinclair A. Nutrition, ageing and ill health. *Br j Nutr.* 1998;80:7-23.

92. Garry PJ, Hunt WC, Koehler KM, et al. Longitudinal study of dietary intakes and plasma lipids in healthy elderly men and women. *Am J Clin Nutr.* Mar 1992;55(3):682-688.

93. Glynn NW, Meilahn EN, Charron M, et al. Determinants of bone mineral density in older men. *J Bone Miner Res.* Nov 1995;10(11):1769-1777.

94. Golden NH. Osteoporosis prevention: a pediatric challenge. *Arch Pediatr Adolesc Med.* Jun 2000;154(6):542-543.

95. Goodpaster BH, Krishnaswami S, Harris TB, et al. Obesity, regional body fat distribution, and the metabolic syndrome in older men and women. *Arch Intern Med.* Apr 11 2005;165(7):777-783.

96. Goya Wannamethee S, Shaper A, Morris R, et al. Measures of adiposity in the identification of metabolic abnormalities in elderly men. *Am J Clin Nutr.* 2005;81:1313-1321.

97. Griffin MR, Ray WA, Fought RL, et al. Black-white differences in fracture rates. *Am J Epidemiol.* Dec 1 1992;136(11):1378-1385.

98. Grimston SK, Willows ND, Hanley DA. Mechanical loading regime and its relationship to bone mineral density in children. *Med Sci Sports Exerc.* Nov 1993;25(11):1203-1210.

99. Guralnik J, Fried J, Salive M. Disability as a public health outcome in the aging population. *Am Rev Public Health.* 1996;17:25-46.

100. Gustavsson A, Thorsen K, Nordstrom P. A 3-year longitudinal study of the effect of physical activity on the accrual of bone mineral density in healthy adolescent males. *Calcif Tissue Int.* Aug 2003;73(2):108-114.

101. Haapanen N, Miilunpalo S, Pasanen M, et al. Association between leisure time physical activity and 10-year body mass change among working-aged men and women. *Int J Obes Relat Metab Disord.* Apr 1997;21(4):288-296.

102. Haffner SM, Valdez RA, Hazuda HP, et al. Prospective analysis of the insulin-resistance syndrome (syndrome X). *Diabetes.* Jun 1992;41(6):715-722.

103. Hakkinen K, Alen M, Komi PV. Changes in isometric force- and relaxation-time, electromyographic and muscle fibre characteristics of human skeletal muscle during strength training and detraining. *Acta Physiol Scand.* Dec 1985;125(4):573-585.

104. Hakkinen K, Kallinen M, Linnamo V, et al. Neuromuscular adaptations during bilateral versus unilateral strength training in middle-aged and elderly men and women. *Acta Physiol Scand.* Sep 1996;158(1):77-88.

105. Hakkinen K, Komi PV. Electromyographic changes during strength training and detraining. *Med Sci Sports Exerc.* 1983;15(6):455-460.

106. Hakkinen K, Kraemer WJ, Newton RU, et al. Changes in electromyographic activity, muscle fibre and force production characteristics during heavy resistance/power strength training in middle-aged and older men and women. *Acta Physiol Scand.* Jan 2001;171(1):51-62.

107. Hakkinen K, Newton RU, Gordon SE, et al. Changes in muscle morphology, electromyographic activity, and force production characteristics during progressive strength training in young and older men. *J Gerontol A Biol Sci Med Sci.* Nov 1998;53(6):B415-423.

108. Halioua L, Anderson JJ. Lifetime calcium intake and physical activity habits: independent and combined effects on the radial bone of healthy premenopausal Caucasian women. *Am J Clin Nutr.* Mar 1989;49(3):534-541.

109. Halle JS, Smidt GL, O'Dwyer KD, et al. Relationship between trunk muscle torque and bone mineral content of the lumbar spine and hip in healthy postmenopausal women. *Phys Ther.* Nov 1990;70(11):690-699.

110. Hallfrisch J, Muller D, Drinkwater D, et al. Continuing diet trends in men: the Baltimore Longitudinal Study of Aging (1961-1987). *J Gerontol.* Nov 1990;45(6):M186-191.

111. Harada A, Mizuno M, Takemura M, et al. Hip fracture prevention trial using hip protectors in Japanese nursing homes. *Osteoporos Int.* 2001;12(3):215-221.

112. Hassmen P, Ceci R, Backman L. Exercise for older women: a training method and its influences on physical and cognitive performance. *Eur J Appl Physiol Occup Physiol.* 1992;64(5):460-466.

113. Hawkins SA, Wiswell RA, Marcell TJ. Exercise and the master athlete--a model of successful aging? *J Gerontol A Biol Sci Med Sci.* Nov 2003;58(11):1009-1011.

114. Hedley AA, Ogden CL, Johnson CL, et al. Prevalence of overweight and obesity among US children, adolescents, and adults, 1999-2002. *Jama.* Jun 16 2004;291(23):2847-2850.

115. Heinonen A, Kannus P, Sievanen H, et al. Good maintenance of high-impact activity-induced bone gain by voluntary, unsupervised exercises: An 8-month follow-up of a randomized controlled trial. *J Bone Miner Res.* Jan 1999;14(1):125-128.

116. Heinonen A, Oja P, Kannus P, et al. Bone mineral density in female athletes representing sports with different loading characteristics of the skeleton. *Bone.* Sep 1995;17(3):197-203.

117. Heinrich CH, Going SB, Pamenter RW, et al. Bone mineral content of cyclically menstruating female resistance and endurance trained athletes. *Med Sci Sports Exerc.* Oct 1990;22(5):558-563.

118. Heymsfield SB, Wang J, Heshka S, et al. Dual-photon absorptiometry: comparison of bone mineral and soft tissue mass measurements in vivo with established methods. *Am J Clin Nutr.* Jun 1989;49(6):1283-1289.

119. Hodgson JM, Wahlqvist ML, Balazs ND, et al. Coronary atherosclerosis in relation to body fatness and its distribution. *Int J Obes Relat Metab Disord.* Jan 1994;18(1):41-46.

120. Holbrook TL, Barrett-Connor E. A prospective study of alcohol consumption and bone mineral density. *Bmj.* Jun 5 1993;306(6891):1506-1509.

121. Hollenbach KA, Barrett-Connor E, Edelstein SL, et al. Cigarette smoking and bone mineral density in older men and women. *Am J Public Health.* Sep 1993;83(9):1265-1270.

122. Horber FF, Kohler SA, Lippuner K, et al. Effect of regular physical training on age-associated alteration of body composition in men. *Eur J Clin Invest.* Apr 1996;26(4):279-285.

123. Houmard JA, Wheeler WS, McCammon MR, et al. An evaluation of waist to hip ratio measurement methods in relation to lipid and carbohydrate metabolism in men. *Int J Obes.* Mar 1991;15(3):181-188.

124. Hughes VA, Frontera WR, Dallal GE, et al. Muscle strength and body composition: associations with bone density in older subjects. *Med Sci Sports Exerc.* Jul 1995;27(7):967-974.

125. Hughes VA, Frontera WR, Roubenoff R, et al. Longitudinal changes in body composition in older men and women: role of body weight change and physical activity. *Am J Clin Nutr.* Aug 2002;76(2):473-481.

126. Hughes VA, Frontera WR, Wood M, et al. Longitudinal muscle strength changes in older adults: influence of muscle mass, physical activity, and health. *J Gerontol A Biol Sci Med Sci.* May 2001;56(5):B209-217.

127. Hui SL, Johnston CC, Jr., Mazess RB. Bone mass in normal children and young adults. *Growth.* Spring 1985;49(1):34-43.

128. Hui SL, Slemenda CW, Johnston CC, Jr. The contribution of bone loss to postmenopausal osteoporosis. *Osteoporos Int.* Oct 1990;1(1):30-34.

129. Hunter GR, Kekes-Szabo T, Snyder SW, et al. Fat distribution, physical activity, and cardiovascular risk factors. *Med Sci Sports Exerc.* Mar 1997;29(3):362-369.

130. Hunter GR, McCarthy JP, Bamman MM. Effects of resistance training on older adults. *Sports Med.* 2004;34(5):329-348.

131. Hunter GR, Wetzstein CJ, Fields DA, et al. Resistance training increases total energy expenditure and free-living physical activity in older adults. *J Appl Physiol.* Sep 2000;89(3):977-984.

132. Hurley BF. Age, gender, and muscular strength. *J Gerontol A Biol Sci Med Sci.* Nov 1995;50 Spec No:41-44.

133. Hyakutake S, Goto S, Yamagata M, et al. Relationship between bone mineral density of the proximal femur and lumbar spine and quadriceps and hamstrings torque in healthy Japanese subjects. *Calcif Tissue Int.* Sep 1994;55(3):223-229.

134. Isomaa B, Almgren P, Tuomi T, et al. Cardiovascular morbidity and mortality associated with the metabolic syndrome. *Diabetes Care.* Apr 2001;24(4):683-689.

135. Ivey FM, Tracy BL, Lemmer JT, et al. Effects of strength training and detraining on muscle quality: age and gender comparisons. *J Gerontol A Biol Sci Med Sci.* Mar 2000;55(3):B152-157; discussion B158-159.

136. Janssen I, Heymsfield SB, Wang ZM, et al. Skeletal muscle mass and distribution in 468 men and women aged 18-88 yr. *J Appl Physiol.* Jul 2000;89(1):81-88.

137. Janssen I, Ross R. Effects of sex on the change in visceral, subcutaneous adipose tissue and skeletal muscle in response to weight loss. *Int J Obes Relat Metab Disord.* Oct 1999;23(10):1035-1046.

138. Jensen J, Christiansen C, Rodbro P. Cigarette smoking, serum estrogens, and bone loss during hormone-replacement therapy early after menopause. *N Engl J Med.* Oct 17 1985;313(16):973-975.

139. Jensen MD, Cryer PE, Johnson CM, et al. Effects of epinephrine on regional free fatty acid and energy metabolism in men and women. *Am J Physiol.* Feb 1996;270(2 Pt 1):E259-264.

140. Jozsi AC, Campbell WW, Joseph L, et al. Changes in power with resistance training in older and younger men and women. *J Gerontol A Biol Sci Med Sci.* Nov 1999;54(11):M591-596.

141. Judex S, Gross TS, Zernicke RF. Strain gradients correlate with sites of exercise-induced bone-forming surfaces in the adult skeleton. *J Bone Miner Res.* Oct 1997;12(10):1737-1745.

142. Kalapotharakos VI, Michalopoulos M, Strimpakos N, et al. Functional and neuromotor performance in older adults: effect of 12 wks of aerobic exercise. *Am J Phys Med Rehabil.* Jan 2006;85(1):61-67.

143. Kanehisa H, Okuyama H, Ikegawa S, et al. Sex difference in force generation capacity during repeated maximal knee extensions. *Eur J Appl Physiol Occup Physiol.* 1996;73(6):557-562.

144. Kannus P, Jozsa L, Renstrom P, et al. The effects of training, immobilization, and remobilization on musculoskeletal tissue. *Scand J Med Sci Sports.* 1992;2:100-118.

145. Kannus P, Parkkari J, Niemi S, et al. Prevention of hip fracture in elderly people with use of a hip protector. *N Engl J Med.* Nov 23 2000;343(21):1506-1513.

146. Kehayias JJ, Fiatarone MA, Zhuang H, et al. Total body potassium and body fat: relevance to aging. *Am J Clin Nutr.* Oct 1997;66(4):904-910.

147. Kellie SE, Brody JA. Sex-specific and race-specific hip fracture rates. *Am J Public Health.* Mar 1990;80(3):326-328.

148. Khosla S, Riggs BL. Pathophysiology of age-related bone loss and osteoporosis. *Endocrinol Metab Clin North Am.* Dec 2005;34(4):1015-1030, xi.

149. Kleerekoper M, Nelson DA, Peterson EL, et al. Body composition and gonadal steroids in older white and black women. *J Clin Endocrinol Metab.* Sep 1994;79(3):775-779.

150. Klibanski A, Neer RM, Beitins IZ, et al. Decreased bone density in hyperprolactinemic women. *N Engl J Med.* Dec 25 1980;303(26):1511-1514.

151. Klitgaard H, Mantoni M, Schiaffino S, et al. Function, morphology and protein expression of ageing skeletal muscle: a cross-sectional study of elderly men with different training backgrounds. *Acta Physiol Scand.* Sep 1990;140(1):41-54.

152. Kohrt WM. Body composition by DXA: tried and true? *Med Sci Sports Exerc.* Oct 1995;27(10):1349-1353.

153. Kohrt WM, Malley MT, Dalsky GP, et al. Body composition of healthy sedentary and trained, young and older men and women. *Med Sci Sports Exerc.* Jul 1992;24(7):832-837.

154. Kotani K, Tokunaga K, Fujioka S, et al. Sexual dimorphism of age-related changes in whole-body fat distribution in the obese. *Int J Obes Relat Metab Disord.* Apr 1994;18(4):207-202.

155. Kritz-Silverstein D, Barrett-Connor E. Grip strength and bone mineral density in older women. *J Bone Miner Res.* Jan 1994;9(1):45-51.

156. Kroemer KH. Assessment of human muscle strength for engineering purposes: a review of the basics. *Ergonomics.* Jan 1999;42(1):74-93.

157. Kroger H, Kotaniemi A, Vainio P, et al. Bone densitometry of the spine and femur in children by dual-energy x-ray absorptiometry. *Bone Miner.* Apr 1992;17(1):75-85.

158. Kroger H, Tuppurainen M, Honkanen R, et al. Bone mineral density and risk factors for osteoporosis--a population-based study of 1600 perimenopausal women. *Calcif Tissue Int.* Jul 1994;55(1):1-7.

159. Kuczmarski RJ, Flegal KM, Campbell SM, et al. Increasing prevalence of overweight among US adults. The National Health and Nutrition Examination Surveys, 1960 to 1991. *Jama.* Jul 20 1994;272(3):205-211.

160. Kyle UG, Genton L, Hans D, et al. Age-related differences in fat-free mass, skeletal muscle, body cell mass and fat mass between 18 and 94 years. *Eur J Clin Nutr.* Aug 2001;55(8):663-672.

161. Kyle UG, Genton L, Hans D, et al. Total body mass, fat mass, fat-free mass, and skeletal muscle in older people: cross-sectional differences in 60-year-old persons. *J Am Geriatr Soc.* Dec 2001;49(12):1633-1640.

162. Kyle UG, Genton L, Lukaski HC, et al. Comparison of fat-free mass and body fat in Swiss and American adults. *Nutrition.* Feb 2005;21(2):161-169.

163. Kyle UG, Gremion G, Genton L, et al. Physical activity and fat-free and fat mass by bioelectrical impedance in 3853 adults. *Med Sci Sports Exerc.* Apr 2001;33(4):576-584.

164. Kyle UG, Morabia A, Schutz Y, et al. Sedentarism affects body fat mass index and fat-free mass index in adults aged 18 to 98 years. *Nutrition.* Mar 2004;20(3):255-260.

165. Langlois JA, Rosen CJ, Visser M, et al. Association between insulin-like growth factor I and bone mineral density in older women and men: the Framingham Heart Study. *J Clin Endocrinol Metab.* Dec 1998;83(12):4257-4262.

166. Larsson B, Svardsudd K, Welin L, et al. Abdominal adipose tissue distribution, obesity, and risk of cardiovascular disease and death: 13 year follow up of participants in the study of men born in 1913. *Br Med J (Clin Res Ed).* May 12 1984;288(6428):1401-1404.

167. Larsson L. Histochemical characteristics of human skeletal muscle during aging. *Acta Physiol Scand.* Mar 1983;117(3):469-471.

168. Larsson L, Grimby G, Karlsson J. Muscle strength and speed of movement in relation to age and muscle morphology. *J Appl Physiol.* Mar 1979;46(3):451-456.

169. Law MR, Cheng R, Hackshaw AK, et al. Cigarette smoking, sex hormones and bone density in women. *Eur J Epidemiol.* Jul 1997;13(5):553-558.

170. Lexell J. Human aging, muscle mass, and fiber type composition. *J Gerontol A Biol Sci Med Sci.* Nov 1995;50 Spec No:11-16.

171. Lexell J, Henriksson-Larsen K, Winblad B, et al. Distribution of different fiber types in human skeletal muscles: effects of aging studied in whole muscle cross sections. *Muscle Nerve.* Oct 1983;6(8):588-595.

172. Lexell J, Taylor CC, Sjostrom M. What is the cause of the ageing atrophy? Total number, size and proportion of different fiber types studied in whole vastus lateralis muscle from 15- to 83-year-old men. *J Neurol Sci.* Apr 1988;84(2-3):275-294.

173. Lindle RS, Metter EJ, Lynch NA, et al. Age and gender comparisons of muscle strength in 654 women and men aged 20-93 yr. *J Appl Physiol.* Nov 1997;83(5):1581-1587.

174. Lintsi M, Kaarma H, Kull I. Comparison of hand-to-hand bioimpedance and anthropometry equations versus dual-energy X-ray absorptiometry for the assessment of body fat percentage in 17-18-year-old conscripts. *Clin Physiol Funct Imaging.* Mar 2004;24(2):85-90.

175. Looker AC, Wahner HW, Dunn WL, et al. Proximal femur bone mineral levels of US adults. *Osteoporos Int.* 1995;5(5):389-409.

176. Lu PW, Briody JN, Ogle GD, et al. Bone mineral density of total body, spine, and femoral neck in children and young adults: a cross-sectional and longitudinal study. *J Bone Miner Res.* Sep 1994;9(9):1451-1458.

177. Lynch NA, Metter EJ, Lindle RS, et al. Muscle quality. I. Age-associated differences between arm and leg muscle groups. *J Appl Physiol.* Jan 1999;86(1):188-194.

178. MacKelvie KJ, Petit MA, Khan KM, et al. Bone mass and structure are enhanced following a 2-year randomized controlled trial of exercise in prepubertal boys. *Bone.* Apr 2004;34(4):755-764.

179. Madsen KL, Adams WC, Van Loan MD. Effects of physical activity, body weight and composition, and muscular strength on bone density in young women. *Med Sci Sports Exerc.* Jan 1998;30(1):114-120.

180. Madsen OR, Schaadt O, Bliddal H, et al. Relationship between quadriceps strength and bone mineral density of the proximal tibia and distal forearm in women. *J Bone Miner Res.* Dec 1993;8(12):1439-1444.

181. Malina RM. crescita e maturazione di atleti banbini e adolescenti praticanti atletica leggera (Growth and Maturation of child and adolescent track and field athletes. *Atletica Studi (Rome).* 2006(Suppl 1,2):1-464.

182. Marcus R, Kosek J, Pfefferbaum A, et al. Age-related loss of trabecular bone in premenopausal women: a biopsy study. *Calcif Tissue Int.* Jul 1983;35(4-5):406-409.

183. Matsumoto AM. Andropause: clinical implications of the decline in serum testosterone levels with aging in men. *J Gerontol A Biol Sci Med Sci.* Feb 2002;57(2):M76-99.

184. Mazess RB, Barden HS. Bone density in premenopausal women: effects of age, dietary intake, physical activity, smoking, and birth-control pills. *Am J Clin Nutr.* Jan 1991;53(1):132-142.

185. Mazess RB, Barden HS, Bisek JP, et al. Dual-energy x-ray absorptiometry for total-body and regional bone-mineral and soft-tissue composition. *Am J Clin Nutr.* Jun 1990;51(6):1106-1112.

186. Mazess RB, Barden HS, Drinka PJ, et al. Influence of age and body weight on spine and femur bone mineral density in U.S. white men. *J Bone Miner Res.* Jun 1990;5(6):645-652.

187. Mazess RB, Barden HS, Ettinger M, et al. Spine and femur density using dual-photon absorptiometry in US white women. *Bone Miner.* May 1987;2(3):211-219.

188. McComas A. *Skeletal muscle: Form and function.* Champaign, IL: Human Kinetics; 1996.

189. McCroy J, Salacinski A, Hunt S, et al. Isometric Thigh Muscle Strength In Elite Senior Athletes. *Med Sci Sports Exerc* 2007;39(5):S51.

190. Meleski BW, Shoup RF, Malina RM. Size, physique, and body composition of competitive female swimmers 11 through 20 years of age. *Hum Biol.* Sep 1982;54(3):609-625.

191. Melton LJ. *Epidemiology of fractures*. New York: Raven Press; 1988.

192. Melton LJ, 3rd, Atkinson EJ, O'Connor MK, et al. Determinants of bone loss from the femoral neck in women of different ages. *J Bone Miner Res.* Jan 2000;15(1):24-31.

193. Metter EJ, Lynch N, Conwit R, et al. Muscle quality and age: cross-sectional and longitudinal comparisons. *J Gerontol A Biol Sci Med Sci.* May 1999;54(5):B207-218.

194. Miller AE, MacDougall JD, Tarnopolsky MA, et al. Gender differences in strength and muscle fiber characteristics. *Eur J Appl Physiol Occup Physiol.* 1993;66(3):254-262.

195. Mokdad AH, Serdula MK, Dietz WH, et al. The continuing epidemic of obesity in the United States. *Jama.* Oct 4 2000;284(13):1650-1651.

196. Mokdad AH, Serdula MK, Dietz WH, et al. The spread of the obesity epidemic in the United States, 1991-1998. *Jama.* Oct 27 1999;282(16):1519-1522.

197. Moller N, O'Brien P, Nair KS. Disruption of the relationship between fat content and leptin levels with aging in humans. *J Clin Endocrinol Metab.* Mar 1998;83(3):931-934.

198. Moritani T, deVries HA. Neural factors versus hypertrophy in the time course of muscle strength gain. *Am J Phys Med.* Jun 1979;58(3):115-130.

199. Murray MP, Duthie EH, Jr., Gambert SR, et al. Age-related differences in knee muscle strength in normal women. *J Gerontol.* May 1985;40(3):275-280.

200. Murray MP, Gardner GM, Mollinger LA, et al. Strength of isometric and isokinetic contractions: knee muscles of men aged 20 to 86. *Phys Ther.* Apr 1980;60(4):412-419.

201. Nelson ME, Fiatarone MA, Morganti CM, et al. Effects of high-intensity strength training on multiple risk factors for osteoporotic fractures. A randomized controlled trial. *Jama.* Dec 28 1994;272(24):1909-1914.

202. Nguyen-Duy TB, Nichaman MZ, Church TS, et al. Visceral fat and liver fat are independent predictors of metabolic risk factors in men. *Am J Physiol Endocrinol Metab.* Jun 2003;284(6):E1065-1071.

203. Nguyen T, Sambrook P, Kelly P, et al. Prediction of osteoporotic fractures by postural instability and bone density. *Bmj.* Oct 30 1993;307(6912):1111-1115.

204. Nguyen TV, Kelly PJ, Sambrook PN, et al. Lifestyle factors and bone density in the elderly: implications for osteoporosis prevention. *J Bone Miner Res.* Sep 1994;9(9):1339-1346.

205. Nordstrom P, Lorentzon R. Site-specific bone mass differences of the lower extremities in 17-year-Old ice hockey players. *Calcif Tissue Int.* Dec 1996;59(6):443-448.

206. Nordstrom P, Pettersson U, Lorentzon R. Type of physical activity, muscle strength, and pubertal stage as determinants of bone mineral density and bone area in adolescent boys. *J Bone Miner Res.* Jul 1998;13(7):1141-1148.

207. Nordstrom P, Thorsen K, Bergstrom E, et al. High bone mass and altered relationships between bone mass, muscle strength, and body constitution in adolescent boys on a high level of physical activity. *Bone.* Aug 1996;19(2):189-195.

208. Nordstrom P, Thorsen K, Nordstrom G, et al. Bone mass, muscle strength, and different body constitutional parameters in adolescent boys with a low or moderate exercise level. *Bone.* Oct 1995;17(4):351-356.

209. Nurmi-Lawton JA, Baxter-Jones AD, Mirwald RL, et al. Evidence of sustained skeletal benefits from impact-loading exercise in young females: a 3-year longitudinal study. *J Bone Miner Res.* Feb 2004;19(2):314-322.

210. Ooms ME, Lips P, Van Lingen A, et al. Determinants of bone mineral density and risk factors for osteoporosis in healthy elderly women. *J Bone Miner Res.* Jun 1993;8(6):669-675.

211. Organization WH. Obesity: preventing and managing the global epidemic. Report of a WHO Consultation on Obesity. Geneva, Switzerland. . *World Health Organization.* World Health Organization; 1998.

212. Overend TJ, Cunningham DA, Paterson DH, et al. Thigh composition in young and elderly men determined by computed tomography. *Clin Physiol.* Nov 1992;12(6):629-640.

213. Oyster N, Morton M, Linnell S. Physical activity and osteoporosis in post-menopausal women. *Med Sci Sports Exerc.* 1984;16(1):44-50.

214. Panel NE. Clinical guidelines on the identification, evaluation, and treatment of overweight and obesity in adults: evidence report. Vol NIH publication number 02-4084. NIH; 2002.

215. Pascot A, Lemieux S, Lemieux I, et al. Age-related increase in visceral adipose tissue and body fat and the metabolic risk profile of premenopausal women. *Diabetes Care.* Sep 1999;22(9):1471-1478.

216. Peiris AN, Sothmann MS, Hoffmann RG, et al. Adiposity, fat distribution, and cardiovascular risk. *Ann Intern Med.* Jun 1 1989;110(11):867-872.

217. Penn I-W, Wang Z, Buhl K, et al. Body Composition and Two Compartment model assumptions in male long distance runners. *Med Sci Sports Exerc.* 1993;26(3):392-397.

218. Perez HR. The effects of competitive road-racing on the body composition, pulmonary function, and cardiovascular system of sport cyclists. *J Sports Med Phys Fitness.* Jun 1981;21(2):165-172.

219. Piechaczek H. Oznaczanie tluszczu ciata metodami densytometryczna i antropometryczna (estimation of body fat with densitometric and anthropometric methods). *Mater Pr Antropol.* 1975;89:3-48.

220. Pierson RN, Lin D, Phillips R. Total body potassium in health: effects of age, sex, height and fat. *Am J Physiol.* 1974;226:206-212.

221. Pincivero DM, Green RC, Mark JD, et al. Gender and muscle differences in EMG amplitude and median frequency, and variability during maximal voluntary contractions of the quadriceps femoris. *J Electromyogr Kinesiol.* Jun 2000;10(3):189-196.

222. Pirnay F, Bodeux M, Crielaard JM, et al. Bone mineral content and physical activity. *Int J Sports Med.* Oct 1987;8(5):331-335.

223. Pocock N, Eisman J, Gwinn T, et al. Muscle strength, physical fitness, and weight but not age predict femoral neck bone mass. *J Bone Miner Res.* Jun 1989;4(3):441-448.

224. Pocock NA, Eisman JA, Hopper JL, et al. Genetic determinants of bone mass in adults. A twin study. *J Clin Invest.* Sep 1987;80(3):706-710.

225. Porter MM, Vandervoort AA, Lexell J. Aging of human muscle: structure, function and adaptability. *Scand J Med Sci Sports.* Jun 1995;5(3):129-142.

226. Pouliot MC, Despres JP, Lemieux S, et al. Waist circumference and abdominal sagittal diameter: best simple anthropometric indexes of abdominal visceral adipose tissue accumulation and related cardiovascular risk in men and women. *Am J Cardiol.* Mar 1 1994;73(7):460-468.

227. Pouliot MC, Despres JP, Nadeau A, et al. Visceral obesity in men. Associations with glucose tolerance, plasma insulin, and lipoprotein levels. *Diabetes.* Jul 1992;41(7):826-834.

228. Powers S, Howley E. *Exercise Physiology: Theory and Application to Fitness and Performance*. Fifth Edition ed. New York: Mc Graw-Hill; 2004.

229. Prior JC, Vigna YM, Schechter MT, et al. Spinal bone loss and ovulatory disturbances. *N Engl J Med.* Nov 1 1990;323(18):1221-1227.

230. Proctor DN, Balagopal P, Nair KS. Age-related sarcopenia in humans is associated with reduced synthetic rates of specific muscle proteins. *J Nutr.* Feb 1998;128(2 Suppl):351S-355S.

231. Pruitt LA, Jackson RD, Bartels RL, et al. Weight-training effects on bone mineral density in early postmenopausal women. *J Bone Miner Res.* Feb 1992;7(2):179-185.

232. Pun KK, Wong FH, Loh T. Rapid postmenopausal loss of total body and regional bone mass in normal southern Chinese females in Hong Kong. *Osteoporos Int.* Feb 1991;1(2):87-94.

233. Pyka G, Lindenberger E, Charette S, et al. Muscle strength and fiber adaptations to a year-long resistance training program in elderly men and women. *J Gerontol.* Jan 1994;49(1):M22-27.

234. Pyron MI. The aging athlete: risks and benefits of exercise. *Curr opin in Orthopaedics.* 2002 2002;13:128-133.

235. Raguso CA, Kyle U, Kossovsky MP, et al. A 3-year longitudinal study on body composition changes in the elderly: role of physical exercise. *Clin Nutr.* Aug 2006;25(4):573-580.

236. Ramnemark A, Nyberg L, Lorentzon R, et al. Hemiosteoporosis after severe stroke, independent of changes in body composition and weight. *Stroke.* Apr 1999;30(4):755-760.

237. Rantanen T, Masaki K, Foley D, et al. Grip strength changes over 27 yr in Japanese-American men. *J Appl Physiol.* Dec 1998;85(6):2047-2053.

238. Rattarasarn C, Leelawattana R, Soonthornpun S, et al. Relationships of body fat distribution, insulin sensitivity and cardiovascular risk factors in lean, healthy non-diabetic Thai men and women. *Diabetes Res Clin Pract.* May 2003;60(2):87-94.

239. Ravn P, Cizza G, Bjarnason NH, et al. Low body mass index is an important risk factor for low bone mass and increased bone loss in early postmenopausal women. Early Postmenopausal Intervention Cohort (EPIC) study group. *J Bone Miner Res.* Sep 1999;14(9):1622-1627.

240. Ravussin E, Smith SR. Increased fat intake, impaired fat oxidation, and failure of fat cell proliferation result in ectopic fat storage, insulin resistance, and type 2 diabetes mellitus. *Ann N Y Acad Sci.* Jun 2002;967:363-378.

241. Reaven GM. Banting lecture 1988. Role of insulin resistance in human disease. *Diabetes.* Dec 1988;37(12):1595-1607.

242. Recker RR, Davies KM, Dowd RM, et al. The effect of low-dose continuous estrogen and progesterone therapy with calcium and vitamin D on bone in elderly women. A randomized, controlled trial. *Ann Intern Med.* Jun 1 1999;130(11):897-904.

243. Reed RL, Pearlmutter L, Yochum K, et al. The relationship between muscle mass and muscle strength in the elderly. *J Am Geriatr Soc.* Jun 1991;39(6):555-561.

244. Reid IR. Steroid-induced osteoporosis. *Osteoporos Int.* 1997;7 Suppl 3:S213-216.

245. Reid IR, Ames R, Evans MC, et al. Determinants of total body and regional bone mineral density in normal postmenopausal women--a key role for fat mass. *J Clin Endocrinol Metab.* Jul 1992;75(1):45-51.

246. Reid IR, Evans MC, Ames RW. Volumetric bone density of the lumbar spine is related to fat mass but not lean mass in normal postmenopausal women. *Osteoporos Int.* Nov 1994;4(6):362-367.

247. Reid IR, Evans MC, Cooper GJ, et al. Circulating insulin levels are related to bone density in normal postmenopausal women. *Am J Physiol.* Oct 1993;265(4 Pt 1):E655-659.

248. Reid IR, Legge M, Stapleton JP, et al. Regular exercise dissociates fat mass and bone density in premenopausal women. *J Clin Endocrinol Metab.* Jun 1995;80(6):1764-1768.

249. Reid IR, Plank LD, Evans MC. Fat mass is an important determinant of whole body bone density in premenopausal women but not in men. *J Clin Endocrinol Metab.* Sep 1992;75(3):779-782.

250. Ribom E, Ljunggren O, Piehl-Aulin K, et al. Muscle strength correlates with total body bone mineral density in young women but not in men. *Scand J Med Sci Sports.* Feb 2004;14(1):24-29.

251. Rice CL, Cunningham DA, Paterson DH, et al. Arm and leg composition determined by computed tomography in young and elderly men. *Clin Physiol.* Jun 1989;9(3):207-220.

252. Rico H, Gonzalez-Riola J, Revilla M, et al. Cortical versus trabecular bone mass: influence of activity on both bone components. *Calcif Tissue Int.* Jun 1994;54(6):470-472.

253. Riechman SE, Schoen RE, Weissfeld JL, et al. Association of physical activity and visceral adipose tissue in older women and men. *Obes Res.* Oct 2002;10(10):1065-1073.

254. Riggs BL. Pathogenesis of osteoporosis. *Am J Obstet Gynecol.* May 1987;156(5):1342-1346.

255. Riggs BL, Khosla S, Melton LJ, 3rd. Sex steroids and the construction and conservation of the adult skeleton. *Endocr Rev.* Jun 2002;23(3):279-302.

256. Riggs BL, Melton LJ, 3rd. Evidence for two distinct syndromes of involutional osteoporosis. *Am J Med.* Dec 1983;75(6):899-901.

257. Riggs BL, Melton LJ, 3rd. Involutional osteoporosis. *N Engl J Med.* Jun 26 1986;314(26):1676-1686.

258. Rikli RE, McManis BG. Effects of exercise on bone mineral content in postmenopausal women. *Res Q Exerc Sport.* Sep 1990;61(3):243-249.

259. Rissanen A, Heliovaara M, Aromaa A. Overweight and weight changes in 17000 adult Finns. *Int J Obes.* 1988;12:391-401.

260. Rissanen AM, Heliovaara M, Knekt P, et al. Determinants of weight gain and overweight in adult Finns. *Eur J Clin Nutr.* Sep 1991;45(9):419-430.

261. Risser WL, Lee EJ, LeBlanc A, et al. Bone density in eumenorrheic female college athletes. *Med Sci Sports Exerc.* Oct 1990;22(5):570-574.

262. Ross R, Freeman JA, Janssen I. Exercise alone is an effective strategy for reducing obesity and related comorbidities. *Exerc Sport Sci Rev.* Oct 2000;28(4):165-170.

263. Ross R, Janssen I. Is abdominal fat preferentially reduced in response to exercise-induced weight loss? *Med Sci Sports Exerc.* Nov 1999;31(11 Suppl):S568-572.

264. Roubenoff R. Origins and clinical relevance of sarcopenia. *Can J Appl Physiol.* Feb 2001;26(1):78-89.

265. Roubenoff R. Sarcopenia: a major modifiable cause of frailty in the elderly. *J Nutr Health Aging.* 2000;4(3):140-142.

266. Roubenoff R, Hughes VA. Sarcopenia: current concepts. *J Gerontol A Biol Sci Med Sci.* Dec 2000;55(12):M716-724.

267. Rubin CT, Lanyon LE. Regulation of bone mass by mechanical strain magnitude. *Calcif Tissue Int.* Jul 1985;37(4):411-417.

268. Rudman D, Kutner M, Rogers C. Impaired growth hormone secretion in the adult population: relation to age and adiposity. *J Clin Invest.* 1981;67:1361-1369.

269. Ruffing J, Cosman F, Zion M, et al. Determinants of bone mass and bone size in a large cohort of physically active young adult men. *Nutr Metab (Lond).* 2006;3:14.

270. Ryan AS, Elahi D. Loss of bone mineral density in women athletes during aging. *Calcif Tissue Int.* Oct 1998;63(4):287-292.

271. Ryan AS, Nicklas BJ, Elahi D. A cross-sectional study on body composition and energy expenditure in women athletes during aging. *Am J Physiol.* Nov 1996;271(5 Pt 1):E916-921.

272. Sandstrom P, Jonsson P, Lorentzon R, et al. Bone mineral density and muscle strength in female ice hockey players. *Int J Sports Med.* Oct 2000;21(7):524-528.

273. Schettler AE, Gustafson EM. Osteoporosis prevention starts in adolescence. *J Am Acad Nurse Pract.* Jul 2004;16(7):274-282.

274. Schwartz RS. Trophic factor supplementation: effect on the age-associated changes in body composition. *J Gerontol A Biol Sci Med Sci.* Nov 1995;50 Spec No:151-156.

275. Schwartz RS, Jaeger LF, Veith RC. The thermic effect of feeding in older men: the importance of the sympathetic nervous system. *Metabolism.* Jul 1990;39(7):733-737.

276. Sebastian A, Harris ST, Ottaway JH, et al. Improved mineral balance and skeletal metabolism in postmenopausal women treated with potassium bicarbonate. *N Engl J Med.* Jun 23 1994;330(25):1776-1781.

277. Seeman E, Hopper JL. Genetic and environmental components of the population variance in bone density. *Osteoporos Int.* 1997;7 Suppl 3:S10-16.

278. Seeman E, Melton LJ, 3rd, O'Fallon WM, et al. Risk factors for spinal osteoporosis in men. *Am J Med.* Dec 1983;75(6):977-983.

279. Seidell JC, Andres R, Sorkin JD, et al. The sagittal waist diameter and mortality in men: the Baltimore Longitudinal Study on Aging. *Int J Obes Relat Metab Disord.* Jan 1994;18(1):61-67.

280. Services UDoHaH. Nutrition and overweight. In: Healthy People 2010. Washington DC.: US Government Printing Office; 2000.

281. Shih MS, Cook MA, Spence CA, et al. Relationship between bone formation rate and osteoblast surface on different subdivisions of the endosteal envelope in aging & osteoporosis. *Bone.* May-Jun 1993;14(3):519-521.

282. Shimokata H, Andres R, Coon P, et al. Studies in the distribution of body fat. II. Longitudinal effects of change in weight. *Int J Obes* 1989;13:455-464.

283. Shiraki M, Shiraki Y, Aoki C, et al. Vitamin K2 (menatetrenone) effectively prevents fractures and sustains lumbar bone mineral density in osteoporosis. *J Bone Miner Res.* Mar 2000;15(3):515-521.

284. Silverman SL, Madison RE. Decreased incidence of hip fracture in Hispanics, Asians, and blacks: California Hospital Discharge Data. *Am J Public Health.* Nov 1988;78(11):1482-1483.

285. Simon LS. Osteoporosis. *Clin Geriatr Med.* Aug 2005;21(3):603-629, viii.

286. Singh MA. Exercise and aging. *Clin Geriatr Med.* May 2004;20(2):201-221.

287. Singh MA, Ding W, Manfredi TJ, et al. Insulin-like growth factor I in skeletal muscle after weight-lifting exercise in frail elders. *Am J Physiol.* Jul 1999;277(1 Pt 1):E135-143.

288. Sipila S, Suominen H. Muscle ultrasonography and computed tomography in elderly trained and untrained women. *Muscle Nerve.* Mar 1993;16(3):294-300.

289. Sipila S, Suominen H. Ultrasound imaging of the quadriceps muscle in elderly athletes and untrained men. *Muscle Nerve.* Jun 1991;14(6):527-533.

290. Sipila S, Viitasalo J, Era P, et al. Muscle strength in male athletes aged 70-81 years and a population sample. *Eur J Appl Physiol Occup Physiol.* 1991;63(5):399-403.

291. Slemenda C, Brandt KD, Heilman DK, et al. Quadriceps weakness and osteoarthritis of the knee. *Ann Intern Med.* Jul 15 1997;127(2):97-104.

292. Slemenda C, Longcope C, Peacock M, et al. Sex steroids, bone mass, and bone loss. A prospective study of pre-, peri-, and postmenopausal women. *J Clin Invest.* Jan 1 1996;97(1):14-21.

293. Slemenda CW. Body composition and skeletal density--mechanical loading or something more? *J Clin Endocrinol Metab.* Jun 1995;80(6):1761-1763.

294. Slemenda CW, Miller JZ, Hui SL, et al. Role of physical activity in the development of skeletal mass in children. *J Bone Miner Res.* Nov 1991;6(11):1227-1233.

295. Smith BJ, Phillips PJ, Heller RF. Asthma and chronic obstructive airway diseases are associated with osteoporosis and fractures: a literature review. *Respirology.* Jun 1999;4(2):101-109.

296. Smith E, Tommerup L. Exercise: A prevention and treatment for osteoporosis and injurious falls in the older adult. *J Aging Phys Activity.* 1995;3:178-192.

297. Snow-Harter C, Bouxsein M, Lewis B, et al. Muscle strength as a predictor of bone mineral density in young women. *J Bone Miner Res.* Jun 1990;5(6):589-595.

298. Snow-Harter C, Whalen R, Myburgh K, et al. Bone mineral density, muscle strength, and recreational exercise in men. *J Bone Miner Res.* Nov 1992;7(11):1291-1296.

299. Sorkin JD, Muller DC, Andres R. Longitudinal change in height of men and women: implications for interpretation of the body mass index: the Baltimore Longitudinal Study of Aging. *Am J Epidemiol.* Nov 1 1999;150(9):969-977.

300. Sprynarova S, Parizkova J. Functional capacity and body composition in top weight-lifters, swimmers, runners and skiers. *Int Z Angew Physiol.* 1971;29(2):184-194.

301. Sternfeld B, Ngo L, Satariano W, et al. Associations of body composition with phyiscal performance and self reported functional limitation in elderly men and women. *Am J Epidemiol.* 2002;156:110-121.

302. Stone B PS, Velez N, Zhang A, Miller M, Greenspan S. . PredictingSkeletal Integrity in Master Athletes and Non-Athlete Controls[abstract]. . *American Geriatrics Society AnnualScientific Meeting, Seattle, WA,* . May 2-6, 2007 (accepted for posterpresentation).

303. Stone K, Bauer DC, Black DM, et al. Hormonal predictors of bone loss in elderly women: a prospective study. The Study of Osteoporotic Fractures Research Group. *J Bone Miner Res.* Jul 1998;13(7):1167-1174.

304. Suominen H. Bone mineral density and long term exercise. An overview of cross-sectional athlete studies. *Sports Med.* Nov 1993;16(5):316-330.

305. Suzuki Y, Mizushima Y. Osteoporosis in rheumatoid arthritis. *Osteoporos Int.* 1997;7 Suppl 3:S217-222.

306. Suzuki Y, Murakami T, Haruna Y, et al. Effects of 10 and 20 days bed rest on leg muscle mass and strength in young subjects. *Acta Physiol Scand Suppl.* 1994;616:5-18.

307. Taaffe DR, Cauley JA, Danielson M, et al. Race and sex effects on the association between muscle strength, soft tissue, and bone mineral density in healthy elders: the Health, Aging, and Body Composition Study. *J Bone Miner Res.* Jul 2001;16(7):1343-1352.

308. Taaffe DR, Robinson TL, Snow CM, et al. High-impact exercise promotes bone gain in well-trained female athletes. *J Bone Miner Res.* Feb 1997;12(2):255-260.

309. Tabensky A, Duan Y, Edmonds J, et al. The contribution of reduced peak accrual of bone and age-related bone loss to osteoporosis at the spine and hip: insights from the daughters of women with vertebral or hip fractures. *J Bone Miner Res.* Jun 2001;16(6):1101-1107.

310. Tracy BL, Ivey FM, Hurlbut D, et al. Muscle quality. II. Effects Of strength training in 65- to 75-yr-old men and women. *J Appl Physiol.* Jan 1999;86(1):195-201.

311. Tremollieres FA, Pouilles JM, Ribot C. Vertebral postmenopausal bone loss is reduced in overweight women: a longitudinal study in 155 early postmenopausal women. *J Clin Endocrinol Metab.* Sep 1993;77(3):683-686.

312. Treuth MS, Hunter GR, Kekes-Szabo T, et al. Reduction in intra-abdominal adipose tissue after strength training in older women. *J Appl Physiol.* Apr 1995;78(4):1425-1431.

313. Tucker LA, Peterson TR. Objectively measured intensity of physical activity and adiposity in middle-aged women. *Obes Res.* Dec 2003;11(12):1581-1587.

314. Tuominen JT, Impivaara O, Puukka P, et al. Bone mineral density in patients with type 1 and type 2 diabetes. *Diabetes Care.* Jul 1999;22(7):1196-1200.

315. Tzankoff SP, Norris AH. Effect of muscle mass decrease on age-related BMR changes. *J Appl Physiol.* Dec 1977;43(6):1001-1006.

316. Van Pelt RE, Evans EM, Schechtman KB, et al. Contributions of total and regional fat mass to risk for cardiovascular disease in older women. *Am J Physiol Endocrinol Metab.* May 2002;282(5):E1023-1028.

317. Vandervoort AA. Aging of the human neuromuscular system. *Muscle Nerve.* Jan 2002;25(1):17-25.

318. Vandervoort AA, McComas AJ. Contractile changes in opposing muscles of the human ankle joint with aging. *J Appl Physiol.* Jul 1986;61(1):361-367.

319. Velez N ZA, Miller M, Perera S, Greenspan S. . The Effect of HighImpact Exercise on Skeletal Integrity in Master Athletes [abstract]. *Presented at the annual meeting of the American Geriatrics Society.* 2006.

320. Vico L, Pouget JF, Calmels P, et al. The relations between physical ability and bone mass in women aged over 65 years. *J Bone Miner Res.* Mar 1995;10(3):374-383.

321. Vikman HL, Ohisalo JJ. Regulation of adenylate cyclase in plasma membranes of human intraabdominal and abdominal subcutaneous adipocytes. *Metabolism.* Jun 1993;42(6):739-742.

322. Villareal DT, Apovian CM, Kushner RF, et al. Obesity in older adults: technical review and position statement of the American Society for Nutrition and NAASO, The Obesity Society. *Obes Res.* Nov 2005;13(11):1849-1863.

323. Villareal DT, Banks M, Siener C, et al. Physical frailty and body composition in obese elderly men and women. *Obes Res.* Jun 2004;12(6):913-920.

324. Visser M, Harris T, Langlois J, et al. Body fat and skeletal muscle mass in relation to phyiscal disablity in very old men and women of the Framingham Heart Study. *J Gerontol A Biol Sci Med Sci.* 1998;53:M214-221.

325. Visser M, Kiel DP, Langlois J, et al. Muscle mass and fat mass in relation to bone mineral density in very old men and women: the Framingham Heart Study. *Appl Radiat Isot.* May-Jun 1998;49(5-6):745-747.

326. Visser M, Langlois J, Guralnik J, et al. High body fatness, but not low fat free mass, predicts disablity in older me and women: The Cardiovascular Health Study. *Am J Clin Nutr.* 1998;68:584-590.

327. Vuori I, Heinonen A, Sievanen H, et al. Effects of unilateral strength training and detraining on bone mineral density and content in young women: a study of mechanical loading and deloading on human bones. *Calcif Tissue Int.* Jul 1994;55(1):59-67.

328. Walton C, Lees B, Crook D, et al. Body fat distribution, rather than overall adiposity, influences serum lipids and lipoproteins in healthy men independently of age. *Am J Med.* Nov 1995;99(5):459-464.

329. Wang W, Wang Z, Faith MS, et al. Regional skeletal muscle measurement: evaluation of new dual-energy X-ray absorptiometry model. *J Appl Physiol.* Sep 1999;87(3):1163-1171.

330. Welle S, Thornton C, Statt M. Myofibrillar protein synthesis in young and old human subjects after three months of resistance training. *Am J Physiol.* Mar 1995;268(3 Pt 1):E422-427.

331. Welten DC, Kemper HC, Post GB, et al. Weight-bearing activity during youth is a more important factor for peak bone mass than calcium intake. *J Bone Miner Res.* Jul 1994;9(7):1089-1096.

332. Willett WC, Dietz WH, Colditz GA. Guidelines for healthy weight. *N Engl J Med.* Aug 5 1999;341(6):427-434.

333. Williamson D. Descriptive epidemiology of body weight and weight change in US adults. *Ann Intern Med.* 1993;119:646-649.

334. Williamson DF, Madans J, Anda RF, et al. Recreational physical activity and ten-year weight change in a US national cohort. *Int J Obes Relat Metab Disord.* May 1993;17(5):279-286.

335. Wilmerding M, Gibson A, Mermier C, et al. Body compositon analysis in dancers: methods and recommendations. *J of Dance Med and Sci.* 1993;7(1):24-31.

336. Wilmore JH, Costill DL. *Physiology of Sport and Exercise*. Third Ed ed. Champaign, IL: Human Kinetics; 2004.

337. Wilson GJ, Murphy AJ. The use of isometric tests of muscular function in athletic assessment. *Sports Med.* Jul 1996;22(1):19-37.

338. Winegard KJ, Hicks AL, Sale DG, et al. A 12-year follow-up study of ankle muscle function in older adults. *J Gerontol A Biol Sci Med Sci.* May 1996;51(3):B202-207.

339. Withers RT, Craig NP, Bourdon PC, et al. Relative body fat and anthropometric prediction of body density of male athletes. *Eur J Appl Physiol Occup Physiol.* 1987;56(2):191-200.

340. Wittich A, Mautalen CA, Oliveri MB, et al. Professional football (soccer) players have a markedly greater skeletal mineral content, density and size than age- and BMI-matched controls. *Calcif Tissue Int.* Aug 1998;63(2):112-117.

341. Wong S, Janssen I, Ross R. Abdominal adipose tissue distribution and metabolic risk. *Sports Med.* 2003;33(10):709-726.

342. Young A, Stokes M, Crowe M. The size and strength of the quadriceps muscles of old and young men. *Clin Physiol.* Apr 1985;5(2):145-154.

343. Young A, Stokes M, Crowe M. Size and strength of the quadriceps muscles of old and young women. *Eur J Clin Invest.* Aug 1984;14(4):282-287.

344. Zamboni M, Armellini F, Milani MP, et al. Body fat distribution in pre- and post-menopausal women: metabolic and anthropometric variables and their inter-relationships. *Int J Obes Relat Metab Disord.* Jul 1992;16(7):495-504.