# LONGITUDINAL RESISTANCE TRAINING IN THE ELDERLY:
# EFFECTS OF 3 YEARS OF DETRAINING ON THE RETENTION OF STRENGTH

# LONGITUDINAL RESISTANCE TRAINING IN THE ELDERLY: EFFECTS OF 3 YEARS OF DETRAINING ON THE RETENTION OF STRENGTH

By

Kelly M. Smith, B.P.E.

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AUTHOR: Kelly M. Smith, B.P.E. (M$^c$Master University)

SUPERVISOR: Dr. N. McCartney

SUPERVISORY COMMITTEE: A.L. Hicks and C.E. Webber

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## DEDICATION

I would like to dedicate this thesis to my parents Linda and Stewart for their unwavering support and confidence in me. Their encouragement, love, and understanding will always be appreciated in ways I cannot express.

And to Christopher Beard my best friend and confidant. Your support, loyalty, love, understanding and sense of humor have helped me to attain this goal and for that, I am forever indebted.

## ABSTRACT

Dynamic muscle strength (1 RM), symptom limited treadmill endurance, and bone mineral density and content, were compared among three groups (5 males and 5 females in each group) of elderly subjects (mean age of 72.5 years) who had either continued to weight train twice per week for 5 years (TR), ceased to weight train after 2 years (DETR), or had acted as controls throughout (CON). The TR and DETR trained hard (progressing up to 3 sets at up to 80% of 1 RM) for 2 years; the TR continued training for an additional 3 years at a maintenance level (2-3 sets at 60-70% 1RM), whereas the DETR stopped training; the 10 CON subjects did not train for the duration of the study but took part in identical testing procedures. After two years of resistance training, dynamic strength in the TR and DETR groups increased significantly above the baseline and CON values for all exercises ($p<0.0001$). Following 3 years of maintenance level training, leg press, arm curl, and bench press 1 RM (sum of both limbs) in the TR remained 21.6kg (17%), 15.7kg (82%), and 8.3kg (34%) above baseline values respectively. The 1 RM in the DETR were 18.4kg (14%), 5.3kg (24%), and 1.4kg (9%) above baseline for leg press, arm curl, and bench press after 5 years, whereas the CON declined over the 5 year period by 18.4kg (9.7%), 4.4kg (19%), and 3.5kg (6%) respectively. There were non-significant improvements in treadmill performance in the TR and DETR and decline in the CON after 2 years of resistance training. Treadmill performance declined between years 2 and 5 in all groups. Bone mineral density and content were not different among the groups across all time points. We conclude that: 1) The strength gains from long-term resistance training in the elderly are not entirely lost even after

3 years of detraining, 2) The effects are specific to the exercises performed in the training program.

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# 1.0 REVIEW OF LITERATURE

## 1.1 INTRODUCTION

Aging is a complicated life-long process involving many subtle changes that occur in the body with the passage of time. The study of the changes associated with aging has become increasingly important, as the North American population grows progressively older. Modern sophisticated medical techniques and advanced health care has led to an increased life expectancy among North Americans and this will continue to rise into the twenty-first century. Proper diet and exercise are important for promoting healthy lifestyles, but the exercise needs and benefits in the elderly have not been adequately addressed. Exercise in the elderly has become an increasingly important area of research with the aging of the population. The decline in the physiological and mental functioning of humans is an inevitable consequence of the biological aging process. With aging, there is a general decline in functioning of a number of physiological systems which will eventually manifest into a decreased capacity for the body to function properly. Two systems of primary interest here are the muscular system and the skeletal system. The age-related changes associated with these systems have widespread implications for functioning in later life and are the primary focus of this investigation.

This review will focus on the changes associated with the aging of the human body. First, it will outline the changes in the muscular system associated with aging and the proposed mechanisms responsible for these changes. Second, the age related changes in the skeletal system will be addressed. Finally, the effects of exercise, specifically resistance training, on the changes in the muscular and the skeletal systems will be reviewed.

## 1.2 AGING AND THE MUSCULAR SYSTEM

### 1.2.1 INTRODUCTION

Aging is characterised by a gradual reduction in strength and endurance that may hamper the performance of certain tasks. The effect of aging on muscle strength will be reviewed and the mechanisms behind these changes will be examined.

### 1.2.2 CHANGES IN MUSCULAR STRENGTH

#### (i) ISOMETRIC STRENGTH

Studies of the vastus lateralis muscle in men indicate that isometric strength levels peak between the 2nd and 3rd decades of life. Isometric strength remains relatively stable during the 4th and 5th decades and begins to decline during the 6th decade of life at a rate of 10-15% per decade (Larsson et al., 1979; Young et al., 1985; Frontera et al., 1991; Hurley, 1995; Lexell, 1995). Isometric strength measures in the quadriceps of young men are on average 30-47% higher than those reported in older men (Larsson et al., 1979; Young et al., 1985; Frontera et al., 1991). Losses in muscle strength appear to be most dramatic after the age of 70 with some investigations observing a decline in strength of greater than 1% per year after the 7th decade of life (Ward, 1994). The decline in isometric strength ranges from 24% to 45 % between the 5th and 8th decades of life and this decline in isometric strength with aging may be underestimated due to the cross-sectional nature of these investigations (Larsson et al., 1979; Hurley, 1995; Lexell, 1995).

There is apparently a greater absolute decline in maximal isometric voluntary strength in the muscles of the lower extremities as related to the muscles of the upper extremities suggesting a preservation of upper body strength with aging (Christ et al., 1992). When expressed in relative terms, the upper body strength of men in their 7th decade of life are approximately 40% of those in their 3rd decade of life (Era et al., 1992). This relative difference in upper body strength between the young and the old is similar to the relative decline in maximum isometric strength in the vastus lateralis muscle (Larsson et al., 1979; Young et al., 1985; Frontera et al., 1991). When strength decline was expressed as a percentage of lower body strength, the age related differences in upper body strength disappear (Bremben et al., 1991; Era et al., 1992). This suggests that the absolute strength loss may be greater in larger and stronger muscles of the lower extremity, however when expressed as a relative change in strength with time, there are no apparent differences in strength loss between the muscles of the upper and lower extremities.

It has been suggested that the timing of the decline in maximum isometric strength may be different between the muscles of the upper and lower body. It has been demonstrated that the decline in muscular strength occurs earlier in the muscles of the lower body than in the muscles of the upper body (Bremben et al., 1991). The investigation by Christ and colleagues (1992) demonstrated that in women, the youngest age group cohort consistently had the highest maximal force output while the oldest age group had the lowest maximal force for all 6 muscle groups studied. Here, a decline in arm strength of 12% in 20 years began between the 3rd and 4th decades (Christ et al., 1992).

In longitudinal studies of isometric knee extensor strength, strength losses ranging from 9-27% after five years (Aniansson et al., 1983), 10-22% after seven years (Aniansson et al., 1986) and 25-35% after eleven years were observed in elderly men and women (Aniansson et al., 1992). The decline in maximal isometric force was noted for all muscle groups, however the magnitude of decline varied among the different muscle groups tested. Winegard and colleagues (1996) noted a decline in maximum voluntary strength of the plantar flexors over twelve years in the very old (73-97 years) elderly. Here, there was a 26.6% decline in MVC of the plantar flexors in males and a 20.8% decline in females (Winegard et al, 1996). This decline is similar to that demonstrated by Aniansson and colleagues in 1992 and suggest that the true decline in maximal isometric strength may be underestimated in short-term cross-sectional investigations.

### (ii) ISOKINETIC STRENGTH

Age associated declines in slow speed isokinetic peak torque values of the quadriceps muscle are similar to those of isometric strength changes in both men and women (Larsson et al., 1979; Harries and Bassey, 1990; Frontera et al., 1991). There is an average decline of 10-35% in isokinetic peak torque with age, and it is generally accepted that the greatest decline in peak torque is noted at the fastest velocities of contraction (Aniansson et al., 1986, 1992; Frontera et al., 1991).

In a cross-sectional study of muscle strength and mass in the elderly there was a 15.5% to 26.7% decrease in strength between a group of 65 to 78 year olds when compared to the strength of 45 to 54 year old men and women (Frontera et al., 1991). When these strength differences were normalized for fat free mass or muscle mass, the age-related differences in strength disappeared for all measures except for knee extensor strength at the fastest velocity tested (240°/s) (Frontera et al., 1991). In terms of absolute strength, men were between 42% and 63% stronger than the women, however, when this was expressed per kilogram of muscle mass, these differences also disappeared (Frontera et al., 1991). It has been demonstrated that older men take longer to reach peak torque than younger men, thus demonstrating a greater loss in muscle power than in strength with age (Bassey et al., 1992).

Conversely, age-related gender differences in isokinetic peak torque were observed by Hurley (1995) to be greater at higher speeds of contraction in the human quadriceps muscle. Similarly, in a study of 70 year-old males and females, Aniansson and colleagues (1980a) demonstrated a functional decline in isokinetic strength of the quadriceps muscle with increasing velocities. The males and females demonstrated similar trends (namely a decline in peak torque) with increasing speed of muscle action from 30 to 180 degrees per second (Aniansson et al., 1980a). This is similar to investigations on the elbow flexors and knee extensors where, with age, the loss in strength was noted to be greater for the faster velocities of movement (Calmels et al., 1995).

### (iii) MUSCLE POWER CAPACITY

When the mechanical properties in the muscles of the young and elderly were compared, there was a decline in *specific tension* (force per unit CSA) of about 40% in elderly women compared with young subjects (Davies, Thomas, & White, 1986). Changes in muscle quality with age have also been observed in males. A decline in muscle strength per unit cross-sectional area was observed in older men compared to younger men (Overend et al., 1992). This finding is consistent with other investigations in older males (Young et al., 1985; Frontera et al., 1991; Reed et al., 1991). There were however no gender differences noted in the elderly groups that were apparent in the younger age groups (Davies et al., 1986).

## 1.3 MECHANISMS OF CHANGE IN STRENGTH

### 1.3.1 INTRODUCTION

There are many possible mechanisms responsible for the changes in strength from early to late adulthood and into old age. The decline in muscle function with aging has been attributed to factors such as a decrease in the total number and diameter of individual muscle fibers, a possible impairment of excitation contraction coupling, and or a decreased number and activation of high threshold motor units (Type II). It has been suggested that losses in muscle mass, force, and power do not result solely from the decrease in physical activity commonly associated with increasing age (disuse atrophy) but are due to intrinsic age-related changes in the muscles and in muscle fibers that appear to be immutable and irreversible (Faulkner et al., 1995). It is important to note that the changes in strength occur in different muscles at different times, the decline in muscular strength is specific to the muscle tested, and these age-related changes may vary from one muscle to the next (Aoyagi & Shephard, 1992).

### 1.3.2 CHANGES I N MUSCLE CROSS-SECTIONAL AREA AND MUSCLE MASS

Aging is characterised by a reduction in lean body mass (LBM). Muscle atrophy is particularly noticeable in the lower, weight-bearing extremities (Aoyagi & Shephard, 1992). The loss of skeletal muscle mass with age in humans has been demonstrated both directly and indirectly. Indirect evidence of disuse atrophy is found in studies utilizing the urinary excretion of creatinine as reflections of muscle creatine content and total muscle mass. Here, the excretion of urinary creatinine decreases by nearly 50% between the ages of 20 and 90 which was related to the decline in muscle mass with age (Tzankoff & Norris, 1977). A 30% decline in muscle mass is observed between 20 and 90 years. It is speculated that this decrease in muscle mass may be wholly responsible for the age-related decline in basal metabolic rate (Tzankoff & Norris, 1977).

In a cross-sectional investigation it was determined that there was no appreciable decline in muscle cross sectional area of the quadriceps in men aged 11 to 70 years (Larsson et al., 1979). It is important to note that in this investigation, muscle cross-sectional area was determined by mid-thigh circumference, which does not discern the distribution of fat mass and fat free mass (Larsson et al., 1979). Using electrical bio-impedance, a decline in mid-arm and thigh muscle areas was observed in a group of elderly men and women as compared to a group of middle-aged men and women; the decrease was greater in men than in women for the mid-arm where it appeared to remain relatively stable in females in later life (Reed et al., 1991).

Direct evidence of muscle wasting with age was presented by Lexell et al. (1988). In this investigation, human vastus lateralis muscles were examined at post-mortem in men between 15 and 83 years of age. It was determined that aging atrophy of the human vastus lateralis muscle begins around 25 years of age and thereafter accelerates. The average reduction in muscle area between 20 and 80 years of age was 40 %, with approximately 10% of the muscle area lost by the age of 50 (Lexell, 1988).

The development and introduction of radiological imaging, has allowed muscle mass and muscle cross-sectional area to be estimated. Using ultrasonography, Young et al. (1984, 1985) found 25-35% reductions in the cross-sectional area of the quadriceps muscle in older men and women compared to the young. Furthermore, computerized tomography of individual muscles has shown similar age-related reductions in cross-sectional area of the quadriceps (Klitgaard et al., 1990; Overend et al., 1992), the biceps brachii and triceps muscles (Rice et al., 1993), and the plantar flexors (Rice et al., 1989). Computed tomography demonstrated that after the age of 30, there is a decrease in the CSA of the thigh coupled with decreased muscle density and increased infiltration of intramuscular fat. This is particularly evident in females (Evans, 1995).

Several studies have documented increases in fat and connective tissue (non-muscle tissue) within the muscles of older individuals. Rice and colleagues (1989), observed 27%, 45%, and 81% more non-muscle tissue in the arm flexors, arm extensors, and plantar flexors respectively, of older persons as compared with younger persons. Increases in non-muscle tissue of 59.4% in the quadriceps and 127.3% in the hamstrings were observed with increasing age, but no significant differences in total thigh girth were evident between the muscles of the young and the old (52.7±1.7 cm and 50.5±0.6 cm respectively) (Overend et al., 1992).

Due to the age-related infiltration of fat and connective tissue, the reduction in muscle contractile tissue is much greater than the actual reduction in muscle volume and muscle cross-sectional area with age (Lexell, 1995). Gross measurements such as thigh circumference would therefore underestimate the true reduction in the muscle contractile tissue with aging. Muscle atrophy and the decline in muscle mass appear to be highly related to decreases in both the number of muscle fibers and in the diameters of the remaining fibers.

### 1.3.3 CHANGES IN MUSCLE FIBER SIZE AND NUMBER

Muscle atrophy may be the result of a gradual, selective loss of muscle fibers. The vastus lateralis muscle is the most widely studied muscle in humans. In an autopsy study, the number of muscle fibers in the mid-section of the vastus lateralis specimens was found to be lower in elderly men (70-73 years) by about 110,000 fibers than in young men (19-37 years) (Lexell et al., 1983). This represents a 23% difference between the muscles of elderly and young subjects. The loss in fiber number appears to begin about age 25 and accelerates with increasing age (Lexell, 1983). A reduction in fiber number with increasing age could involve a loss of a specific type of muscle fiber, which may also affect the fiber type proportions with increasing age.

Muscle biopsy studies have attempted to determine if there is a selective reduction in muscle fiber type with age and have found that the reduction in fiber number within the vastus lateralis muscles of the human quadriceps muscle with age generally affects both types of fibers to the same extent (Lexell, 1995). Thus, fiber type proportions remain consistent over time and any differences found between various studies, may be explained by the inherent variability in the fiber type composition in a human muscle.

In order to comprehend the possible causes of aging atrophy in human muscle, attempts have been made to assess the muscle morphology of aging muscles using muscle biopsies from healthy individuals. In the vastus lateralis muscle the overall conclusion is rather consistent: Type II (fast-twitch) fiber size is reduced with increasing age while the size of Type I (slow twitch) fibers is much less, if at all affected (Larsson et al., 1978; Aniansson et al., 1981; Grimby et al., 1982; Aniansson et al., 1986; Essen-Gustavsson & Borges, 1986;

Lexell et al., 1988). From these findings, it was concluded that much of the loss in muscle strength is due to a selective atrophy of Type II muscle fibers which were smaller in diameter when compared to those at younger ages (Larsson et al., 1978). In cross-sectional investigations on the fiber areas of the vastus lateralis muscle, there is a general decline in fiber area with age ranging from 1-6% for Type I fibers and 25-35% in Type II fibers (Larsson et al., 1978; Lexell & Taylor, 1991). When the same muscle was examined in subjects aged 20 to 70 years, the Type I fibers declined in size by 15% and 25%, and the type II fibers declined 19% and 45%, in males and females respectively with increasing age (Essen-Gustavsson & Borges, 1986). This greater decline in fiber size in females suggests that females are at significantly greater risk of atrophy than are males, even though males are generally known to have moderately larger fiber areas and mean fiber areas in the biceps brachii (Type I fibers) and the vastus lateralis (Type II fibers) in their youth (Miller et al., 1993).

The reduction in fiber size is, however, rather moderate in comparison to the large reductions seen in whole muscle volume with aging and in particular the estimated reduction in muscle contractile tissue. Whole-limb muscle cross-sections examined post-mortem demonstrated that the total number of muscle fibers is significantly reduced with increasing age (Lexell et al., 1983). In follow-up to this study, it was found that the aging atrophy of the vastus lateralis was caused by a combination of both a loss of muscle fibers and a reduction in the muscle fiber size (Lexell et al., 1988). For the vastus lateralis muscle, the cross-sectional area is mainly determined by the total number of fibers and, to a lesser extent, by the size and or the number of type 2 muscle fibers. This indicates that the reduction of fibers is the main explanation for the reduced area of the vastus lateralis muscle with increasing age (Lexell et al., 1995; Lexell & Downham, 1992b). Although the vastus lateralis muscle has been intensely studied in humans, any conclusions based on this muscle may be unique to it and cannot necessarily be generalized to the muscles of the upper extremities.

### 1.3.4 MUSCLE FIBER TYPE COMPOSITION AND DISTRIBUTION

A reduction in fiber number with advancing age could involve a loss of a specific type of fiber and thus would affect the fiber type proportion in later life. It has been suggested that the decrease in muscle strength with aging may result from changes in the muscle fiber composition or the proportional distribution of muscle fibers of the whole muscle. It has been demonstrated in the young that males tend to have a greater proportion of Type II muscle fibers in the vastus lateralis muscle than do females (61.9±2.2% and 50.2±3.1% respectively). Thus, the total cross-sectional area occupied by Type II fibers is also greater in males (67.4±2.6% and 47.4±4.4% respectively) (Miller et al., 1993); similar observations have been made in the elderly (Grimby et al., 1982).

In a cross-sectional study by Larsson et al. (1979), there was a decline in the relative proportion of Type II muscle fibers when comparisons were made among subjects aged 20-29 years (mean of 59.5±3.9%) and 60-65 years (mean of 45±4.5%), suggesting that there is both a selective atrophy of Type II fibers as well as a decline in their relative proportion with increasing age. Further studies revealed similar trends of altered fiber type distributions and decreased fiber areas during aging characterized specifically by a decline in the relative occurrence of Type II fibers from approximately 60% to 45% between the third and seventh decade, as well as by a fiber atrophy preferentially affecting Type II fibers (Grimby et al., 1982; Larsson, 1983; Saltin & Gollnick, 1983; Aoyagi & Shephard, 1992).

Histochemistry has demonstrated that with increasing age, the relative distribution of fibers did not differ with age or gender in the lateral gastrocnemius muscle (Coggan et al., 1992) or the vastus lateralis muscle (Essen-Gustavsson & Borges, 1986). There was, however, a significant decline in mean fiber area which was evident predominantly in the Type II fibers (Essen-Gustavsson & Borges, 1986). It was also noted that the Type I fibers occupied a larger percentage of the total muscle area than Type II fibers in the older men and women (60.0±2.6% vs. 53.6±2.0%) (Coggan et al., 1992). This suggests that the muscle cross-sectional area occupied by Type II fibers is significantly reduced with increasing age, and this reduction is a result of a combined effect of reduced fiber number and reduced fiber size. Thus increasing age leads to a greater loss of contractile tissue of fast-twitch type than of slow-twitch type, ultimately leading to the age-related atrophy as well as to the reduction in muscle strength that follows (Lexell, 1995).

### 1.3.5 FUNCTIONING OF THE MOTOR UNIT

It has been suggested that the decline in muscle strength results primarily from a decline in the functioning of the motor unit. With human aging, a decrease in muscle mass leads to reduced voluntary and electrically evoked contractile strength by the 7th decade for most muscle groups studied. These changes in skeletal muscle may be secondary to alterations in the functional integrity of the nervous system (Christ et al., 1992; Doherty, Vandervoort, & Brown, 1993). Loss of muscle and nerve fibers may result from irreversible fiber damage, or from a permanent denervation with loss of contact between the nerve and the muscle fiber (Lexell, 1995). Myopathic changes are very rare, neurogenic changes being much more common in muscles of the old. Electromyography demonstrates a decrease in the number of ventral root nerve fibers resulting in a decline in the number of functioning motor units with aging (Brown, 1972; Campbell et al., 1973; Brown et al., 1988; Aoyagi & Shephard, 1992; Doherty & Brown, 1993; Doherty et al., 1993). The remaining or surviving motor units also demonstrate an increase in size and take on the characteristics of low threshold motor units (Type I). This appears to correlate with the trend of decreasing numbers of Type II or high threshold motor units with aging.

These findings have perpetuated the notion of senile muscle atrophy (Aoyagi & Shephard, 1992). Briefly, senile muscle atrophy is thought to take place when there is a loss of terminal sprouting at the neuromuscular junction resulting in axonal withdrawal. Sprouting is a normal process of end plate repair and reconnection which occurs throughout life, but the capacity for this process deteriorates during senescence with an associated muscular atrophy and a degeneration of both muscle fibers and end plate structures (Aoyagi & Shephard, 1992). From this, it is suggested that there may be problems in the recruitment patterns of the muscle fibers remaining, particularly in sedentary individuals. Thus, it is conceivable that an age-related decline in habitual activity may contribute to a loss of muscle strength through a deterioration of motor unit recruitment patterns (Aoyagi & Shephard, 1992). The long term study in the very old elderly by Winegard and colleagues (1996) demonstrated that there were no changes in isometric twitch torque in the plantar and dorsi-flexors of the ankle over twelve years as well as no impairment in the ability to fully activate the muscles as demonstrated by the interpolated twitch technique (Winegard et al, 1996).

It seems likely that the two main reasons for the age-associated decline of maximum voluntary strength are: (1) a progressive decline in the number of muscle fibers with a decreased CSA of a given muscle group; (2) denervation due to death of the motor neurons with a subsequent reinnervation of a proportion of the affected fibers. The effect of motor unit loss on maximum voluntary strength in older men and women was examined and it was found that motor unit loss, even in healthy active individuals, is a primary factor in the age-associated decline in contractile strength (Doherty et al., 1993a). The α-motor neurons are particularly affected by aging, and their losses have been shown to develop by the 7th decade in both the proximal and distal musculature (Doherty et al., 1993b). By the 7th decade, there are about half the number of functional motor units of young adults in the biceps brachii and the brachialis muscles of older adults (Doherty et al., 1993b). Despite this loss of functional motor units, the elderly are still able to fully activate their muscles. Thus, the decline in contractile forces in older subjects are most likely the result of reductions in the quantity rather than the quality of muscle mass (Doherty et al., 1993b). This is supported by the findings of Vandervoort and McComas (1986) where the deterioration in muscle function with aging was determined to be due to a selective loss or atrophy of Type II muscle fibers rather than an alteration of recruitment patterns of the motor units.

Fiber type grouping is noted with increasing age providing indirect evidence of a continuous process of denervation and reinnervation of the muscle fibers (Lexell et al., 1986). From ages 30 to 60 years fiber types are randomly arranged and above 60 years this arrangement changes to exhibit clusters of similar muscle fiber types in close knit groups. Fiber type grouping, atrophy, and irregularly shaped fibers all provide evidence of an ongoing process of denervation-reinnervation whereby the muscle fibers that have been denervated following the loss of the neuromuscular contact are reinnervated by the surviving motor neurons (namely, the low threshold motor neurons) as well as increasing the size of the remaining motor units (Brown, 1973; Campbell et al., 1973; Doherty et al., 1993a; 1993b). The permanently denervated muscle fibers are therefore lost and replaced with fat and connective tissue, thus providing a likely explanation for a decrease in fiber number and an increase in non-muscle tissue and the subsequent loss in muscle strength (Doherty, Vandervoort & Brown, 1993a). It is also likely that the denervation-reinnervation process is one of the primary contributors to the reduction in muscle volume that accompanies increasing age (Lexell, 1995).

## 1.4 AGING AND THE SKELETAL SYSTEM

### 1.4.1 INTRODUCTION

In skeletal biology it has become an accepted theory that under normal circumstances there is a close matching of the structure of bone with its particular function. This principle, known as Wolff's Law, specifies that bone accommodates the habitual loads to which it is subjected by altering its amount and distribution of mass (Marcus, 1995). Presently, it is thought that this adaptive response leads to optimization of load-induced strains throughout the skeleton. With aging, there is a general decline in the amount of habitual physical activity particularly around the 6th decade of life, which could present a possible mechanism for bone loss. This may have significant implications regarding the therapeutic use of exercise to help build bone mass or perhaps deter its inevitable loss with aging. Osteoporosis is defined as an absolute decrease in the amount of bone, leading to fractures after minimal trauma (Riggs

& Melton, 1986). It is one of the major underlying factors contributing to the increased risk of bone fractures, disability, and premature death in the elderly, particularly in women.

This review will first outline the composition of the skeletal system and the mechanisms responsible for bone loss or accretion. Second, the effects of aging on the skeletal system will be addressed. Finally, a brief overview of the pathology of osteoporosis will be presented.

### 1.4.2 MECHANISMS OF BONE LOSS

There are two main components of bone, which are classified by their relative metabolic activity. Cortical bone is solid, and densely packed, and is often referred to as compact bone. It forms the outer walls of all bones but predominates in the shafts of the long bones of the appendicular skeleton. Trabecular or spongy bone is porous and resembles a honeycomb. Trabecular bone traverses the internal cavities of the skeleton and is the major component of the axial skeleton (vertebrae) and in the distal ends of the long bones of the appendicular skeleton (Feicht-Sanborn, 1990). Trabecular bone is metabolically more active and makes up much less of the skeleton (about 20%) than does cortical bone (about 80%). Trabecular bone is the major component of much of the weight bearing axial skeleton and with its high sensitivity to changes in mineral homeostasis, it could be a potential target for increases in bone mass as well as fractures with aging interventions.

Bone is metabolically a highly active tissue, which goes through the processes of modeling and remodeling throughout life. After the completion of skeletal growth early in the third decade of life, bone is renewed through remodeling cycles (Edwards & Perry, 1994). Bone formation and bone resorption does not occur randomly throughout the skeleton but follows a programmed sequence at discrete foci called bone remodeling units (Riggs et al., 1986). This process of remodeling involves a delicate balance between bone formation (performed by cells called osteoblasts) and bone resorption (performed by osteoclasts) (Gunby & Morely, 1994). In humans, osteoclasts appear on a previously inactive surface, and over a period of about 30 days, construct a tunnel in cortical bone or a lacuna on the surface of trabecular bone. The osteoclasts are then replaced by osteoblasts, which fill in the resorption cavity over a period of about 130 days, to create a new structural unit of bone (Perry et al., 1993; Riggs & Melton, 1986). The relative rate of bone turnover is determined mainly by the frequency of activation of new bone remodeling units. In young persons, these two systems are tightly coupled to produce increases in bone mass or bone accretion. Bone loss implies an uncoupling of the phases of remodeling, with a relative increase in bone resorption over bone formation. Age-related bone loss is a possible result of alterations in calcium absorption, vitamin D metabolism, osteoblastic and osteoclastic activity, or a combination of these factors (Gunby & Morely, 1994). Whatever the mechanism, the major consequence of bone loss is fracture.

### 1.4.3 AGING AND BONE LOSS

Bone loss is a normal correlate of aging, starting in early adulthood and continuing well into the 7th and 8th decades of life. Once skeletal growth has been completed, bone mass increases by increasing the diameter of bone (radial growth) until about the age of 30 (modeling), there is then a brief period of stability followed by an age-related loss in bone mass (Edwards & Perry, 1994). Bone loss in both genders begins shortly after peak bone mass or density is attained which is about 20-45 years of age (Gunby & Morely, 1994). It is estimated that throughout a normal life span, women lose 35% of their cortical and 50% of their trabecular bone mass, whereas men lose slightly less than this (25% and 35% respectively) (Edwards & Perry, 1994).

The quantity of bone lost varies according to the type of bone that is affected. Cortical bone goes through two distinct phases of bone decline. This biphasic pattern of bone loss has been identified for both cortical and trabecular bone: a protracted slow phase that occurs in both sexes, and a transient accelerated phase that occurs predominantly in women after menopause (Riggs et al., 1983; Riggs & Melton, 1986). The slow phase begins around the age of 40 years and results in a decline of between 0.3% and 0.5% per year; a rate which increases with increasing age and eventually slows in later life. In females, there is a subsequent accelerated post-menopausal phase of cortical bone loss that is super-imposed on this pattern. Here, the rate of decline is increased to a 2% to 3% loss in bone per year immediately following the onset of menopause. The rate of bone loss declines with age, becoming equivalent to the slow age-associated decline by about 8 to 10 years after menopause. Trabecular bone appears to be affected by a slow rate of decline that begins between the ages of 30 and 35 years. The rate of loss is somewhere between 0.6% to 2.4% per year in women and 1.2% per year in men (Riggs et al., 1983; Riggs & Melton, 1986; Gunby & Morely, 1994). Thus, in women, the extent of the pre-menopausal, trabecular bone loss may have an initial rate that is greater than that for cortical bone loss.

The mechanisms responsible for the biphasic pattern of bone loss are associated with two different abnormalities of bone remodeling (Riggs et al., 1983). It is thought that the slow age-dependent phase results primarily from an impaired bone formation (Riggs &

Melton, 1986). The osteoclasts produce resorption cavities of normal depth, however, the osteoblasts are unable to refill these cavities completely. This failure appears to occur equally in both the cortical and trabecular bones. The accelerated phase, which occurs in women soon after menopause, is characterized by a high rate of bone turnover with increased activity of both the osteoclasts and osteoblasts. There appears to be an increased number of osteoclasts post-menopause; each of these creating a deeper cavity to fill (Riggs & Melton, 1986). The osteoblasts are unable to fill the cavities adequately despite the increase in activity and thus, a net loss in bone tissue results (Edwards & Perry, 1994). In this type of osteoporosis, there is a greater proportional loss of trabecular bone than cortical bone. In a three-year longitudinal study conducted by Riggs et al. (1986), a continuous loss in bone over adult life with a mean rate of loss of 1.2% per year in normal women was measured using dual-photon absorptiometry. The rates of bone loss were similar in pre-menopausal and post-menopausal women (Riggs et al., 1986). It was also observed that substantial bone loss from the lumbar spine had already occured prior to menopause. This suggests that factors other than estrogen deprivation must contribute to the pathogenesis of osteoporosis. From this, they proposed that the loss of trabecular bone begins at an earlier age and proceeds to a greater extent during the pre-menopausal and early post-menopausal years than does the loss of cortical bone (Riggs et al., 1986).

### 1.4.4 OSTEOPENIA AND OSTEOPOROSIS

Osteopenia is defined as an absolute decrease in the amount of bone relative to that found in young adults of the same gender (Edwards & Perry, 1994). It is characterized by fractures after minimal trauma (Gunby & Morely, 1994). Osteoporosis is the series of clinical syndromes of osteopenia with reduced amounts of matrix and calcified bone. Syndromes associated with abnormal rates of mineral to matrix (usually an increase in matrix) are called osteomalacia and are defined by an inability to calcify matrix resulting in increased matrix compared to calcified bone either with or without osteopenia. There are two distinct types of normal bone loss or involutional osteoporosis which are separated on the basis of clinical features, densitometric and hormonal changes, and the relation of disease patterns to menopause and age (Riggs et al., 1983). The two distinct syndromes of osteoporosis are: (1) type I or post-menopausal; (2) type II or age-related osteoporosis. The two most important factors in the development of osteoporosis are: (1) the amount of peak bone mass attained in early bone growth (initial bone mass); (2) the rate of bone loss in mid- to late-adulthood.

### (i) Type I Osteoporosis-Post Menopausal Osteoporosis

Type I osteoporosis occurs with greater prevalence in women than in men with the ratio being approximately 6:1, and is primarily characterized by an accelerated rate of bone loss. It generally occurs within 10 to 15 years following menopause. It affects 5% to 25% of all women in early menopause and is characterized by increased loss of trabecular bone, and fractures of the vertebrae and the distal radius (Riggs et al., 1983; Riggs & Melton, 1986; Edwards & Perry, 1994). Type I osteoporosis is primarily due to the loss of estrogen which makes the bone sensitive to the effects of parathyroid hormone (PTH) which will eventually lead to an increase in serum calcium levels. In turn, this results in decreased calcium absorption and a negative calcium balance (Riggs & Melton, 1986; Edwards & Perry, 1994)). Thus, a redistribution of the source of calcium occurs, from primarily the diet during the pre-menopausal period, to the skeleton as the primary calcium source in the post-menopausal period; with the resultant loss of skeletal calcium in the latter period (Edwards & Perry, 1994).

### (ii) Type II Osteoporosis- Age-Related Osteoporosis

Type II osteoporosis occurs in both men and women, however, it is more predominant in females at a ratio of about 2:1. This greater predominance in elderly women is attributed to the accelerated rate of bone loss after menopause (Riggs & Melton, 1986). This type of osteoporosis predominates beyond the age of 70 years and involves the loss of both trabecular and cortical bone. The rate of bone loss is not accelerated, however senile osteoporosis is associated with trabecular thinning, and fractures of the vertebrae and the hip (Riggs et al., 1983). The two most important factors in this type of osteoporosis are the impaired metabolism and subsequent production of 1,25 dihydroxy vitamin D ($1,25(OH)_2D$) and a decreased osteoblast function. The primary pathogenesis is the decreased renal functioning with age which results in a decreased production of $1,25(OH)_2D$ which in turn decreases calcium absorption from the diet causing calcium to be mobilized from the skeleton (Gunby & Morely, 1994). It has also been discussed that a decline in dietary vitamin D coupled with a decreased conversion of vitamin D to 25 hydroxy vitamin D (25OHD) in the liver in the elderly also contribute to the impaired production of $1,25(OH)_2D$ (Edwards & Perry, 1994). Thus, overall, there is a loss of calcium from the skeleton that results in a decreased bone mass and normal bone mineral density.

## 1.5 ADAPTATIONS TO RESISTANCE TRAINING IN THE ELDERLY

### 1.5.1 INTRODUCTION

Exercise training in the elderly has become an important area of investigation over the past few years. With the continual aging of the population, methods of preserving muscular strength and endurance are becoming increasingly important in order to prevent or slow the decline in muscular strength and decline in skeletal health associated with normal aging. The effects of resistance training on the muscular and skeletal systems of the elderly will be reviewed.

### 1.5.2 MUSCULAR SYSTEM

The changes that occur in the muscular system in the elderly with resistance training have been heavily investigated over the past two decades. Strength training in the elderly produces changes in the muscular system similar to those demonstrated in younger males and females with similar training, and in some cases, the changes are more pronounced in the elderly than in the young.

#### (i) DYNAMIC STRENGTH

Early studies of resistance training in the elderly indicated that 12 to 26 weeks of training elicited only minimal changes in muscle strength of men and women between the ages of 60 and 75 years. Aniansson & Gustavsson (1981) studied the effects of 12 weeks of resistance training on quadriceps strength in 12 males with a mean age of 72 years and found that this short-term training resulted in an 18% increase in muscle strength as determined by peak torque. This investigation utilized a dynamic resistance training protocol that included both concentric and eccentric muscle actions. In another study by Aniansson et al. (1984), 15 females with a mean age of 73 years had a mean increase in quadriceps strength of 9% following 26 weeks of resistance training using elastic bands as the resistive method.

Increases of 107.4% and 226.7% in the dynamic strength of the extensors and flexors of the knee were observed following 12 weeks of high-intensity strength training at 80% of 1 RM in 12 males mean age 66±2 years (Frontera et al., 1988). This increase averaged out to a strength gain of approximately 5% per training day across the extensors and flexors of the knee and which resulted in an increased 1 RM strength of the left knee extensors from 20±1 to 40±2 kg (Frontera et al., 1988, 1990). In a study of 13 females aged 69±1 years following 12 weeks of dynamic resistance training of the quadriceps muscle, similar strength increases of 115±27% in leg curl, 28.3±6% in leg press, and 28.3±4% in hip extensor strength were noted (Charette et al., 1991). This response to strength training suggests that both men and women will respond in a similar manner to high-intensity resistance training.

Dynamic strength changes in the biceps brachii appear to be lower than those changes seen in the lower body muscles (namely the quadriceps) with an increase in 1 RM strength of 48% in 1 RM after 12 weeks of progressive arm flexor training (Brown et al., 1990); there was also an increase in the dynamic strength of 12% in the contralateral untrained control arm. In the triceps brachii, 24 weeks of high-intensity strength training resulted in a 30% increase in dynamic 1 RM strength and a 20.5% increase in maximum voluntary contraction (isometric) strength (Rice et al., 1993). This is similar to the findings of Lexell and colleagues (1995) where 11 weeks of high intensity resistance training at 85% one-repetition maximum resulted in 49% and 163% increases in strength in the elbow flexors and knee extensors respectively. Thus it appears that high-intensity resistance training of the muscles of the upper-body will produce changes in strength about half that observed in the lower body following resistance training.

In frail, institutionalized men and women, muscle strength is an important determinant of functional capacity, and increased risk of fall and fracture. In a group of 10 institutionalized males and females, there was a dramatic increase in dynamic strength of the knee extensors (from 8 to 21 kg) resulting from just 8 weeks of high-intensity strength training (Fiatarone et al., 1990). The mean increase in strength after training was 174±31% suggesting that even the frail elderly are able to resistive train at high-intensity with significant elevations in strength. Further investigations continued examining the effects of resistance training among the frail, institutionalized elderly. Here, 100 subjects (37 male, 63 female) with a mean age of 87.1±0.6 years increased their 1 RM strength 113±8% with exercise training (Fiatarone et al., 1994). The training group also exhibited an increase in gait speed (11.8%), stair climbing power (28.4%) and levels of spontaneous activity with no changes in these measures in the control group. These findings demonstrate that frail elderly men and women retain the capacity to adapt to a progressive resistance training protocol well into the 10th decade of life.

Investigations of resistance training in the elderly are predominantly of relatively short duration (about 8 to 26 weeks). There are very few longitudinal studies of the changes in strength with high-intensity dynamic strength training lasting longer than this. In a long-term resistance training study by Pyka et al. (1994), 16 subjects trained for a period of 30 weeks and 8 subjects trained for 52 weeks. During this time, 6 subjects served as controls. After 8 weeks of moderate-intensity resistance training, there was a significant increase in 1 RM strength as compared with baseline values, however, after this time further changes in strength tended to plateau (Pyka et al., 1994). Following 52 weeks of resistance training, there were significant increases in leg extension (95±10%), leg press (53±10%), and bench press (49±7%) 1 RM strength. Over this time, the control group consistently lost leg extension (-6.0±4.2%), leg press (-7.6±3%), and bench-press (-8.0±3.2%) 1 RM strength but these changes were not significantly different from baseline values (Pyka et al., 1994). The control and the exercising groups were significantly different from each other in all muscle groups tested following 15 weeks of resistance training and this difference was only widened with further training.

In the longest study of resistance training in the elderly to date, McCartney et al. (1995 & 1996) have demonstrated significant increases in 1 RM dynamic strength in males and females aged 60 to 80 years. Exercisers increased their dynamic strength significantly between 20 and 65% in arm curl, bench press, military press, and leg press following two-years of high-intensity resistance training with no significant changes in 1 RM strength noted for the control subjects (McCartney et al., 1995 & 1996). These data suggest that elderly individuals from 60 to 80 years of age are able to strength train for extended periods of time and additional observations suggested the gains in strength may be partially transferred to other measures of functional capacity such as cycling power and treadmill endurance.

### (ii) CHANGES IN MUSCLE COMPOSITION

### (a) CROSS-SECTIONAL AREA

Following 12 weeks of high intensity resistance training in the elderly, large increases in strength were correlated with a corresponding increase in the cross-sectional area of the quadriceps muscle of 9.3% and a total muscle area increase of 11.4%, as measured by computerized tomography (Frontera et al., 1988). The increase in CSA was accompanied by an increased 24-hour urinary excretion of 3-methly-L-histidine by 40.8% indicating that the increase in muscle size and muscle strength resulting from progressive resistance training was due to an increased rate of myofibrillar turnover (Frontera et al., 1988). A mean gain in quadriceps strength of 174±31% was coupled with increases in both mid-thigh muscle area (measured by CT scans) of 9.0±4.5% and an increase in mean quadriceps area of about 15±8% (Fiatarone et al., 1990). Although there were changes in muscle area resulting from strength training, there were no changes demonstrated in thigh girth or skin-fold measurements following training (Fiatarone et al., 1990). These results suggest that the increases in muscular strength as a result of resistance training may be due in part to an increase in muscle cross-sectional area.

Similar changes in muscle cross-sectional area were observed following 12 weeks of resistance training in the biceps brachii. Here, there was a 17% increase in muscle cross-sectional area of the elbow flexors in the trained arm with no increase in the untrained arms of elderly males (Brown et al., 1990). An increase of 8.6% in muscle-plus-bone cross-sectional area of the triceps brachii was noted following short-term resistance training in the elderly however these changes were not significant (Rice et al., 1993). Thus, resistance training in the elderly results in increases in muscle cross-sectional area to a similar extent in the muscles of the upper and lower extremities.

Following one year of resistance training, increases in muscle strength were accompanied by a mean increase in knee extensor cross-sectional area (as measured by computerized tomography) of 5.5%, where the controls increased 1.7% (McCartney et al., 1995). After 2-years of high-intensity resistance training, the experimental subjects increased their knee extensor cross-sectional area to 8.7% above baseline values confirming that continued training results in further significant muscle hypertrophy in the muscles of healthy elderly individuals (McCartney et al., 1996). This change in cross-sectional area is slightly lower than those of other investigations of the quadriceps muscles (Frontera et al., 1988; Fiatarone et al., 1990) and the muscles of the upper arm (Brown et al., 1990; Rice et al., 1993) over shorter periods of exercise training. These apparent differences may be partially due to the number of exercise training bouts per week. In studies of shorter duration, subjects exercise trained 3 times per week and in the long-term training studies (2-years duration), the subjects' resistance trained only 2 times per week. Another possible explanation is the relative fitness of the subjects at the start of the study as well as the nature of their habitual activity. These conclusions are however speculative as these factors can rarely be completely controlled for in resistance training studies of the elderly.

### (b) FIBER TYPE

An increase in mean muscle fiber area of the Type I muscle fibers of 33.5% and in Type II fibers of 27.6% has been observed following 12 weeks of resistance training in the elderly (Frontera et al., 1988). Increases in muscular strength and cross-sectional area of the biceps brachii were also accompanied by a 14% and 30% increase in fiber area of the Type I and Type II muscle fibers respectively (Brown et al., 1990). There was however no change in the percentage distribution of Type I fibers in the biceps muscle in either the trained or the untrained (control) arm (Brown et al., 1990). The 12% increase in strength of the untrained control arm with no change in muscle size or relative fiber distribution, suggests that neural adaptations mediated some of the increase in strength in response to resistance training in these older individuals (Brown et al., 1990).

Large increases in dynamic strength of the quadriceps muscle corresponded with a 20.1±6.8% (456±169 $\mu m^2$) increase in mean Type II fiber area with no significant change in Type I fiber area following 12 weeks of high intensity training in elderly women (Charette et al., 1991). There were no changes observed in the control group. From this, they concluded that progressive resistance training can increase strength in elderly women and that the skeletal muscle retains the capacity to undergo hypertrophy well into the 7th decade (Charette et al., 1991). In contrast to these investigations, a short-term investigation of knee extensor training (25 sessions) resulted in a small but significant increase in cross-sectional area (3%) with no concomitant increase in the fiber areas of either Type I or Type II muscle fibers (Grimby, 1992). High intensity resistance training resulted in significant increases in the Type I and Type II fiber areas in the biceps brachii after only 11 weeks of training (Lexell et al, 1995). There was also a significant positive correlation between the relative increase in the proportional area of Type II fibers in the vastus lateralis muscle and the relative increase in dynamic muscular strength of the knee extensors (Lexell et al, 1995).

In studies of longer duration, increases in Type I muscle fiber area of 29.4±1% (15 weeks) and 58.5±13.7% (30 weeks) were noted following whole-body resistance training (Pyka et al., 1994). There was no significant change in fiber area of Type II muscle fibers by 15 weeks, however, by 30 weeks of training, the cross-sectional area of this particular muscle fiber type increased 66.6±9.5% over baseline values (Pyka et al., 1994). In the study by Pyka et al. (1994) it took Type II fibers a relatively greater length of time to adapt to resistance training although they eventually demonstrated a greater relative hypertrophy than Type I muscle fibers (Pyka et al., 1994). This could be due to a reduced training intensity (75% compared to 80-85% of 1 RM strength) or to the generalized, whole- body nature of the exercise training protocol. In any event, it confirms that resistance training in the elderly leads to a sustained increase in muscle strength, and significant hypertrophy of Type I and more so Type II muscle fibers.

### (iii) THE EFFECTS OF RESISTANCE TRAINING ON FUNCTIONAL CAPACITY

The effects of resistance training on various measures of functional ability of the well elderly have been examined. Nichols et al., (1995a) found that sixty men and women who participated in a moderate- or high- intensity resistance training program, increased strength compared with controls for shoulder press (19.1-43.7%), lattissimus dorsi pull down (16.4-34.9%), and fly exercises (15.7-19.4%) (moderate-high) in elderly men and women. These increases in strength were significantly associated with measures of mobility and balance as well as walking speed. This is important as walking speed is reported to decline as much as 12-16% per decade after the age of 60 years and any changes in the positive direction may be functionally significant in this age group (Nichols et al., 1995a).

Similarly, 12 weeks of high-intensity weight lifting training in elderly men, resulted in large increases in 1 RM strength and was associated with an increased $VO_{2max}$ ($l \bullet min^{-1}$) of 6% when measured during maximum cycle ergometry (Frontera et al., 1990). On the other hand, there was no change in relative maximum oxygen uptake or the $VO_{2max}$ during maximum arm ergometry (Frontera et al., 1990).

Similar findings were noted following a randomized trial of progressive resistance training in 142 healthy (76 exercisers, 66 controls) elderly males and females aged 60 to 80 years. After one year of resistance training, there was a 7.1% and 17.8% increase in maximum cycle ergometry and treadmill performance respectively; with the control group showing minimal gains (1.1% and 3.4% respectively) (McCartney et al., 1995). Significant elevations above baseline values and the control group in measures of cycle-ergometry and treadmill endurance were still present following two-years of resistance training (McCartney et al., 1996). These data suggests that elderly individuals are able to transfer some of the gains in strength to other measures of functional capacity such as cycling power, treadmill endurance, and perhaps $VO_{2max}$.

### 1.5.3 DETRAINING

The effects of detraining on measures of dynamic strength have primarily been conducted using young healthy subjects and have been of relatively short duration ranging from 14 days to 32 weeks of detraining. In young male power-trained athletes who had been training for several years (mean of 8 years), 14 days of resistive exercise detraining resulted in no significant changes in measures of dynamic 1 RM strength, although a general decline was noted in all exercises (Hortobagyi et al., 1993). A significant 12 % decline in maximum isokinetic eccentric knee extensor force and a significant decrease in Type II muscle fiber area of 6.4% was evident after detraining with no significant changes in surface EMG activity (Hortobagyi et al., 1993). It was suggested that short-term detraining might affect eccentric strength and or the size of Type II muscle fibers leaving other aspects of neuromuscular performance uninfluenced.

The neural role in detraining is also hypothesized by Narici et al (1989). Here, 60 days of unilateral quadriceps resistance training followed by 40 days of detraining in young males (23-34 years) resulted in a similar pattern of decline in strength and cross sectional area as reported for the increase in strength. They determined that CSA, iEMG (integrated electromyography), and MVC (maximum voluntary contraction) are seen to decrease in a similar time course to that of training; the neural factors seem thus to exert the same weight during both periods (Narici et al., 1989). They calculated that the increase in muscle size contributed 40% of the increase in force while the remaining 60% appeared to be attributable to an increased neural drive.

In young males, 12 weeks of resistance training resulted in significant increases in isokinetic peak torque with the greatest increases in strength being noted at the slowest velocity of contraction (Colliander & Tesch, 1992). Following 12 weeks of detraining, a general decline in measures of peak torque were observed at all contraction velocities with the greatest difference again being noted at the slowest contraction velocity. This trend was observed for both eccentric and concentric muscle actions (Colliander & Tesch, 1992). Similar results in females have also been noted. Following 20 weeks of high-intensity resistance training, lower-body strength increased between 67-148% for measures of dynamic

1 RM strength (Staron et al., 1989 & 1991). These increases in strength were coupled with significant hypertrophy of all fiber types with the fast twitch fibers being affected to the greatest extent. After 32 weeks of detraining, there was a significant decline in leg press (32%) and leg extension (29%) strength, however, these values still remained significantly elevated above pre-training values (Staron et al., 1991).

The effects of reduced training and detraining on muscular strength has been examined in young males and females. Training resulted in significant increases in isometric knee extensor strength (21.4±17.5%) and dynamic training weight (49.5±14.7%) following 10 to 18 weeks of high-intensity dynamic weight lifting training (Graves et al., 1988). After 12 weeks of detraining, there was a 68% decline in maximum isometric strength as compared to post-training values. Reduced training frequency from 3 days per week to as little as one day per week at the same high-intensity resulted in no significant changes in muscular strength over this same 12 week period. This suggests that when the intensity of strength training is maintained, training frequency does not affect the maintenance of muscular strength (Graves et al., 1988).

The effects of detraining on skeletal muscle strength in the elderly have not been adequately addressed. Previous research has focused primarily on the effects of endurance training and detraining on cardiovascular fitness. Here, it is noted that detraining occurs in two phases, the initial phase is characterized by a rapid decline in cardiovascular fitness which is followed by a relatively stable decline thereafter. By 8 weeks, all the beneficial effects of endurance training have been lost (Coyle, 1990).

Following 8 weeks of resistance training in the frail elderly, yielding large increases in 1 RM strength (136±16%), the investigators examined a period of detraining (Fiatarone et al., 1990). This period of detraining was characterised by a rapid decline in strength whereby the subjects had returned to 115±23% above baseline values by 2 weeks and after just 4 weeks of no training, strength measures remained 92±23% above baseline muscle strength (Fiatarone et al., 1990). This decline in muscular strength represents a 32% loss of relative strength after 4 weeks of detraining.

Contrary to this, a recent investigation of cardiovascular endurance and resistance training revealed that adaptations to training in the elderly are relatively resilient to periods of detraining (Sforzo et al., 1995). In males and females over the age of 60 years, 10 weeks of detraining resulted in a slight decline in treadmill and cycle workloads as compared to post-training values, however treadmill performance remained significantly elevated above baseline. Increases in muscular strength demonstrated a different pattern of decline such that the adaptations were stable for about 5 weeks after heavy resistance training and by 10 weeks, both dynamic strength (12 RM) and isokinetic peak torque and total work had reverted to near baseline values (Sforzo et al., 1995).

The disparity in the timeline for detraining in the elderly may be attributed to the age of the subjects, the relative fitness of the subjects, the length of the intervention and the number of subjects in each of the previous studies. The subjects in the study by Fiatarone et al., 1990 had a mean age of 90±1 years and were all residents of a long-term care facility. The 9 subjects' strength trained for 8 weeks at a high intensity. On the other hand, 99 community dwelling elderly with no previous history of medical illness participated in 16 weeks of resistance training (Sforzo et al., 1995). The mean age of the subjects was 67±5 years. Thus, the differences in the degree of detraining may be a result of the differences in subject fitness and age.

### 1.5.4 EXERCISE TRAINING AND THE SKELETAL SYSTEM

Many research findings support the view that weight-bearing activity is beneficial to skeletal health at any age. Rapid and severe bone loss often manifests itself during periods of disuse and weightlessness (Aloia, 1981). Physical exercise has been identified as a determinant of bone gain in the growth phase, and physical inactivity has been implicated in the involutional phase of bone loss (Aloia, 1981).

### (i) BONE MASS, MUSCLE MASS, AND MUSCULAR STRENGTH

Anatomical studies have clearly demonstrated the strong positive relationship between muscle mass and bone mass (Doyle et al., 1970); for example, a significant correlation between the ash weight of the third vertebral body and the psoas weight from necroscopies (Doyle et al., 1970). Thus, as muscle mass and bone mass are tightly correlated, it might be expected that muscle strength and bone mass would also demonstrate a similar relationship. In a study of 68 post-menopausal women, bone mineral density of the spine was positively correlated to back extensor strength ($r=0.31$, $p=0.004$), suggesting that back strength may contribute to vertebral bone mineral density (Sinaki et al., 1986). In recent investigations the association between muscle strength, lean body mass, and BMD was examined in 56 pairs of monozygotic and dizygotic twins to determine the genetic influence on the relationship between muscle strength, mass, and BMD (Seeman et al., 1996). The study was controlled for age, sex, genetic composition and habitual physical activity levels. It was determined that genetic factors accounted for between 60-80% of the individual variances of both femoral neck BMD and lean mass. A 10% increment of femoral neck BMD was associated with a 15% increment of lean body mass (Seeman et al., 1996). Muscle strength and BMD were correlated before, but not after adjusting for lean body mass, suggesting that the association between greater muscle mass and greater BMD are likely to be genetically determined (Seeman et al., 1996).

The relationship between muscular strength, muscle mass, and bone mass have been demonstrated. The isokinetic strength of the knee and elbow flexors and extensors was compared with vertebral (lumbar spine L2-L4) and femoral bone mineral density (BMD) in 107 females aged 44 to 87 years (Calmels et al., 1995). Here, upper body strength correlated highly with vertebral BMD ($r=0.30$, $p=0.003$) and femoral BMD correlated more closely with lower limb strength ($r=0.28$, $p=0.005$). It was also observed that the decline in vertebral and femoral BMD occurred in two distinct phases; the first during the 5th and 6th decades and the next between the 7th and 8th decades. This time frame of declining bone mass with age correlates well with the theory of Riggs and colleagues (1983), outlining an initial decline in BMD during the post-menopausal period (5th and 6th decades) and a secondary decline as a senile bone loss, or osteoporosis after the 7th decade.

### (ii) EXERCISE, MUSCULAR STRENGTH, AND BONE DENSITY

Several cross-sectional and longitudinal investigations have examined the effect of exercise on bone mass and density. Overall, the results of cross-sectional studies on athletes suggest that physical activity has a positive effect on bone mass. Early cross-sectional studies evaluated bone density in the distal femur in 64 male athletes and 39 non-athletes, finding increased bone density in the athletes, with the greatest density noted in the dominant leg (Nilsson & Westlin, 1971). Of the various groups of athletes tested, weight lifters had the highest bone densities, whereas swimmers had bone mass values similar to those of the controls (Nilsson & Westlin, 1971). Other studies of athletes have generally supported these findings, but there is considerable variation in the magnitude and significance of the differences between the athletes and non-athletes depending on age, gender, type of sport and training, and the bone site under investigation (Suominen, 1993).

In the older athlete, findings suggest that middle-aged and elderly male athletes from various sports have significantly higher BMC and BMD values in several bone sites when compared with non-athletes whereas studies on elderly women do not demonstrate differences between athletes and non-athletes (Suominen, 1993). In another study, the bone mineral content of the lumbar spine and the distal radius were reported to be about 11% greater in the oldest age-group (55-70 years) of athletic women as compared to non-athletic controls (Jacobson et al., 1984). Higher BMD of the spine (Lane et al., 1986) and BMC of the spine and radius (Nelson et al., 1988) was noted in male and female long-distance runners when compared to non-runners. This finding is consistent in cross-sectional investigations comparing athletes to non-athletes suggesting that regular weight-bearing physical activity provides an adequate stimulus to maintain bone mineral density and content in the elderly. The effects of body mass and lean body mass are also important determinants of BMD particularly in the elderly where these measures tend to decline.

### (iii) EXERCISE TRAINING AND BONE MASS

The specific effects of exercise training on bone mass in the elderly are controversial. The findings from cross-sectional studies of athletes are encouraging, however it is not known whether these subjects were pre-selected based on their inherently greater bone density or whether increased bone density is a direct effect of the exercise.

Increases in dynamic muscle strength resulting from 9 months of moderate to high-intensity resistance training and its association with bone mineral density was examined in a small group of post-menopausal women (mean age 53) (Pruitt et al., 1992). Mean increases in strength of 22.7-36.3% corresponded to a 1.6±1.2% increase in BMD at the lumbar spine and a decrease of -2.7±1.2% at the femoral neck (Pruitt et al., 1992). One-year of high-intensity resistance training resulting in large increases in dynamic strength eluted no significant changes in bone mineral density or bone mineral content, although a general decline in both measures was observed with increasing age (McCartney et al., 1995).

After 2-years, there was a significant decline in bone mineral density and whole body bone mineral in the exercise group with small but significant increases being observed in the control group (McCartney et al., 1996). It is important to note however, that at the start of this investigation, the training group had the higher reported bone measures compared with the controls and this trend was retained throughout the study (McCartney et al., 1995 and 1996). Similarly, Rockwell and colleagues (1990) reported a 57% increase in muscle strength, but also observed a -3.9±1% decline in lumbar spine BMD. If exercise does increase BMD, no data are available defining the increment in muscular strength or muscle mass necessary to produce a given increment in BMD.

The effects of high-intensity strength training on the BMD of the whole body, lumbar spine, and the hip of active older women 60 to 84 years of age was examined by Nichols et al. (1995). BMD at all sites tested were significantly correlated with age but significant increases in strength (from 14.5%-71%) after 12 months of training resulted in no significant changes in BMD at any site. The authors speculate that whole body high-intensity resistance training may not be a sufficient stimulus to evoke significant changes in bone measures (Nichols et al., 1995b). The findings of this investigation suggest that age is the single most important factor determining bone density in the elderly.

Exercise training may however provide a protective effect against the age associated decline in bone mass. A one-year vigorous walking program preserved bone density of the lumbar spine when compared to a group of sedentary age matched controls. No effect of exercise was observed at any other bone site or in total body calcium (Nelson et al., 1991). Recently, the effects of a one-year high-intensity (80% 1RM) resistance training program on bone health was examined in a group of 40 women aged 50-70 years (Nelson et al., 1994). The control group who did not exercise throughout the study exhibited declines in femoral neck BMD (-2.5%), lumbar spine BMD (-1.8%) and total body BMC (-1.2%). The women in the exercise group demonstrated an apparent protective effect of strength training on femoral neck BMD (0.9%), lumbar spine BMD (1.0%), and total body BMC (0.0%). The resistance training provided a significant positive effect on measures of bone when compared to the control group. This training protocol also increased muscle mass and strength, balance and overall levels of physical activity (Nelson et al., 1994). Although increases in bone mass as a result of resistance training are rare, any possible protective effect exercise may have on preserving bone mass and bone integrity in the elderly may be functionally significant.

The evidence of a static relationship between bone mass and resistance exercise predominates, however there are a few studies which have demonstrated significant alterations in bone mass resulting from exercise training. In a randomized trial of hormone (estrogen) replacement therapy in surgically menopausal women, increases of 8.3% in lumbar spine and 4.1% in radial BMD following one year of resistance training were observed (Notelovitz et al., 1991). The subjects provided with the estrogen therapy only maintained their bone mass over this time period with no significant changes in BMD at these sites (Notelovitz et al., 1991). An increase of 3.8% in BMD of the distal radius in post-menopausal women with no change in BMC was observed following 5 months of moderate-intensity resistance training specifically for the upper body (Simkin et al., 1987). These results are similar to those of the previous study suggesting that resistance training may bring about small but significant increases in bone integrity. Perhaps exercise intervention coupled with hormone replacement therapy is necessary in order to preserve and accentuate bone mass in women late in life. Another speculative conclusion of this investigation is that to produce increases in measures of bone integrity, the exercise training protocol must be highly specific to the area of bone being assessed. Thus, the loading of the muscles of the area to be investigated must be stressed in order to produce significant alterations in bone mass and density.

### 1.5.5 DETRAINING AND BONE MASS

There have been two studies demonstrating the effects of detraining on bone health. A small but significant increase (3.4%) in BMC of the wrist was observed in subjects who squeezed a tennis ball maximally 3 times, 3 times per day for 6 weeks (Beverley et al., 1989). These changes had reversed to 2.6% below baseline values following a detraining period of 6 months. Another study conducted by Dalsky et al. (1988), used an exercise program which consisted of walking, jogging, and stair climbing, for a total of 50 minutes, 3 times weekly, in women aged 55 to 70 years. BMC of the lumbar spine increased by 5.2% after 9-months of training and by 6.1% following 22 months of training (Dalsky et al., 1988). After 9-months, the control group had lost 1.4% of BMC. Most of the gains in BMC demonstrated in the exercising groups returned to 1.1% above baseline (not significant) within a 13 month detraining period, suggesting that exercise needs to be continued to be beneficial to bone mass in the elderly (Dalsky et al., 1988).

## 1.6 SUMMARY

Normal human aging is characterized by a decline in muscular strength resulting in an overall muscle weakness and a decreased capacity to perform activities of daily living. This decline in strength is the result of disuse and muscle atrophy (decline in muscle mass). Dramatic increases in muscular strength and endurance have been observed in the elderly with exercise training (particularly resistance training) of varying duration. These investigations indicate that elderly individuals are capable of participating in an exercise program designed to increase strength and thus may increase their capacity for completing activities of daily living; however, training must be progressive and continuous to preserve and maintain these changes.

With age, there is also a steady decline in measures of bone integrity (bone mineral density and content). The evidence regarding the effects of exercise on bone are conflicting, with some investigations demonstrating increases in bone density and others eliciting no changes or a slight decline. Most agree that resistance training in the elderly will provide increases in dynamic muscular strength with any benefit to skeletal integrity being one of preservation of bone mass rather than one of dramatic bone accretion.

To date, there is very little known about the effects of detraining on muscular strength and bone properties in the elderly. The studies that demonstrate changes with detraining have reported declines in muscular strength similar to those in young adults. There is currently very little evidence on the effects of long-term resistance training in the elderly. The effects of detraining following a period of long-term heavy resistance training on muscular strength in the elderly have also yet to be determined. The changes in bone density and content following training and detraining in the elderly also need to be explored.

## 1.7 PURPOSE

The present study describes the findings of a 5- year investigation of resistance training in the elderly. The main purpose(s) of the study was to examine the effects of resistance training, detraining, and ageing on:

(a) Dynamic Strength

(b) Symptom limited endurance during treadmill walking

(c) Bone mineral density and content

## 2.0 METHODS

### 2.1 SUBJECTS

Thirty healthy men and women aged 65-81 years, volunteered for the study. The investigation was approved by the President's committee on Ethics of Research on Human Subjects, McMaster University, and each subject gave their written informed consent to participate. Exclusion criteria included cardiopulmonary disease, osteoporosis, orthopedic disability, smoking, and a relative weight >130% of predicted (McCartney et al., 1995,1996).

At the 5-year follow-up testing time, each subject completed the modified Baecke questionnaire for older adults as a measure of habitual physical activity (PAH-Q). The results of this questionnaire are outlined in Table 1 (page 49). This tool is both valid and reliable for use in the elderly (Voorrips et al., 1991).

### 2.2 STUDY DESIGN

The study design is outlined in figure 1. The elderly subjects were allocated to one of three groups (5 males and 5 females per group) who had either continued to weight train for 5 years (TR), ceased to weight train after 2 years (DETR), or had acted as controls throughout (CON). The TR and DETR groups strength trained at a high intensity, twice per week for 2 years progressing up to 3 sets at up to 80% 1RM. The TR group continued to strength train at a maintenance level (2-3 sets at 60-70% 1RM) for another 3 years, whereas the DETR group stopped training. The 10 control subjects did not train for the duration of the study but were involved in identical testing procedures.

Figure 1. Study Design

| | **TR** | **DETR** | **CON** |
|---|---|---|---|
| | 5♂, 5♀ | 5♂, 5♀ | 5♂, 5♀ |
| 2 Years | HEAVY RESISTANCE TRAINING | | USUAL ACTIVITY |
| 3 Years | MODERATE RESISTANCE TRAINING | DE-TRAINING | USUAL ACTIVITY |

## 2.3 TRAINING

For two years, subjects in the TR and DETR groups participated in a supervised, progressive resistance training program twice per week, each session lasting approximately 1.0 hour. The subjects performed 2-3 sets of 8-10 repetitions for the upper body and 10-12 repetitions for the lower body exercises, at an intensity ranging up to 80% of their one repetition maximum (1 RM). Each session started with about 5 minutes of low intensity or unloaded cycling (approximately 50-75 watts) as a warm-up exercise. The subjects then proceeded to strength train with the following exercises: unilateral arm curl (AC), unilateral leg (LP) and calf press, bilateral triceps extensions, overhead unilateral military press, bilateral supine bench press (BP), unilateral knee extensions, and plantar flexion on a specially designed apparatus. The TR and DETR groups had their 1 RM strength on the BP, MP, AC, and LP tested regularly to ensure they were exercising at the appropriate intensity (McCartney et al., 1995, 1996).

Following two years of heavy resistance training, the subjects of the TR group continued strength training at a moderate intensity in a maintenance level program. The intensity of the training was decreased and a greater emphasis was placed on cardiovascular fitness and stretching exercises. The TR group continued strength training at a lower intensity (about 60% to 70% of 1RM) on all the exercises, however, they also increased the amount and duration of cycling as well as treadmill walking being added to their fitness program. They continued to train twice weekly; and the exercise sessions gradually increased in duration from between 1.0 to 1.5 hours in length. The subjects in the DETR and the CON group were self-reportedly not involved in any type of formal resistance training program over the 3-year detraining period.

## 2.4 MEASUREMENT OF DYNAMIC STRENGTH

The subjects' one repetition maximum (1RM), determined to be the heaviest weight that could be lifted once through a full range of movement, was measured for unilateral arm curl, unilateral leg press, and bilateral supine bench press. Single-arm curl (AC) strength was performed on a custom built apparatus specifically designed for the purposes of the study (Rubicon Industries, Stoney Creek, Ontario). Leg press (LP) and bench press (BP) 1RM strength was determined using a multi-station weightlifting machine (model 4141-162; Global Gym and Fitness Equipment Limited, Weston, Ontario).

## 2.5 TREADMILL ENDURANCE

Subjects performed an incremental treadmill (Quinton Q55xt) walking test until they: (1) Reported a Borg rating of perceived exertion (RPE) of 7 (very severe) for leg discomfort or dypsnea; (2) reached their age predicted maximum heart rate (MHR) as determined using a single V5 ECG lead as well as by palpation; (3) voluntarily could not continue, at which time the test was terminated by the attending investigator. The criteria for ending the test was not made known to the subjects. The treadmill protocol was as follows: during the first 2 minutes the walking speed was 2.0 mph at an elevation of 10%, this was increased to 2.5 mph and 12% grade for minutes 2 to 4, and in each additional 2 minute interval the speed remained constant and the grade increased by 2% to a maximum of 24%. Symptoms of leg effort and dypsnea were rated separately at the end of each minute and heart rate was monitored continuously.

## 2.6 BONE DENSITY AND CONTENT

Bone mass of the lumbar spine and the whole body were measured using the Hologic QDR 4500, a multiple detector, fan beam, Dual Energy X-Ray Densiometer. The QDR estimates the bone mineral content (BMC) in grams (g) and the bone mineral density (BMD) in grams per centimeter squared (g/cm$^2$). The QDR uses a low level of X-rays of two different energies to estimate BMC and BMD. At the lumbar spine, BMD and BMC were calculated for L1, L2, L3, and L4. Whole body and regional measurements with this instrument have been demonstrated to be both accurate and precise (1%) (Brathe, et al., 1997). During all testing sessions, the equipment was running within the respective guidelines of the company and a quality control (QC) for the QDR was completed each morning or prior to each set of scans. The equipment was well within the functioning capabilities and the QC was well within standard limits (confidence interval of plus or minus 0.5%).

Baseline lumbar spine and total body bone mineral density and content were measured using dual photon absorptiometry ($^{153}$Gd based Norland 2600 dichromatic densitometer). Data obtained with this instrument have been shown to be both accurate and precise (McCartney et al, 1995 and 1996). To account for the differences in the two methods of collection, both the absolute data and the ratio relation (%) using the CON group as the standard will be analysed to asses the impact of the intervention on the TR and the DETR groups.

## 2.7 STATISTICAL ANALYSIS

The data were analyzed using a 3-way mixed analysis of variance (ANOVA) with a 3(Group) x 2(Gender) x 3(Time) design with repeated measures of the last factor using the Statistica (Statsoft Inc.) data analysis program. The Tukey Honestly Significant Difference (HSD) method was used as a post-hoc test to determine specific differences between the groups. The effect of greatest interest is the group by time interaction in order to evaluate the effect of training and detraining. The absolute and relative changes will be analysed separately for further clarity. A probability level of $p \leq 0.05$ was considered statistically significant. All values are expressed as mean ± standard deviation unless otherwise stated, as well, the error bars have been left off the figures for clarity.

# 3.0 RESULTS

## 3.1 SUBJECTS

Subject characteristics are summarized in Table 1. There were no significant differences between the TR, DETR, and CON groups with respect to age (years), gender (male or female), height (centimeters), weight (Kg) or level of habitual physical activity (PAH-Q as measured by the modified Baecke). All of the subjects completed all tests.

## 3.2 DYNAMIC STRENGTH

There were no significant differences noted between the right and left limbs for arm curl or leg press 1 RM strength, thus all values are noted as the sum of both limbs. Males were significantly stronger than the females for all measures of dynamic strength (arm curl $p<0.001$; leg press $p<0.001$; bench press $p<0.001$) and this finding is consistent across all groups. Due to this, the data have been collapsed by gender and re-analysed for specific effect of group by time. Table 2 represents the average rates of changes in dynamic strength expressed as percent change per year for the males and females of each group.

### 3.2.1 ARM CURL

**(i) Changes in Absolute Strength**

Figure 2 represents the 1 RM strength (sum of both arms) for the TR, DETR, and CON groups over the five-year investigation. The three groups were not significantly different from one another at baseline (time 0 years) with mean AC 1 RM values of 17.3±6.6 kg, 23.1±17.6 kg, and 22.1±10.0 kg for the TR, DETR, and CON groups respectively. Following two years of heavy resistance training, the TR and DETR groups demonstrated significant increases in mean AC strength of 22.1±19.4 kg ($p=0.0001$) and 16.1±16.8 kg

| **Group** | **Age (years)** | **Height (cm)** | **Weight (Kg)** | **Modified Baecke Questionnaire for Older Adults (PAH-Q)** |
|---|---|---|---|---|
| **TR** | 74.9(4.2) | 164.4(8.0) | 67.6(12.0) | 14.8(7.7) |
| **DETR** | 72.3(3.5) | 165.5(9.0) | 76.1(13.0) | 12.7(9.2) |
| **CON** | 70.2(3.1) | 162.6(11.0) | 76.7(14.0) | 15.0(8.1) |

**Table 1.** Subject Characteristics expressed as mean(SD)

|  |  | TR |  | DETR |  | CON |  |
|---|---|---|---|---|---|---|---|
| Exercise | Gender | 0-2 years | 2-5 years | 0-2 years | 2-5 years | 0-2 years | 2-5 years |
| AC | Male | 81.3 | -6.6 | 45.3 | -7.9 | -1.0 | -5.1 |
|  | Females | 32.6 | -2.9 | 36.6 | -10.7 | -2.6 | -2.2 |
| BP | Males | 22.7 | -7.3 | 25.2 | -10.1 | 0.8 | -4.4 |
|  | Females | 35.1 | -3.9 | 30.4 | -10.3 | 7.8 | -4.3 |
| LP | Males | 13.8 | -2.4 | 19.9 | -4.9 | -4.6 | -0.9 |
|  | Females | 14.1 | -2.8 | 12.0 | -4.0 | 3.4 | -4.5 |
| TM | Males | 12.76 | -8.2 | 13.7 | -9.7 | -2.9 | -14.0 |
|  | Females | 13.3 | -5.5 | 15.1 | -11.4 | 0.6 | 3.4 |

**Table 2.** Mean relative rates of change in measures of dynamic strength (unilateral arm-curl (AC), unilateral leg-press (LP), bilateral bench press (BP)) and treadmill endurance in percent per year (%/year) for the TR, DETR, and CON groups from 0-2 years and 2-5 years.

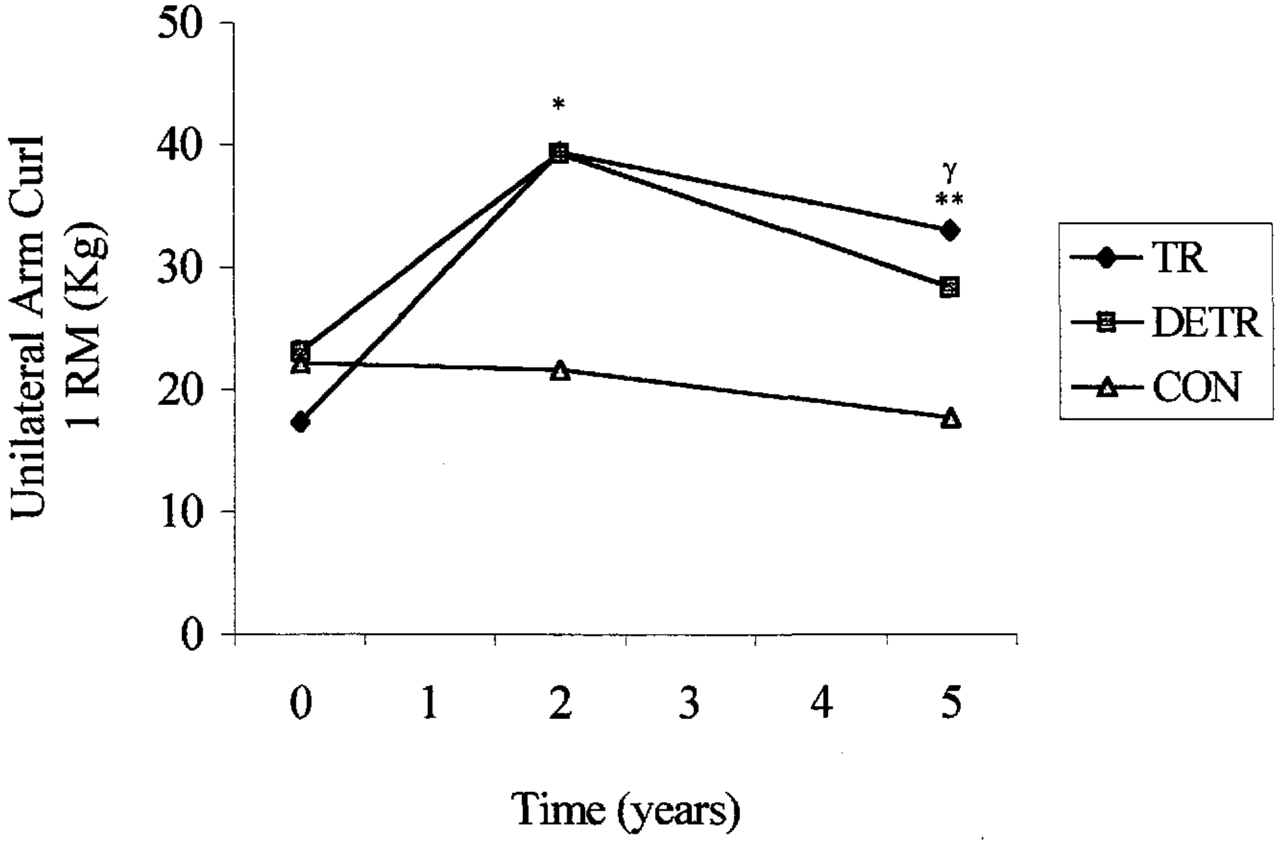

**Figure 2:** Unilateral arm-curl 1RM strength over 5 years. (*denotes the TR and DETR groups are significantly different from CON; ** denotes the TR group is significantly different from baseline at 5 years; γ denotes the TR group is significantly different from CON at 5 years).

(p=0.002) above their baseline values. The TR group continued to train at a moderate intensity for a subsequent period of about 3 years. Over this time, AC strength remained 15.7±16.9 kg above pre-training values (p=0.003). The DETR group ceased resistance training after the initial two year period, however, after 3 years of no training, their AC 1 RM strength remained 5.3±4.9kg above their baseline values. This elevation above baseline did not reach significance (p=0.88). The CON demonstrated a further decline in AC strength over the next 3 years. At the five-year testing time, the CON was 4.4±2.9 kg below their baseline AC strength measures however this difference was not statistically significant. The TR and DETR groups were not significantly different from one another after five years, however, the TR remained significantly elevated above the CON (p=0.004).

**(ii) Relative Changes in Strength**

Figure 3 represents the relative changes in arm-curl strength over 5 years for the TR, DETR, and CON. Following 2 years of heavy resistance training, the TR and DETR groups demonstrated a relative increase in strength from baseline of 113.9% and 81.9% for the males and females combined. The changes in relative strength for the TR and DETR groups were significantly different from the CON group which declined in strength -3.6% over this time.

Following 3-years of moderate resistance training, the TR group remained 82.2% above their original strength measures. When normalized and expressed as a percentage of baseline 1 RM strength, after 5 years the TR group was significantly different from both the DETR (p=0.01) and the CON (p=0.0001) groups. The DETR group lost strength yet still remained 24.2% above their baseline values following 3 years of no resistance training. The CON group continued to lose strength and 5 years of no resistance training yielded a 19%

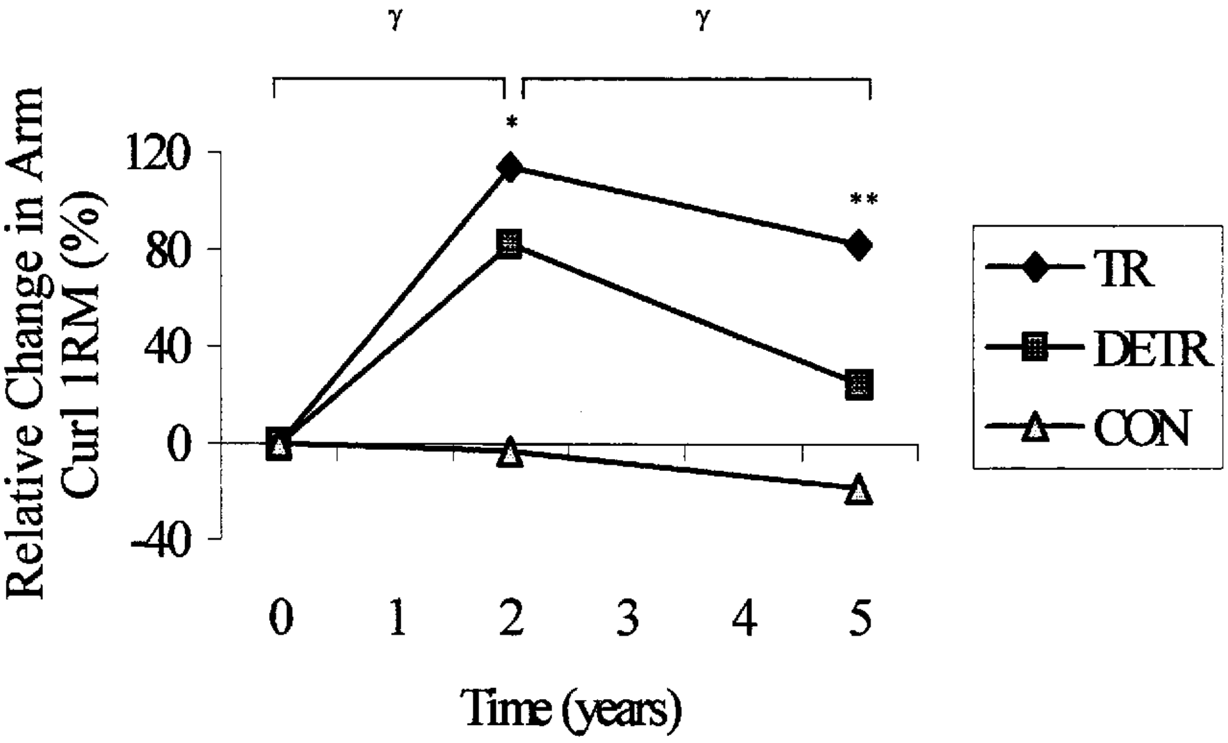

**Figure 3:** Relative change in unilateral arm curl 1RM over 5 years. (* denotes TR and DETR are significantly different from baseline;** denotes the TR group is significantly increased from baseline as compared with the DETR and CON; γ denotes the degree of change is significantly different between the TR and CON group from 0-2 years and 0-5 years).

decline in relative strength. There were non-significant differences noted between the DETR and CON group at this time.

### 3.2.2 LEG PRESS

#### (i) Changes in Absolute Strength

At baseline there was a significant difference in unilateral LP strength (1RM) between the TR, DETR, and CON groups (p<0.0001)(Figure 4). The TR and DETR groups LP 1 RM strength were not significantly different from one another (128.5±36 kg; 135.2±35 kg) but they were both significantly lower than the CON (155.8±49 kg; p=0.0006 and p=0.02 respectively). Two years of heavy resistance training resulted in a mean increase in LP strength for the TR (35.2±18 kg) and DETR (43.5±24kg) which were significantly different from their baseline strength measures (p=0.0001). Over this time, the CON group declined in leg press 1 RM strength 7.0±21 kg. After 2 years of resistance training, there were no significant differences in mean 1 RM strength between the TR and CON groups, yet the DETR was significantly elevated above the CON group (p=0.0002).

Following 3 years of maintenance level resistance training, LP 1 RM strength of the TR group remained significantly elevated above their pre-training values by 21.6±16.7 kg (p=0.01). Over this time, the DETR group declined in 1 RM strength (25.1±18 kg) but still remained 18.4±22 kg elevated above the pre-training values. This approached statistical significance (p=0.056). The 1 RM strength of the CON group continued to decline in leg press 1RM which resulted in an 18.3±18kg decline in LP strength over the 5 years. This value was not quite significantly different from their baseline values (p=0.057). Thus, after five

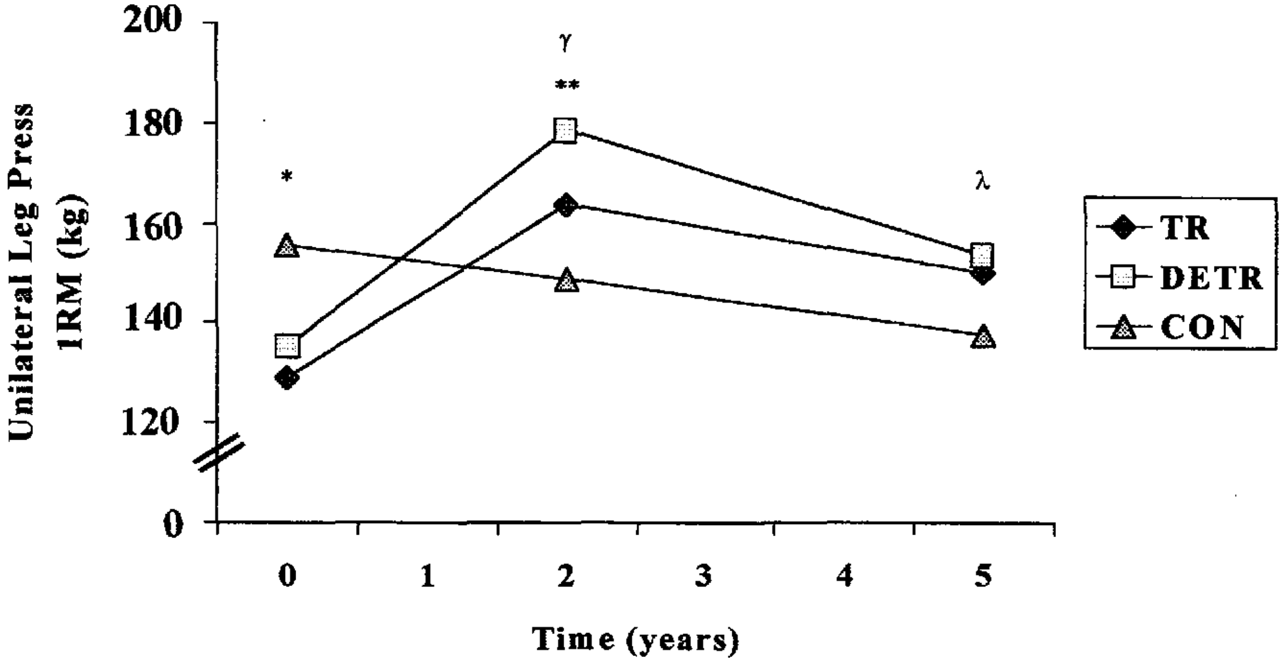

**Figure 4:** Unilateral leg-press 1RM strength over 5 years. (* denotes CON are significantly different from TR and DETR; ** denotes TR and DETR are significantly different from baseline; γ denotes DETR are significantly elevated above CON; λ denotes the TR are significantly different from baseline)

years, there were no significant differences in mean LP 1 RM strength between the TR (150.1±42kg), DETR (153.6±41kg), and CON (137.4±40kg) groups. Thus, the TR and DETR were just as strong as the CON group after 5 years and demonstrate an improvement in their 1RM strength as related to baseline.

**(ii) Relative Changes in Strength**

When the change in dynamic strength is expressed as a percentage of pre-training strength, the TR and DETR groups were both significantly different from the CON group (p=0.0001) following 2 years of high-intensity strength training. As demonstrated in figure 5, the mean increases for the TR and DETR group represented relative increases in LP strength of 27.8% and 31.9% respectively, whereas the CON group declined -1.1%.

After 3 years of maintenance level strength training, LP strength of the TR group remained 17.4±11% above baseline with a general reduction in strength following high-intensity. The DETR group lost strength at an accentuated rate (4.5% per year) but still remained 14.2% above baseline with no training. Over the 5-year study, the CON group continued to lose LP strength with a relative decline from baseline of -9.74%. This change in relative strength approached significance (p=0.057). There were, however, significant differences in mean relative strength change from pre-training between the TR and CON (p=0.0001) and the DETR and CON (p=0.0003).

### 3.2.3 BENCH PRESS

**(i) Absolute Changes in Strength**

At baseline, there were no significant differences in bilateral BP 1 RM between the TR (31.5± 14kg), DETR (36.4±17kg), and CON (39.5±14kg) groups. Two years of high-

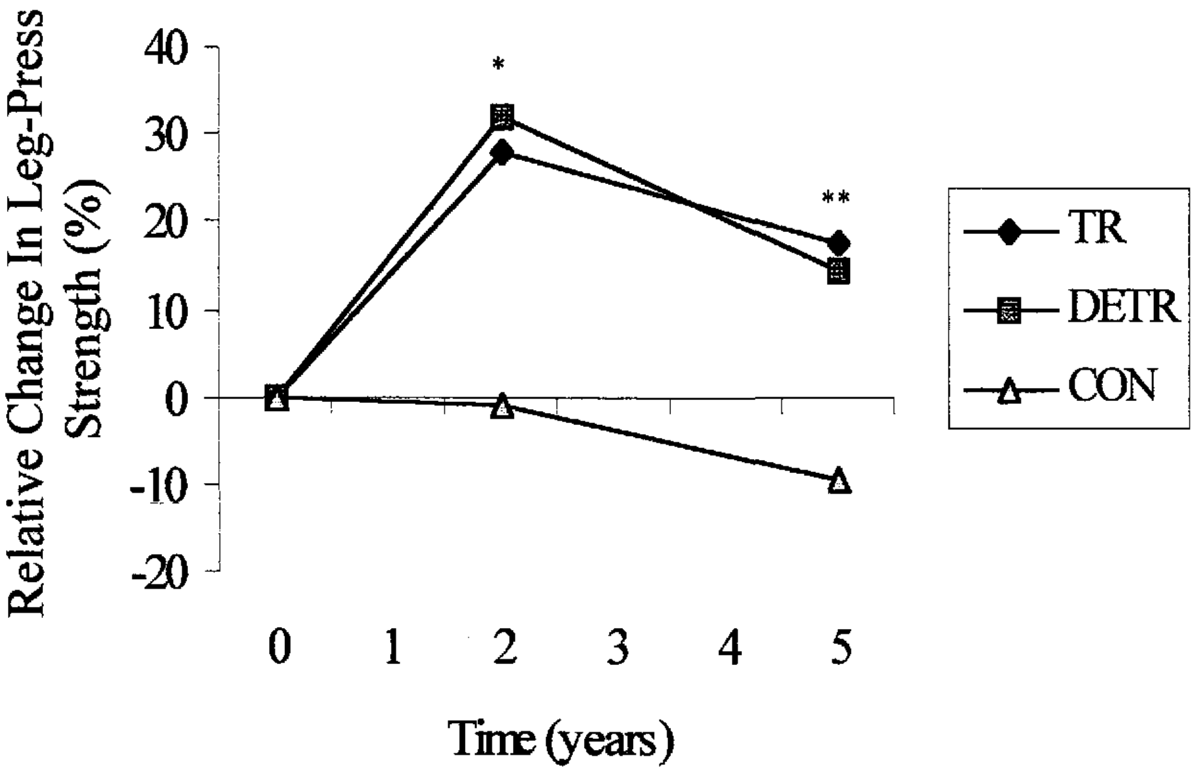

**Figure 5:** Relative change in unilateral leg-press strength over 5 years. (* denotes the change from baseline for the TR and DETR groups are significantly different from CON; ** denotes TR and DETR groups are significantly different from the CON).

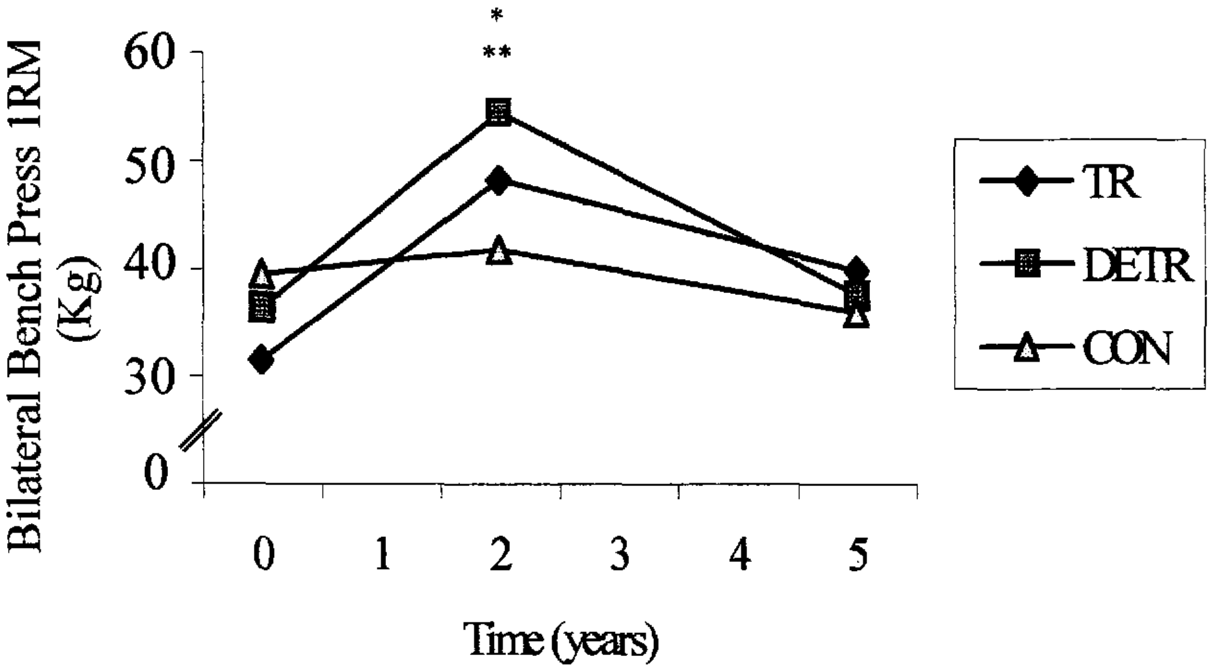

**Figure 6:** Bilateral bench press 1RM strength over 5 years. (* denotes the TR and DETR groups are significantly different from baseline; ** denotes the DETR are significantly elevated above the CON).

intensity resistance training resulted in significant (p=0.0001) increases in BP 1RM for the TR (16.6±10kg) and DETR (18.2±11kg) groups with a non-significant positive change for the CON group (2.7±3.5kg) which is outlined in figure 6. At this time, the TR and DETR groups were not significantly different from each other and the DETR group was significantly elevated above the CON group (p=0.002).

Following 3 years of no resistance training, the DETR group declined in 1 RM strength from their post-training values by about 17kg, however their strength still remained slightly (although not significantly) elevated above their pre-training values (1.4±13kg). With continued training, the TR group retained an 8.3±12kg increase in 1 RM strength above pre-training values (p=0.02). The CON group lost 3.5±6.9kg in BP 1 RM strength during this 3- year period but this was not significantly different from baseline. Thus, after 5 years, there were no significant differences in BP 1 RM strength between the three groups however, the TR group BP 1RM (39.8±20kg) remained slightly elevated above the DETR (37.7±17kg) and the CON (36±11kg).

**(ii) Relative Changes in Strength**

In relative terms, two years of high-intensity resistance training resulted in a mean increase of 57.9±28% in the TR and 55.6±34% in the DETR groups; over this same time period, the CON group also increased in bilateral BP strength by 8.6±16%. There was no difference at this time between the TR and DETR groups and the increases in both groups were significantly greater than that of the CON (p=0.0001). After 3 years of maintenance level resistance training, the TR group remained elevated above their pre-training strength by 34%(p=0.03) and were significantly different compared with both the DETR and CON

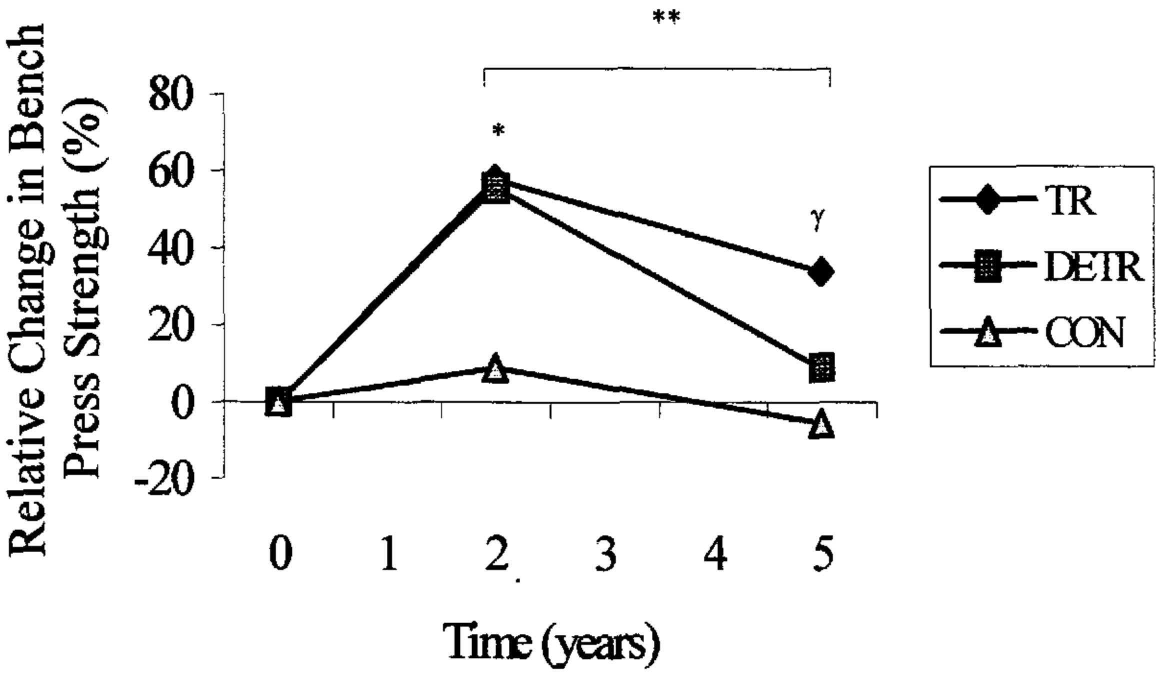

**Figure 7:** Relative change in bilateral bench press strength over 5 years. (* denotes the TR and DETR groups increased significantly over the CON; ** denotes the DETR had a greater degree of decline from years 2-5 than the CON; γ denotes from 0-5 years, the TR and DETR groups retained a greater degree of strength change than the CON).

groups (p=0.02;p=0.0002). Thus, when compared to their baseline values, the TR retained a greater relative strength than did the DETR or the CON groups. There were no significant differences between the DETR and CON groups at 5 years.

## 3.3 TREADMILL ENDURANCE

### (i) Absolute Changes in Time to Exhaustion

Figure 8 represents the changes in treadmill time to exhaustion for the TR, DETR, and CON groups (males and females combined) over the 5-year period. At baseline, there were no significant differences between the TR (15.0±9.5), DETR (16.5±9.0), and CON (24.3±19) groups in time to exhaustion (minutes). Following high-intensity resistance training, there was a general increase in treadmill endurance in the TR (2.5±4) and DETR (2.2±11) whereas the CON group declined slightly (-1.0±9) however, this was not significant.

Following the subsequent moderate-intensity resistance training or detraining period over the next three years, there was a general decline from baseline values in mean time to exhaustion for all the groups. At this time, there were no significant differences in mean treadmill endurance for any of the groups or any differences between the groups (Figure 8). Thus it appears that resistance training of .high- or moderate-intensity had no apparent relationship to treadmill endurance.

### (ii) Relative Changes in Time to Exhaustion

Two years of resistance training revealed relative changes in treadmill endurance in the TR and the DETR groups as compared to baseline (figure 9) although these were not significant. The TR group increased about 26% and the DETR group increased endurance by 29%. The CON group declined 3% over this time and this change was not significantly

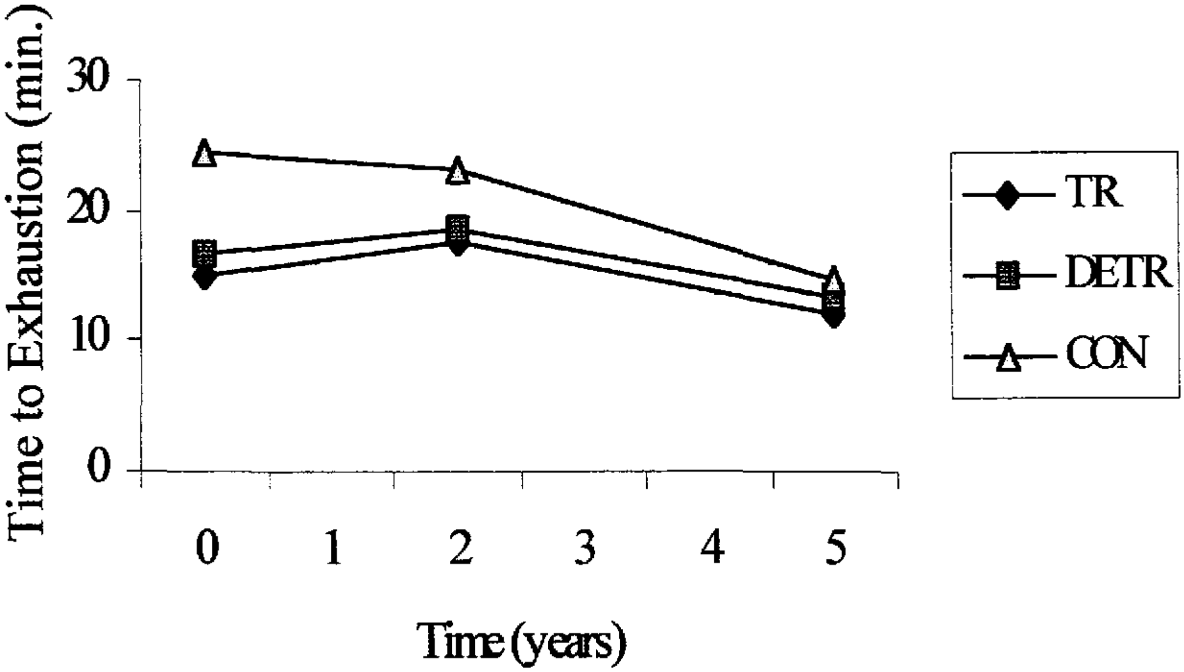

**Figure 8:** Treadmill time to exhaustion over 5 years.

different from baseline. There were no significant differences between the groups for relative time to exhaustion.

An interesting characteristic primarily in the TR and DETR groups was the highly similar change in relative treadmill endurance and relative LP strength during the 2 years of high-intensity training. Collapsed across genders, there was a 13.0% and 13.9% per year increase in TM time and LP strength in the TR group and a 14.4% and 15.9% per year increase in these values for the DETR group respectively.

### 3.4 BONE DENSITY

BMD and BMC of the whole body (TB) and the lumbar spine (LS) were measured. Due to the longitudinal nature of this investigation, two separate machines were used to measure bone integrity. The baseline values were determined using dual photon absorptiometry using the Norland 2600 (McCartney et al., 1995, 1996), and the five-year values were completed as described previously (QDR 4500/A). Due to the nature of the measurements, we have assumed that the differences between the two methods would be systematic and equally represented across all groups. Cross-sectional comparisons between the three groups at both baseline and at 5 years are of primary interest and changes between the baseline and five years have also been noted.

Briefly, there was a significant main effect for gender; males had significantly greater lumbar spine BMD ($p=0.02$) and BMC ($p=0.0001$) than females. This effect was also demonstrated for total body BMD ($p=0.0003$) and BMC ($p<0.0001$). Table 3 represents the mean values for all measures of bone integrity. Here, it is evident that the TR group has the lowest initial values for TBBMD, TBBMC, LSBMD, and LSBMC. This trend is also carried

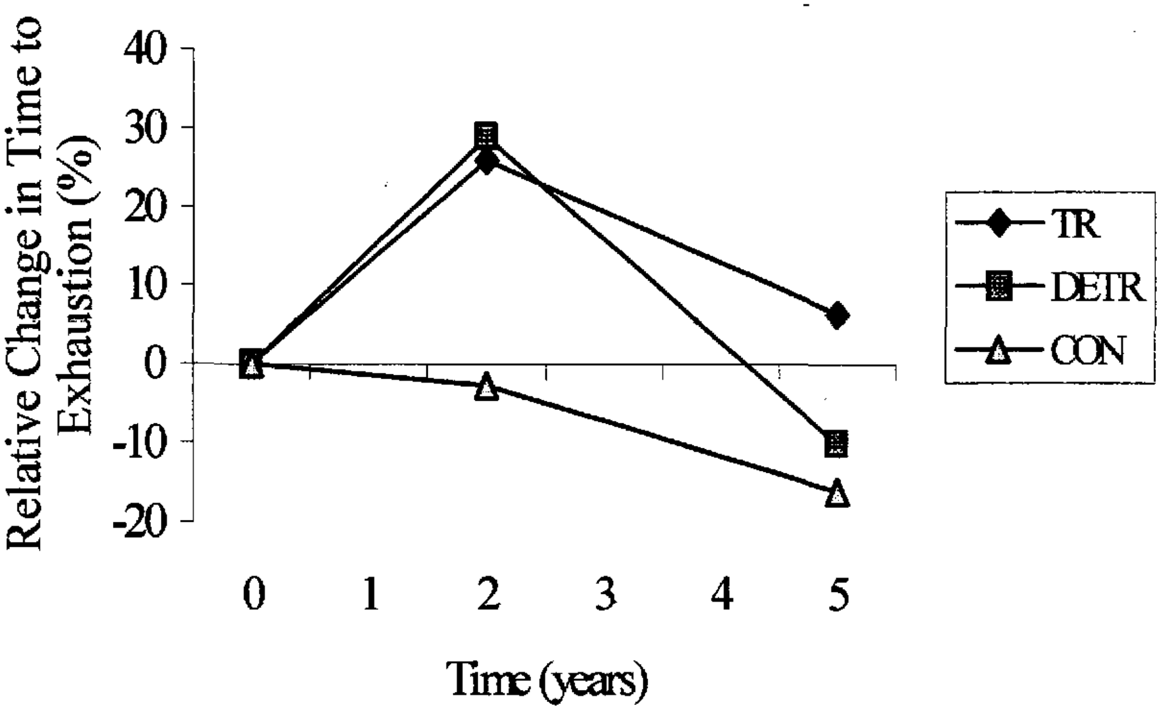

**Figure 9:** Relative change in treadmill time to exhaustion over 5 years.

| | TR | | DETR | | CON | |
|---|---|---|---|---|---|---|
| | **Baseline** | **5 years** | **Baseline** | **5 years** | **Baseline** | **5 years** |
| **TB BMD** | 0.942(0.07) | 1.05(0.25) | 1.038(0.16) | 1.116(0.10) | 1.035(0.13) | 1.143(0.64) |
| (ratio %) | (91.0) | (91.9) | (100.3) | (97.6) | (100) | (100) |
| **TB BMC** | 2310(302) | 1990(226) | 2600(244) | 2264(196) | 2642(422) | 2327(323) |
| (ratio %) | (87.4) | (85.5) | (98.4) | (96.1) | (100) | (100) |
| **LS BMD** | 1.059(0.10) | 0.929(0.10) | 1.174(0.37) | 1.075(0.26) | 1.14(0.19) | 1.05(0.16) |
| (ratio %) | (92.9) | (88.5) | (103.0) | (102.4) | (100) | (100) |
| **LS BMC** | 50.32(2.8) | 44.61(5.3) | 58.95(13.5) | 56.78(11.9) | 55.07(11.0) | 52.42(10.5) |
| (ratio %) | (91.4) | (85.1) | (107.0) | (108.3) | (100) | (100) |

**Table 3.** Mean bone mineral density in g/cm$^2$ (BMD) and bone mineral content in grams (BMC) for the lumbar spine (LS) and the whole body (TB) in each group (training, detraining and control) at baseline and 5 years as mean(SD). The ratio percentage in brackets represent the changes BMD and BMC in the TR and DETR groups as a relation to value of the CON independently at baseline and 5 years.

over to the five year testing time (Table 3). Both the initial and five year data of the DETR and CON groups are quite similar for all bone measures. There is, however, no significant difference between the groups at either baseline or five years as measured cross-sectionally.

# 4.0 DISCUSSION

## 4.1 DYNAMIC STRENGTH

Habitual activity is known to be inversely related to age, with a decline in both occupational and leisure time activities; it is estimated that less than 10% of the adult population in the United States is habitually active in a manner known to induce beneficial physiological adaptations (Aoyagi & Shephard, 1992; Fiatarone and Evans, 1993). The present investigation demonstrates that resistance training over 5 years results in beneficial adaptations in muscle strength, thus helping to counteract the effects of aging on muscle weakness.

### (i) TRAINING

Two-years of high-intensity resistance training resulted in increased strength which was maintained above pre-training values following 3-years of moderate-intensity muscular conditioning. This is consistent with studies demonstrating an increase in muscular strength following both short- (Fiatarone et al., 1990 and 1994; Nichols et al., 1995a and 1995b) and long-term (Pyka et al., 1994) resistance training. This demonstrates that muscle retains the capacity to adapt to exercise training even into the 9th decade of life.

The intensity (percentage of the 1RM) of resistance training was reduced in the training group (TR) which may be the responsible factor for the modest decline in muscular strength between years 2 and 5 for each strength exercise (LP -7.6%, AC –14.2%, BP – 17.8%). The intensity may not have been a large enough stimulus to prevent strength loss and maintain the muscular adaptations resulting from the 2-years of high-intensity strength training (Graves et al., 1988). It has been reported that a reduced training frequency from 3 days per week to as little as 1 day per week at a high-intensity resulted in no significant changes in muscular strength over 12 weeks. This suggests that when the intensity of the resistance training is maintained, training frequency does not affect the maintenance of muscle strength (Graves et al., 1988).

### (ii) DETRAINING

The effect of detraining on skeletal muscle strength in the elderly has not been adequately addressed; very few studies have looked at the magnitude of the change in muscle strength during a time of sedentary living following a period of intense training (particularly resistance training) in the elderly. The present findings demonstrate the effects of 3-years of detraining following 2-years of high-intensity resistance training. After 3-years of detraining, the mean 1RM strength for all exercises remained above pre-training values although this did not reach significance. This trend is similar to that reported by Sforzo and colleagues (1995) where 10 weeks of detraining resulted in a stability of dynamic strength for 5 weeks and then began to decline towards baseline values.

Overall, 3-years of detraining resulted in losses of strength in the order of 29% for upper body and 13% for lower body strength. These results are rather moderate compared to the 32% decline in muscle strength following 4 weeks of detraining in the frail elderly (Fiatarone et al., 1994). The differences in the time course for the decline in strength following resistance training here may be due to the relative fitness of the subjects and the total amount of time spent resistance training to achieve the initial muscular adaptations. The subjects in the present study were all healthy, community dwelling elderly who resistance trained for 2-years at a high-intensity, whereas, Fiatarone et al. (1994) resistance trained frail institutionalized elderly for only 8 weeks. This may suggest that the initial fitness and habitual levels of physical activity of subjects play an important role determining the time course for detraining in the elderly.

The strength decline in the DETR group was accelerated as compared to those who remained resistance training (TR) or those who had never strength trained (CON). These differences can be seen in figures 2 through 7. This is also consistent with the accelerated decline in strength during a period of inactivity following resistance training in the elderly (Fiatarone et al., 1990; Sforzo et al., 1995) and the young (Colliander & Tesch, 1992; Staron et al., 1991). The DETR group remained elevated above their pre-training values even after 3-years of no exercise training suggesting that the longer the initial duration of resistance training, the longer the ability to retain the skeletal muscle adaptations resulting from training (Hortobagyi et al., 1993). Thus, the adaptations to resistance training appear to be maintained longer with longer periods of training.

### (iii) AGING

The group who did not strength train throughout the length of the study may be representative of the effects of aging on muscular strength. Those individuals in the control group (CON) lost upper and lower body strength over the 5-years. The decline in muscular strength as a percentage of baseline strength was slightly greater for the upper body exercises (mean –12%), than the lower body exercises (mean –10%) over the 5 years in the CON group. This trend is consistent with cross-sectional studies which suggest that the age related decline in muscle strength will accelerate with increasing age and that there are systematic differences in the magnitude and rate of strength loss in different muscle groups (Aoyagi &

Shephard, 1992). The rates of decline represented as a relative change in strength per year from years 2-5 were similar in all exercises (AC, BP, LP) between the training and control groups. The rates (table 2) and slopes of decline (figures 2-8) are similar between the TR and DETR groups thus, it may be a true indication of human aging on muscular strength that occur in, and around, the eighth decade of life, regardless of muscular conditioning. This, however, is speculative as the TR group decreased the intensity of resistance training which may not have provided a large enough stimulus to prevent strength loss and maintain the muscular adaptations resulting from 2-years of high-intensity strength training (Graves et al., 1988).

Coggan et al., (1992) suggest that controlling for levels of habitual physical activity in the elderly is of great importance and that comparisons of sedentary and active older individuals is not valid. The subjects in this study were all very similar in their levels of habitual physical activity as measured by the modified Baecke questionnaire for older adults (Table 1), thus negating any possible bias relating to the relative activity of the subjects. The decline in muscle strength may also be related to changes in muscle cross-sectional area with increasing age, however our study did not measure elements of muscle morphology, thus the present findings can neither support or dispute this (Aoyagi & Shephard, 1992).

### 4.2 TREADMILL ENDURANCE

Treadmill endurance was used as a measure of functional capacity in the elderly and demonstrated that strength training, and the resultant changes in muscular strength, may correspond with changes in treadmill endurance. The present data reveal that strength training of high-intensity results in an increased treadmill endurance with no respective increase noted in those subjects who did not train (Figure 8). Following the cessation of high-intensity strength training, there was a general decline in treadmill endurance which closely tracked the decline in leg press strength for the training and detraining groups, but this pattern was not found in the control group (table 2). This supports the findings of McCartney et al. (1995 and 1996) and Sforzo et al. (1995), who concluded that any absolute muscle force after training will require less relative muscular effort from stronger muscles, and will thus be perceived as less demanding and may be tolerated longer. The present findings support this in the fact that the training, detraining, and control groups were not significantly different from each other at the five year testing time for either leg press 1RM strength or for mean treadmill endurance, while their pre-training values indicated a significant difference between the training, detraining, and the control group (highest values) for both these measures respectively. The control group declined the most over the five year time and there was no difference between the groups at the completion of the investigation.

Nichols et al. (1995a), suggests that the age associated decline in functional capacity is directly related to muscle weakness. They found that the increases in muscular strength resulting from high and moderate-intensity resistance training correlated highly with notable increases in both mobility and balance. With an estimated 12% to 16% per decade loss in walking speed on a flat surface after the age of 60, any change in functional capacity resulting from resistance training is both functionally and clinically significant (Nichols et al., 1995). Positive adaptations in functional capacity resulting from resistance training and the concomitant increases in strength have been noted in several investigations, leading to the general conclusion that increased muscular strength and endurance as a result of a resistance training protocol is an important finding and may contribute to the elderly (especially women) maintaining their lifestyles and their ability to complete activities of daily living (Bassey et al., 1988; Fiatarone et al. 1990, 1994; Brown et al., 1995; Sforzo et al., 1995; Trappe et al., 1995; McCartney et al., 1995, 1996).

## 4.3 BONE DENSITY AND CONTENT

Many cross-sectional athlete studies indicate that exercise training may play a beneficial role in increasing bone mass and preventing the onset of osteoporosis (Nilsson and Westlin, 1971). Physical inactivity on the other hand, has a detrimental effect on bone mass in the elderly, with senile bone loss commencing around the 6th decade of life and the rate of loss increasing thereafter. This is comparable to that demonstrated by long periods of weightlessness, as seen in space flight, which results in dramatic decrements in both muscle mass and BMD, suggesting the importance of skeletal loading on bone and muscular health (Aloia, 1981). The findings of this investigation along with the findings of others suggests that resistance training results in relatively few, if any, beneficial adaptations to bone mass. It may however improve coordination and increase muscular strength and thus serve to reduce or prevent the incidence of falls in the elderly.

As there is very little evidence to suggest an improvement in measures of bone density with exercise training, the question of the effects of detraining on bone density also remains unanswered. The few studies which have reported changes in bone density following periods of detraining used strength training of very short duration and extended periods of detraining. Forwood and Burr (1993) found that detraining reduces bone mass back to pre-training values, and concluded that the long term benefits on bone measures are only retained with continuous exercise. Beverly et al (1989) found similar changes following 6 weeks of highly specific wrist training. Here, following 6 months of detraining, there was a subsequent loss in BMC to 2.6% below the women's original baseline values (Beverly et al., 1989). Although it appears that there is some evidence of detraining in these cases, it is difficult to determine whether the decline in bone density reported is that of true detraining or whether it reflects the normal process of bone resorption with increasing age.

The males were significantly different from the females for both BMD and BMC throughout this investigation. The differences in gender were the only significant findings with regards to bone mineral density and content. The males in all groups exhibited considerably greater BMD and BMC of the lumbar spine and whole body with values ranging from 8% to 31% greater (for whole body BMD and lumbar spine BMC) when compared to the females. This is consistent with the literature where males consistently have higher bone mass than females across the age spectrum. The greater bone mass of males compared to females has been attributed to the relatively greater lean body mass of males (Doyle et al., 1970) as well as to greater skeletal stature and a relatively higher level of habitual and occupational physical activity throughout their lifetimes. Our subjects were apparently healthy males and females with relatively high degrees of habitual physical activity, thus the decline in bone mass and bone density in the general population may even be underestimated by our subjects.

Riggs et al. (1986), suggest that the loss in bone is normally about 1.2% per year, however, the rate of this decline may be accelerated in the 7th and 8th decades of life. Christian et al. (1989), found that bone loss is predominantly determined by environmental factors, particularly in men, for whom no genetic influences can be found. This perhaps explains why the proportional magnitude of bone loss was greater in men than in the women for measures of lumbar spine BMD and BMC. This difference however may be due to the relatively greater decline in habitual activity (occupational and leisure) in men than in women as well as to the greater stature of men all leading to the suggestion of enhanced bone loss in women.

## 4.4 SUMMARY

The findings of this investigation suggest that long-term weight lifting training in the elderly is feasible and yields strength and performance benefits well into the 8th decade of life. It also revealed a de novo decline in muscular strength with aging despite continued moderate level resistive exercise training. The findings here suggest that detraining in the elderly is marked by an accelerated decline in muscular dynamic strength which affects functional capacity and treadmill endurance however, the benefits of long-term resistance training are not completely lost even 3-years following cessation of training.

Finally, the present findings suggest that despite the positive skeletal muscle adaptations to long-term resistance training (namely increased muscular strength), bone mass and content are resistant to the effects of loading, and a general decline in BMC and BMD are seen across time in groups that have strength trained for multiple years or in those who did not train at all. The magnitudes of change are similar in all three groups and thus the data suggest that the changes in muscle strength are independent of the changes in bone, which appear to be determined primarily by age.

## 4.5 FUTURE DIRECTIONS

Longitudinal investigations on the effects of resistance training in the elderly are necessary in order to determine the beneficial effects, if any, that exercise in later life has on measures of dependence, quality of life, and psycho-social well-being in an aging population. Studies to determine the mechanisms of strength change in the elderly are also necessary in order to create exercise programs that will produce benefits without creating undue strain on the subjects. Further research is needed to determine the frequency, intensity, and type (resistance, endurance, or a combination) and the duration of training necessary to produce positive changes in muscular strength and endurance in the elderly.

The effects of detraining on muscular strength and endurance need to be studied further; it is necessary to determine the rate of decline in strength and endurance as well as a time course for re-training of muscular strength following a period of detraining or disuse in an elderly population. It is important to establish the requirements necessary for maintaining the adaptations to resistance training in the elderly. The frequency, intensity and duration of the stimulus of resistance training all need to be addressed to properly exercise train older adults to limit the risk of injury and yield the maximum amount of benefit from their exercise.

Further studies on the effects of exercise training on measures of bone integrity are also needed. Future investigations should focus on a holistic approach to exercise in the elderly utilizing both resistance exercise and weight-bearing endurance type exercise to produce changes in bone measures. It appears that research stressing the protective effect of exercise on bone mass late in life would be of greatest benefit rather than those attempting to increase bone mass at a specific site, as has been the focus of previous research. Longitudinal investigations demonstrating the changes in bone mass and density in an elderly male population are also needed as the loss of bone in men may actually occur at a greater rate than previously predicted from cross-sectional studies.

# REFERENCES

Aloia, J.F. Exercise and skeletal health. *Journal of the American Geriatrics Society* 29(3): 104-107, 1981.

Aniansson, A., M. Hedberg, G.B. Henning, and G. Grimby. Muscle morphology, enzymatic activity, and muscle strength in elderly men: a follow-up study. *Muscle & Nerve* 9: 585-591, 1986.

Aniansson, A., G.Grimby, M. Hedberg, and M. Krotkiewski. Muscle morphology, enzyme activity and muscle strength in elderly men and women. *Clinical Physiology* 1: 73-86, 1981.

Aniansson, A., G. Grimby, E. Nygaard, and B. Saltin. Muscle fiber composition and fiber area in various age groups. *Muscle & Nerve* 2: 271-272, 1980.

Aniansson, A., A. Rundgren, and L. Sperling. Evaluation of functional activities of daily living in 70-year-old men and women. *Scandinavian Journal of Rehabilitation Medicine* 12: 145-154, 1980.

Aniansson, A., G. Grimby, M. Hedberg, A. Rundgren, and L. Sperling. Muscle function in old age. *Scandinavian Journal of Rehabilitation Medicine (Suppl)* 6: 43-49, 1978.

Aniansson, A., P. Ljungberg, A. Rundgren, and H. Weltquist. Effect of a training programme for pensioners on condition and muscular strength. *Archives of Gerontology and Geriatrics* 3: 229-241, 1984.

Aniansson, A., and E. Gustavsson. Physical training in elderly men with specific reference to quadriceps muscle strength and morphology. *Clinical Physiology* 1: 87-98, 1981.

Aniansson, A., G. Grimby, and A. Rundgren. Isometric and isokinetic quadriceps muscle strength in 70-year old men and women. *Scandinavian Journal of Rehabilitation Medicine* 12:161-168, 1980.

Aoyagi, Y., and R.J. Shephard. Aging and muscle function. *Sports Medicine* 14(6): 376-396, 1992.

Bassey, E.J., and U.J. Harries. Normal values for handgrip strength in 920 men and women aged over 65 years, and longitudinal changes over 4 years in 620 survivors. *Clinical Science* 84: 331-337, 1993.

Bassey, E.J., M.J. Bendall, and M. Pearson. Muscle strength in the triceps surae and objectively measured customary walking activity in men and women over 65 years of age. *Clinical Science* 74: 85-89, 1988.

Benn, S.J., N. McCartney, and R.S. McKelvie. Circulatory responses to weight lifting, walking, and stair climbing in older males. *Journal of the American Geriatrics Society* 44: 121-125, 1996.

Beverley, M., T.A. Rider, M.J. Evans, and R. Smith. Local bone mineral response to brief exercise that stresses the skeleton. *British Medical Journal* 299: 233-235, 1989.

Blumberg, J., W.L. Kenney, D. Seals, and R. Spina. Exercise and nutrition in the elderly. *Sport Science Exchange* 10(1), 1992.

Booth, F.W., S.H. Weeden, and B.S. Tseng. Effect of aging on human skeletal muscle and motor function. *Medicine and Science in Sports and Exercise* 26(5): 556-560, 1994.

Brathe, N., P. Braillon, D. Ducassou, and B. Basse-Cathalinat. Comparison of two Hologic DXA systems (QDR 1000 and QDR 4500/A). *British Journal of Radiology* 70(835): 728-39, 1997.

Brewer, V., B.M. Meyer, M.S. Keele, J. Upton, and R.D. Hagan. Role of exercise in prevention of involutional bone loss. *Medicine and Science in Sports and Exercise* 15(6): 445-449, 1983.

Brown, W.F. Functional compensation of human motor units in health and disease. *Journal of Neurological Science* 20: 199-209, 1973.

Brown, M., D.R. Sinacore, and H.H. Host. The relationship of strength to function in the older adult. *The Journals of Gerontology: Series A* 50A(Special Issue): 55-59, 1995.

Brown, A.B., N. McCartney, and D.G. Sale. Positive adaptations to weight-lifting training in the elderly. *Journal of Applied Physiology* 69(5): 1725-1733, 1990.

Butterworth, D.E., D.C. Nieman, R. Perkins, B.J. Warren, and R.G. Dotson. Exercise training and nutrient intake in elderly women. *Journal of the American Dietetic Association* 93(6): 653-657, 1993.

Calmels, P., L. Vico, C. Alexandre, and P. Minaire. Cross-sectional study of muscle strength and bone mineral density in a population of 106 women between the ages of 44 and 87 years: relationship with age and menopause. *European Journal of Applied Physiology* 70: 180-186, 1995.

Campbell, M.J., A.J. McComas, and F. Petito. Physiological changes in ageing muscles. *Journal of Neurology, Neurosurgery, and Psychiatry* 36: 174-182, 1973.

Cartee, G.D. Influence of age on skeletal muscle glucose transport and glycogen metabolism. *Medicine and Science in Sports and Exercise* 26(5): 577-585, 1994.

Cartee, G.D. Aging skeletal muscle: response to exericse. *Exerçise and Sport Sciences Reviews* 22: 91-120, 1994.

Casperson, C.J., G.M. Christienson, and R.A. Pollard. Status of the 1990 physical fitness and exercise objectives-evidence from NHIS 1985. *Public Health Reports* 101(6): 587-592, 1986.

Casperson, C.J., A.M. Kriska, and S.R. Dearwater. Physical activity epidemiology as applied to elderly populations. *Bailliere's Clinical Rheumatology* 8(1): 7-27, 1994.

Charette, S.L., L. McEvoy, G. Pyka, C. Snow-Harter, D. Guido, R.A. Wiswell, and R. Marcus. Muscle hypertrophy response to resistance training in older women. *Journal of Applied Physiology* 70(5): 1912-1916, 1991.

Christ, C.B., R.A. Boileau, M.H. Slaughter, R.J. Stillman, J.A. Cameron, and B.H. Massey. Maximal voluntary isometric force production characteristics of six muscle groups in women aged 25 to 74 years. *American Journal of Human Biology* 4: 537-545, 1992.

Coggan, A.R., R.J. Spina, D.S. King, M.A. Rogers, M. Brown, P.M. Nemeth, and J.O. Holloszy. Histochemical and enzymatic comparison of the gastrocnemius muscle of young and elderly men and women. *Journal of Gerontology* 47(3): 871-876, 1992.

Constantini, N.W., and M.P. Warren. Special problems of the female athlete. *Bailliere's Clinical Rheumatology* 8(1): 199-219, 1994.

Cummings, S.R., M.C. Nevitt, W.S. Browner, K. Stone, K.M. Fox, K.E. Ensrud, J. Cauley, D. Black, and T.M. Vogt. Risk factors for hip fracture in white women. *New England Journal of Medicine* 332(12): 767-773, 1995.

Cutler, W.B., E. Friedman, and E. Genovese-Stone. Prevalence of kyphosis in a healthy sample of pre- and postmenopausal women. *American Journal of Physical Medicine and Rehabilitation* 72: 219-225, 1993.

Dalsky, G.P., K.S. Stocke, A.I. Ehsani, E. Slatopolsky, W. Lee, and S.J. Birge. Weight-bearing exercise training and lumbar bone mineral content in post-menopausal women. *Annals of Internal Medicine* 108: 824-828, 1988.

Davies, C.T.M., D.O. Thomas, and M.J. White. Mechanical properties of young and elderly human muscle. *Acta. Medica Scandinavica Supplementum* 711: 219-226, 1986.

Dengel, D.R., J.M. Hagberg, P.J. Coon, D.T. Drinkwater, and A.P. Goldberg. Comparable effects of diet and exercise on body composition and lipoproteins in older men. *Medicine and Science in Sports and Exercise* 26(11): 1307-1315, 1994.

Doherty, T.J., A.A. Vandervoort, and W.F. Brown. Effects of ageing on the motor unit: a brief review. *Canadian Journal of Applied Physiology* 18(4): 331-358, 1993.

Doherty, T.J., A.A. Vandervoort, A.W. Taylor, and W.F. Brown. Effects of motor unit loss on strength in older men and women. *Journal of Applied Physiology* 74(2): 868-874, 1993.

Doyle, F., J. Brown, and C. Lachance. Relation between bone mass and muscle weight. *The Lancet* 1: 391-393, 1970.

Edwards, B.J., and H.M. Perry III. Age-related osteoporosis. *Clinics In Geriatric Medicine* 10(4): 575-588, 1994.

Eiken, P., N. Kolthoff, O. Bärenholdt, F. Hermansen, and S. Pors Nielsen. Switching from DXA pencil-beam to fan-beam. II: Studies in vivo. *Bone*, 15(6): 671-676, 1994.

Ermini, M. Ageing changes in mammalian skeletal muscle. *Gerontology* 22: 301-316, 1976.

Essen-Gustavsson, B., and O. Borges. Histochemical and metabolic characteristics of human skeletal muscle in relation to age. *Acta Physiologica Scandinavica* 126: 107-114, 1986.

Evans, W.J. Reversing sarcopenia: how weight training can build strength and vitality. *Geriatrics* 51(5): 46-53, 1996.

Evans, W.J. Effects of exercise on body compostion and functional capacity of the elderly. *The Journals of Gerontology-Series A* 50A: 147-150, 1995.

Evans, W.J. Exercise, nutrition, and aging. *Clinics in Geriatric Medicine* 11(4): 725-734, 1995.

Evans, W.J. Exercise, nutrition and aging. *Journal of Nutrition* 122: 796-801, 1992.

Faulkner, J.A., S.V. Brooks, and E. Zerba. Muscle atrophy and weakness with aging: contraction-induced injury as an underlying mechanism. *The Journals of Gerontology: Series A* 50A(Special Issue): 124-129, 1995.

Feicht-Sanborn, C. Exercise, calcium, and bone density. *Sports Science Exchange* 24(2), 1990.

Fiatarone, M.A., E.F. O'Neill, N. Doyle, K.M. Clements, S.B. Roberts, J.J. Kehayias, L.A. Lipsitz, and W.J. Evans. The Boston FICSIT Study: the effects of resistance training and nutritional supplementation on physical frailty in the oldest old. *Journal of the American Geriatrics Society* 41(3): 333-337, 1993.

Fiatarone, M.A., E.C. Marks, N.D. Ryan, C.N. Meredith, L.A. Lipsitz, and W.J. Evans. High-intensity strength training in nonagenarians: effects on skeletal muscle. *Journal of the American Medical Association* 263(22): 3029-3034, 1990.

Fiatarone, M.A., E.F. O'Neill, and N.D. Ryan. Elderly gain important benefits from high-intensity exercise. *Geriatrics* 50(1): 56-57, 1995.

Fiatarone, M.A., and W.J. Evans. The etiology and reversibility of muscle dysfunction in the aged. *The Journals of Gerontology* 48: 77-83, 1993.

Fiatarone, M.A., E.F. O'Neil, N.D. Ryan, K.M. Clements, G.R. Solares, M.E. Nelson, S.B. Roberts, J.J. Kehayias, L.A. Lipsitz, and W.J. Evans. Exercise training and nutritional supplementation for physical frailty in very elderly people. *New England Journal of Medicine* 330(25): 1769-1775, 1994.

Fisher, N.M., V.D. Kame, L. Rouse, and D.R. Pendergast. Quantitative evaluation of a home exercise program on muscle and functional capacity of patients with arthritis. *American Journal of Physical Medicine and Rehabilitation* 73: 413-420, 1994.

Forwood, M.R., and D.B. Burr. Physical activity and bone mass: exercises in futility? *Bone and Mineral* 21: 89-112, 1993.

Frontera, W.R., C.N. Meredith, K.P. O'Reilly, and W.J. Evans. Strength training and determinants of $VO_{2max}$ in older men. *Journal of Applied Physiology* 68(1): 329-333, 1990.

Frontera, W.R., V.A. Hughes, K.J. Lutz, and W.J. Evans. A cross-sectional study of muscle strength and mass in 45- to 78-year old men and women. *Journal of Applied Physiology* 71(2): 644-650, 1991.

Frontera, W.R., C.N. Meredith, K.P. O'Reilly, H.G. Knuttgen, and W.J. Evans. Strength conditioning in older men: skeletal muscle hypertrophy and improved function. *Journal of Applied Physiology* 64(3): 1038-1044, 1988.

Gitlin, L.N., M.P. Lawton, L. A. Windsor-Landsberg, M.H. Kleban, L.P. Sands, and J. Posner. In search of psychological benefits: exercise in healthy older adults. *Journal of Aging and Health* 4(2): 174-192, 1992.

Green, J.S., and S.F. Crouse. The effects of endurance training on functional capacity in the elderly: a meta-analysis. *Medicine and Science in Sports and Exercise* 27(6): 920-926, 1995.

Green, J. S., and S.F. Crouse. Endurance training, cardiovascular function and the aged. *Sports Medicine* 16(5): 331-341, 1993.

Grimby, G. Muscle performance and structure in the elderly as studied cross-sectionally and longitudinally. *The Journals of Gerontology Series A* 50A(Special Issue): 17-22, 1995.

Gunby, M.C., and J.E. Morely. Epidemiology of bone loss with aging. *Clinics in Geriatric Medicine* 10(4): 557-574, 1994.

Handorf, P.A., R.T. Withers, R.K. Penhall, and J.L. Plummer. A follow-up study on the effects of training on the fitness and habitual activity patterns of 60- to 70-year-old women. *Archives of Physical medicine and Rehabilitation* 74: 473-477, 1993.

Hickson, R.C., K. Hidaka, and C. Foster. Skeletal muscle fibre type, resistance training, and strength-related performance. *Medicine and Science in Sports and Exercise* 26(5): 593-598, 1994.

Hurley, B.F. Age, gender, and muscular strength. *The Journals of Gerontology: Series A* 50A(Special Issue): 41-44, 1995.

Kallinen, M., and A. Markku. Aging, physical activity and sports injuries. *Sports Medicine* 20(1): 41-52, 1995.

Kenney, W.L. The older athlete: exercise in hot environments. *Sports Science Exchange* 6(3):44, 1993.

Klitgaard, H., and T. Clausen. Increased total concentration of Na-K pumps in vastus lateralis muscle of old trained human subjects. *Journal of Applied Physiology* 67(6): 2491-2494, 1989.

Krolner, B., and S. P. Nielsen. Bone mineral content of the lumbar spine in normal and osteoporotic women: cross-sectional and longitudinal studies. *Clinical Science* 62: 329-336, 1982.

Laforest, S., D. M.M. St-Pierre, J. Cyr, and D. Gayton. Effects of age and regular exercise on muscle strength and endurance. *European Journal of Applied Physiology* 60:104-111, 1990.

Larsson, L. Histochemical characteristics of human skeletal muscle during aging. *Acta. Physiologica Scandinavica* 117: 469-471, 1983.

Larsson, L., G. Grimby, and J. Karlsson. Muscle strength and speed of movement in relation to age and muscle morphology. *Journal of Applied Physiology* 46(3): 451-456, 1979.

Leveille, S.G., and A.Z. LaCroix. Exercise training for very elderly people. *The New England Journal of Medicine* 331(18): 1237-1238, 1994.

Lexell, J., C.C. Taylor, and M. Sjostrom. What is the cause of ageing atrophy? Total number, size and proportion of different fiber types studied in whole vastus lateralis muscle from 15- to 83-year-old men. *Journal of Neurological Sciences* 84: 275-294, 1988.

Lexell, J. Ageing and human muscle: observations from Sweden. *Canadian Journal of Applied Physiology* 18(1): 2-18, 1993.

Lexell, J. Human aging, muscle mass, and fibre type composition. *The Journals of Gerontology Series A* 50A(Special Issue): 11-16, 1995.

Lexell, J., D.Y. Downham, Y. Larsson, E. Bruhn, and B. Morsing. Heavy-resistance training in older Scandinavian men and women: short- and long-term effects on arm and leg muscles. *Scandinavian Journal of Medicine and Science in Sports* 5(6): 329-341, 1995.

Madsen, O.R., H. Bliddal, C. Egsmose, and J. Sylvest. Isometric and isokinetic quadricceps strength in gonarthrosis; inter-relations between quadriceps strength, walking ability, radiology, subchondral bone density, and pain. *Clinical Rheumatology* 14(3): 308-314, 1995.

Marcus, R. Relationship of age-related decreases in muscle mass and strength to skeletal status. *The Journals of Gerontology: Series A* 50A(Special Issue): 86-87, 1995.

Mazzeo, R.S. The influence of exercise and aging on immune function. *Medicine and Science in Sports and Exercise* 26(5): 586-592, 1994.

McCartney, N., A.L. Hicks, J. Martin, and C.E. Webber. Long-term resistance training in the elderly: effects on dynamic strength, exercise capacity, muscle, and bone. *Journal of Gerontology: Biological Sciences* 50A(2): B97-B104, 1995.

McCartney, N., A.L. Hicks, J. Martin, and C.E. Webber. A longitudinal trial of weight training in the elderly: continued improvements in year 2. *Journal of Gerontology: Biological Sciences* 51A(6): B425-B433, 1996.

McClaran, S.R., M.A. Babcock, D.F. Pegelow, W.G. Reddan, and J.A. Dempsey. Longitudinal effects of aging on lung function at rest and exercise in healthy active fit elderly adults. *Journal of Applied Physiology* 78(5): 1957-1968, 1995.

McComas, A.J. Motor unit estimation: methods, results, and present status. *Muscle & Nerve*. 14(July):585-597, 1991.

Miller, A.E.J., J.D. MacDougall, M.A. Tarnopolsky, and D.G. Sale. Gender differences in strength and muscle fiber characteristics. *European Journal of Applied Physiology* 66: 254-262, 1993.

Naessen, T., I. Persson, L. Thor, H. Mallmin, S. Ljunghall, and R. Bergstrom. *British Journal of Obstetrics and Gynecology* 100(May): 454-459, 1993.

Nelson, M.E., M.A. Fiatarone, C.M. Morganti, I. Trice, R.A. Greenberg, and W.J. Evans. Effects of high-intensity strength training on multiple risk factors for osteoporotic fractures. *Journal of the American Medical Association* 272(24): 1909-1914, 1994.

Nelson, D., M. Feingold, E. Mascha, and M. Kleerekoper. Comparison of single-photon and dual-energy x-ray absorptiometry of the radius. *Bone and Mineral*, 18: 77-83. 1992.

Nichols, J.F., K.P. Nelson, K.K. Peterson, and D.J. Sartoris. Bone mineral density responses to high-intensity strength training in active older women. *Journal of Aging and Physical Activity* 3(1): 26-38, 1995.

Nichols, J.F., L.M. Hitzelberger, J.G. Sherman, and P.Patterson. Effects of resistance training on muscular strength and functional abilities of community-dwelling older adults. *Journal of Aging and Physical Activity* 3(3):238-250, 1995.

Nilsson, B.E. and N.E. Westlin. Bone density in athletes. *Clinical Orthopaedics and Related Research* 77(June): 179-182, 1971.

Notelovitz, M., D. Martin, R. Tesar, F.Y. Khan, C. Probart, C. Fields, and L. McKenzie. Estrogen therapy and variable resistance weight training increase bone mineral in surgically menopausal women. *Journal of Bone and Mineral Research* 6(6): 583-590, 1991.

Overend, T.J., D.A. Cunningham, D.H.Patterson, and M.S. Lefcoe. Thigh compostition in young and elderly men determined by computed tomography. *Clinical Physiology* 12: 629-640, 1992.

Posner, J.D., K.M. Gorman, L. Windsor-Landsberg, J. Larsen, M. Bleiman, C.Shaw, B. Rosenberg, and J. Knebl. Low to moderate intensity endurance training in healthy older adults: physiological responses after four months. *Journal of the American Geriatrics Society* 40(3): 1-7, 1992.

Province, M.A., E.C. Hadley, M.C. Hornbrook, L.A. Lipsitz, J.P. Miller, C.D. Mulrow, M.G. Ory, R. W. Sattin, M.E. Tinetti, and S.L. Wolf. *Jornal of the American Medical Association* 273(17): 1341-1347, 1995.

Pruitt, L.S., R.D. Jackson, R.L. Bartels, and H.J. Lehnhard. Weight-training effects on bone mineral density in early postmenopausal women. *Journal of Bone and Mineral Research* 7: 280-285, 1992.

Pyka, G., E. Lindenberger, S. Charette, and R. Marcus. Muscle strength and fiber adaptations to a year-long resistance training program in elderly men and women. *The Journals of Gerontology: Medical Sciences* 49(1): M22-M27, 1994.

Reed, R.L., L. Pearlmutter, K. Yochum, K.E. Meredith, and A.D. Mooradian. The relationship between muscle mass and muscle strength in the elderly. *Journal of the American Geriatrics Society* 39(6): 555-561, 1991.

Reid, I.R., M. Legge, J.P. Stapleton, M.C. Evans, and A.B. Grey. Regular exercise dissociates fat mass and bone density in premenopausal women. *Journal of Clinical Endocrinology and Metabolism* 80(6): 1764-1768, 1995.

Rice, C.L., D.A. Cunningham, D. H. Paterson, and J.R. Dickinson. Strength training alters contractile properties of the triceps brachii in men aged 65-78 years. *European Journal of Applied Physiology* 66: 275-280, 1993.

Rice, C.L., D.A. Cunningham, D.H. Paterson, and P.A. Rechnitzer. Strength in an elderly population. *Archives in Physical Medicine and Rehabilitation* 70: 391-397, 1989.

Riggs, B.L., H.W. Wahner, E. Seeman, K.P. Offord, W.L. Dunn, R.B. Mazess, K.A. Johnson, and L.J. Melton. Changes in bone mineral density of the proximal femur and spine with aging. *Journal of Clinical Investigation* 70: 717-723, 1982.

Riggs, B.L., H.W. Wahner, W.L. Dunn, R.B. Mazess, K.P. Offord and L.J. Melton. Differential changes in bone mineral density of the appendicular and axial skeleton with aging; relationship to spinal osteoporosis. *Journal of Clinical Investigation* 67: 328-335, 1981.

Riggs, B.L., H.W. Wahner, L.J. Melton, L.S. Richelson, H.L. Judd, and K.P. Offord. Rates of bone loss in the appendicular and axial skeletons of women; evidence of substantial vertebral bone loss before menopause. *Journal of Clinical Investigation* 77: 1487-1491, 1986.

Riggs, B.L., and L.J. Melton. Involutional osteoporosis. *The New England Journal of Medicine* 314(26): 1676-1686, 1986.

Rogers, M.A., and W.J. Evans. Changes in skeletal muscle with aging: effects of exrcise training. *Exercise and Sport Science Reviews* 26: 65-102, 1992.

Sale, D.G. Neural adaptation to resistance training. *Medicine and Science in Sport and Exercise* 20(suppl): S135-S145, 1988.

Seeman, E., J.L. Hopper, N.R. Young, C. Formica, P. Goss, and C. Tsalamandris. Do genetic factors explain associations between muscle strength, lean mass, and bone density? A twin study. *American Journal of Physiology (Endocrinology, Metabolism)* 270(33): E320-E327, 1996.

Shephard, R.J., and P.N. Shek. Exercise, aging, and immune function. *International Journal of Sports Medicine* 16(1): 1-6, 1995.

Silvestri, G.A., and D.A. Mahler. Evaluation of dyspnea in the elderly patient. *Clinics in Chest Medicine* 14(3): 393-404, 1993.

Simkin, A., J. Ayalon, and I. Leichter. Increased trabecular bone density due to bone loading exercises in post-menopausal osteoporotic women. *Calcified Tissue International* 40: 59-63, 1987.

Sinaki, M., M.C. McPhee, S.F. Hodgson, J.M. Merritt, and K.P. Offord. Relationship between bone mineral density of spine and strength of back extensors in healthy postmenopausal women. *Mayo Clinic Proceedings* 61: 116-122, 1986.

Sipila, S. J. Viitasalo, P. Era, and H. Suominen. Muscle strength in male athletes aged 70-81 years and a population sample. *European Journal of Applied Physiology* 63: 399-403, 1991.

Slemenda, C.W. Body composition and skeletal density- mechanical loading or something more? *Journal of Clinical Endocrinology and Metabolism* 80(5): 1761-1763, 1995.

Smidt, G.L., S.Y. Lin, K.D. O'Dwyer, and P. R. Blanpied. The effect of high-intensity trunk exercise on bone mineral density of post-menopausal women. *Spine* 17: 280-285, 1992.

Spence, A.P. Biology of Human Aging. Prentice Hall: New Jersey, 1989.

Spina, R.J., R.E. Bourey, T. Ogawa, and A.A. Ehsani. Effects of exercise training on α-adrenergic mediated pressor responses and baroreflex function in older subjects. *The Journals of Gerontology: Biological Sciences* 49(6): B277-B281, 1994.

Staron, R.S., M.J. Leonardi, D.L. Karapondo, E.S. Malicky, J.E. Falkel, F.C. Hagerman, and R.S. Hikida. Strength and skeletal muscle adaptations in heavy-resistance trained women after detraining and retraining. *Journal of Applied Physiology* 70(2): 631-640, 1991.

Staron, R.S., E.S. Malicky, M.J. Leonardi, J.E. Falkel, F.C. Hagerman, and G.A. Dudley. Muscle hypertrophy and fast fiber type conversions in heavy resistance-trained women. *European Journal of Applied Physiology* 60: 71-79, 1989.

Suominen, H. Bone mineral density and long term exercise. *Sports Medicine* 16(5): 316-330, 1993.

Tate, C.A., M.F. Hyek, and G.E. Taffet. Mechanisms for the responses of cardiac muscle to physical activity in old age. *Medicine and Science in Sports and Exercise* 26(5): 561-567, 1994.

Thompson, L.V. Effects of age and training on skeletal muscle physiology and performance. *Physical Therapy* 74(1): 71-81, 1994.

Tinetti, M.E., D.I. Baker, P.A. Garrett, C.M. Gottschalk, M.L. Koch, and R.I. Horwitz. Yale Ficsit: risk factor abatement strategy for fall prevention. *Journal of the American Geriatrics Society* 41(3): 315-320, 1993.

Torgerson, D.J., M.K. Campbell, and D.M. Reid. Life-style, environmental and medical factors influencing peak bone mass in women. *British Journal of Rheumatology* 34: 620-624, 1995.

Tothill, P., A. Avenell, and D.M. Reid. Precision and accuracy measurements of whole-body bone and mineral: comparisons between Hologic, Lunar and Norland dual-energy x-ray absorptiometers. *The British Journal of Radiology*, 67: 1210-1217, 1994.

Trappe, S.W., D.L. Costill, W.J. Fink, and D.R. Pearson. Skeletal muscle characteristics among distance runners: a 20-yr follow-up study. *Journal of Applied Physiology* 78(3): 823-829, 1995.

Tseng, B.S., D.R. Marsh, M.T. Hamilton, and F.W. Booth. Strength and aerobic training attenuate muscle wasting and improve resistance to the development of disability with aging. *The Journals of Gerontology: Series A* 50A(Special Issue): 113-119, 1995.

Tzankoff, S.P., and A.H. Norris. Effect of muslce mass decrease on age-related BMR changes. *Journal of Applied Physiology* 43(6): 1001-1006, 1977.

Vandervoort, A.A. Effects of ageing on human neuromuscular function: implications for exercise. *Canadian Journal of Sport Science* 17(3): 178-184, 1992.

Voorrips, L.E., A.C.J. Ravelli, P.C.A. Dongelmans, P. Deurenberg, and W.A. Van Staveren. A physical activity questionnaire for the elderly. *Medicine and Science in Sports and Exercise* 23: 974-979, 1991.

Wang, H.Y., T.R. Bashore, and E. Friedman. Exercise reduces age-dependent decrease in platelet protein kinase C activity and translocation. *Journal of Gerontology: Medical Sciences* 50A(1): M12-M16, 1995.

Ward, J. Exercise and the older person. *Australian Family Physician* 23(4): 642-649, 1994.

Winegard, K.J., A.L. Hicks, D.G. Sale, A.A. Vandervoort. A 12-year follow-up study of ankle muscle function in older adults. *Journal of Gernontology: Biological Sciences* 51A: B202-B207, 1996.

Wolf, S.L., N.G. Kutner, R.C. Green, and E. McNeely. The Atlanta FICSIT study: two exercise interventions to reduce frailty in elders. *Journal of the American Geriatrics Society* 41(3): 329-332, 1993.

Wolfson, L., R. Whipple, J. Judge, P. Amerman, C. Derby, nd M. King. Training balance and strength in the elderly to improve function. *Journal of the American Geriatrics Society* 41(3): 341-343, 1993.

# Appendix A:

## Subject Characteristics

**Subject Characteristics**

| Subject | Gender | Age | Age(yr) | Height (cm) | Weight (kg) | PAH-Q |
|---|---|---|---|---|---|---|
| A1 | 1 | 2 | 70 | 166.25 | 55.7 | 12.3 |
| A2 | 1 | 2 | 79 | 158.75 | 52.3 | 9.12 |
| A3 | 1 | 2 | 80 | 166.25 | 70.9 | 15.7 |
| A4 | 1 | 2 | 81 | 158.75 | 49.6 | 25.8 |
| A5 | 1 | 2 | 77 | 147.50 | 80.9 | 12.5 |
| A6 | 2 | 2 | 70 | 176.25 | 64.5 | 14.5 |
| A7 | 2 | 1 | 75 | 165.00 | 68.2 | 10.5 |
| A8 | 2 | 2 | 70 | 173.00 | 80.0 | 5.34 |
| A9 | 2 | 2 | 74 | 167.50 | 70.7 | 30.7 |
| A10 | 2 | 2 | 73 | 165.00 | 83.2 | 11.4 |
| B1 | 2 | 2 | 76 | 174.40 | 80.1 | 5.89 |
| B2 | 2 | 1 | 67 | 168.75 | 83.6 | 34.5 |
| B3 | 2 | 2 | 70 | 173.75 | 87.3 | 19.2 |
| B4 | 2 | 2 | 78 | 172.50 | 85.9 | 9.20 |
| B5 | 2 | 2 | 70 | 175.00 | 90.9 | 10.5 |
| B6 | 1 | 2 | 73 | 149.50 | 54.5 | 4.11 |
| B7 | 1 | 2 | 71 | 162.50 | 75.0 | 4.10 |
| B8 | 1 | 1 | 69 | 160.00 | 55.9 | 14.6 |
| B9 | 1 | 2 | 74 | 164.40 | 65.7 | 16.0 |
| B10 | 1 | 2 | 75 | 153.80 | 82.5 | 9.00 |
| C1 | 2 | 2 | 74 | 176.25 | 73.2 | 13.8 |
| C2 | 2 | 1 | 68 | 177.50 | 95.5 | 9.60 |
| C3 | 2 | 1 | 69 | 165.00 | 82.7 | 4.55 |
| C4 | 2 | 1 | 67 | 173.80 | 83.2 | 27.9 |
| C5 | 2 | 1 | 68 | 160.00 | 67.3 | 29.2 |
| C6 | 1 | 2 | 70 | 161.30 | 97.3 | 13.0 |
| C7 | 1 | 2 | 74 | 145.00 | 60.9 | 17.7 |
| C8 | 1 | 2 | 70 | 161.90 | 70.0 | 12.7 |
| C9 | 1 | 2 | 75 | 148.80 | 82.7 | 14.6 |
| C10 | 1 | 1 | 67 | 156.30 | 54.5 | 7.00 |

# Appendix B:

## Raw Data

## Bilateral Bench Press

| | | | Baseline | 2 years | Change(0-2) | | 5 years | Change (2-5) | | Change(0-5) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject | Gender | Age | | | abs | % | | abs | % | abs | % |
| A1 | 1 | 2 | 15 | 28.75 | 13.8 | 91.67 | 30 | 1.25 | 4.35 | 15 | 100 |
| A2 | 1 | 2 | 17.5 | 33.75 | 16.3 | 92.86 | 31.5 | -2.25 | -6.67 | 14 | 80 |
| A3 | 1 | 2 | 22.5 | 35 | 12.5 | 55.56 | 30 | -5 | -14.3 | 7.5 | 33.3 |
| A4 | 1 | 2 | 22.5 | 28.75 | 6.25 | 27.78 | 20 | -8.75 | -30.4 | -2.5 | -11.1 |
| A5 | 1 | 2 | 22.5 | 41.25 | 18.8 | 83.33 | 36.25 | -5 | -12.1 | 13.75 | 61.1 |
| A6 | 2 | 2 | 37.5 | 47.5 | 10 | 26.67 | 37.5 | -10 | -21.1 | 0 | 0 |
| A7 | 2 | 1 | 45 | 70 | 25 | 55.56 | 42.5 | -27.5 | -39.3 | -2.5 | -5.56 |
| A8 | 2 | 2 | 60 | 97.5 | 37.5 | 62.5 | 92.53 | -4.97 | -5.1 | 32.53 | 54.2 |
| A9 | 2 | 2 | 30 | 51.25 | 21.3 | 70.83 | 42.5 | -8.75 | -17.1 | 12.5 | 41.7 |
| A10 | 2 | 2 | 42.5 | 47.5 | 5 | 11.76 | 35 | -12.5 | -26.3 | -7.5 | -17.6 |
| B1 | 2 | 2 | 46 | 65 | 19 | 41.3 | 50 | -15 | -23.1 | 4 | 8.7 |
| B2 | 2 | 1 | 45 | 90 | 45 | 100 | 67 | -23 | -25.6 | 22 | 48.9 |
| B3 | 2 | 2 | 45 | 71.25 | 26.3 | 58.33 | 50 | -21.3 | -29.8 | 5 | 11.1 |
| B4 | 2 | 2 | 52.5 | 67.5 | 15 | 28.57 | 55 | -12.5 | -18.5 | 2.5 | 4.76 |
| B5 | 2 | 2 | 67.5 | 83.75 | 16.3 | 24.07 | 37.5 | -46.3 | -55.2 | -30 | -44.4 |
| B6 | 1 | 2 | 24 | 35 | 11 | 45.83 | 25 | -10 | -28.6 | 1 | 4.17 |
| B7 | 1 | 2 | 21 | 27.5 | 6.5 | 30.95 | 15 | -12.5 | -45.5 | -6 | -28.6 |
| B8 | 1 | 1 | 25 | 32.5 | 7.5 | 30 | 22.5 | -10 | -30.8 | -2.5 | -10 |
| B9 | 1 | 2 | 15 | 33.75 | 18.8 | 125 | 22.5 | -11.3 | -33.3 | 7.5 | 50 |
| B10 | 1 | 2 | 22.5 | 38.75 | 16.3 | 72.22 | 32.5 | -6.25 | -16.1 | 10 | 44.4 |
| C1 | 2 | 2 | 45 | 47.5 | 2.5 | 5.556 | 52.5 | 5 | 10.5 | 7.5 | 16.7 |
| C2 | 2 | 1 | 52.5 | 52.5 | 0 | 0 | 40 | -12.5 | -23.8 | -12.5 | -23.8 |
| C3 | 2 | 1 | 60 | 60 | 0 | 0 | 50 | -10 | -16.7 | -10 | -16.7 |
| C4 | 2 | 1 | 52.5 | 53.75 | 1.25 | 2.381 | 45 | -8.75 | -16.3 | -7.5 | -14.3 |
| C5 | 2 | 1 | 52.5 | 52.5 | 0 | 0 | 42.5 | -10 | -19 | -10 | -19 |
| C6 | 1 | 2 | 25 | 26.25 | 1.25 | 5 | 27.5 | 1.25 | 4.76 | 2.5 | 10 |
| C7 | 1 | 2 | 30 | 32.5 | 2.5 | 8.333 | 25 | -7.5 | -23.1 | -5 | -16.7 |
| C8 | 1 | 2 | 32.5 | 31.5 | -1 | -3.08 | 27.5 | -4 | -12.7 | -5 | -15.4 |
| C9 | 1 | 2 | 22.5 | 33.75 | 11.3 | 50 | 27.5 | -6.25 | -18.5 | 5 | 22.2 |
| C10 | 1 | 1 | 22.5 | 26.5 | 4 | 17.78 | 22.5 | -4 | -15.1 | 0 | 0 |

## Unilateral Leg Press

| | | | Baseline | | | 2 Years | | | Change (0-2yr) | | 5 years | | | Change (2-5yr) | | Change (0-5yr) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject | Gender | Age | Right | Left | Sum | Right | Left | Sum | abs | % | Right | Left | Sum | abs | % | abs | % |
| A1 | 1 | 2 | 60 | 60 | 120 | 75.00 | 70.00 | 145.0 | 25.00 | 20.83 | 65.00 | 65.00 | 130.0 | -15.00 | -10.34 | 10.0 | 8.33 |
| A2 | 1 | 2 | 43 | 42.5 | 85 | 56.3 | 55.00 | 111.25 | 26.25 | 30.88 | 52.50 | 50.00 | 102.5 | -8.750 | -7.865 | 17.5 | 20.6 |
| A3 | 1 | 2 | 55 | 55 | 110 | 56.3 | 61.25 | 117.5 | 7.500 | 6.818 | 60.00 | 60.00 | 120.0 | 2.500 | 2.128 | 10.0 | 9.09 |
| A4 | 1 | 2 | 45 | 45 | 90 | 66.3 | 61.25 | 127.5 | 37.50 | 41.67 | 55.00 | 55.00 | 110.0 | -17.50 | -13.73 | 20.0 | 22.2 |
| A5 | 1 | 2 | 65 | 65 | 130 | 100.0 | 82.50 | 182.5 | 52.50 | 40.38 | 85.00 | 75.00 | 160.0 | -22.50 | -12.33 | 30.0 | 23.1 |
| A6 | 2 | 2 | 70 | 70 | 140 | 78.8 | 78.75 | 157.5 | 17.50 | 12.50 | 72.50 | 72.50 | 145.0 | -12.50 | -7.937 | 5.0 | 3.57 |
| A7 | 2 | 1 | 93 | 100 | 193 | 115.0 | 113.8 | 228.75 | 36.25 | 18.83 | 100.0 | 95.00 | 195.0 | -33.75 | -14.75 | 2.5 | 1.30 |
| A8 | 2 | 2 | 95 | 90 | 185 | 125.0 | 125.0 | 250.0 | 65.00 | 35.14 | 122.5 | 120.0 | 242.5 | -7.500 | -3.000 | 57.5 | 31.1 |
| A9 | 2 | 2 | 63 | 62.5 | 125 | 93.8 | 88.75 | 182.5 | 57.50 | 46.00 | 82.50 | 75.00 | 157.5 | -25.00 | -13.70 | 32.5 | 26.0 |
| A10 | 2 | 2 | 53 | 55 | 108 | 72.50 | 62.50 | 135.0 | 27.50 | 25.58 | 76.25 | 62.50 | 138.8 | 3.750 | 2.778 | 31.3 | 29.1 |
| B1 | 2 | 2 | 93 | 92.5 | 185 | 120 | 115 | 235.0 | 50.00 | 27.03 | 95.00 | 95.0 | 190 | -45 | -19.1 | 5.00 | 2.70 |
| B2 | 2 | 1 | 70 | 70 | 140 | 103 | 102.5 | 205.0 | 65.00 | 46.43 | 95.00 | 100 | 195 | -10 | -4.88 | 55.0 | 39.3 |
| B3 | 2 | 2 | 75 | 70 | 145 | 110 | 107.5 | 217.5 | 72.50 | 50.00 | 85.00 | 85.0 | 170 | -47.5 | -21.8 | 25.0 | 17.2 |
| B4 | 2 | 2 | 70 | 75 | 145 | 105 | 103.8 | 208.75 | 63.75 | 43.97 | 97.50 | 100 | 198 | -11.25 | -5.39 | 52.5 | 36.2 |
| B5 | 2 | 2 | 100 | 100 | 200 | 138 | 126.3 | 263.75 | 63.75 | 31.88 | 105.0 | 100 | 205 | -58.75 | -22.3 | 5.00 | 2.50 |
| B6 | 1 | 2 | 55 | 52.5 | 108 | 61.3 | 58.75 | 120.0 | 12.50 | 11.63 | 55.00 | 50.0 | 105 | -15 | -12.5 | -2.50 | -2.33 |
| B7 | 1 | 2 | 60 | 50 | 110 | 72.5 | 62.5 | 135.0 | 25.00 | 22.73 | 62.50 | 55.0 | 118 | -17.5 | -13.0 | 7.50 | 6.82 |
| B8 | 1 | 1 | 65 | 60 | 125 | 65 | 65.0 | 130.0 | 5.000 | 4.000 | 60.00 | 57.25 | 117 | -12.75 | -9.81 | -7.75 | -6.20 |
| B9 | 1 | 2 | 43 | 42.5 | 85 | 62.5 | 62.5 | 125.0 | 40 | 47.06 | 52.50 | 55.0 | 108 | -17.5 | -14.0 | 22.5 | 26.5 |
| B10 | 1 | 2 | 55 | 55 | 110 | 73.8 | 73.75 | 147.5 | 37.5 | 34.09 | 66.25 | 65.0 | 131 | -16.25 | -11.0 | 21.3 | 19.3 |
| C1 | 2 | 2 | 80 | 80 | 160 | 70 | 75 | 145 | -15 | -9.38 | 77.25 | 77.25 | 155 | 9.5 | 6.552 | -5.5 | -3.44 |
| C2 | 2 | 1 | 105 | 103 | 208 | 105 | 95 | 200 | -7.5 | -3.61 | 95 | 92.5 | 188 | -12.5 | -6.25 | -20 | -9.64 |
| C3 | 2 | 1 | 110 | 113 | 223 | 103 | 102.5 | 205 | -17.5 | -7.87 | 92.5 | 95 | 188 | -17.5 | -8.537 | -35 | -15.7 |
| C4 | 2 | 1 | 100 | 100 | 200 | 90 | 82.5 | 172.5 | -27.5 | -13.8 | 90 | 75 | 165 | -7.5 | -4.348 | -35 | -17.5 |
| C5 | 2 | 1 | 95 | 101 | 196 | 82.5 | 92.5 | 175 | -20.5 | -10.5 | 82.5 | 90 | 173 | -2.5 | -1.429 | -23 | -11.76 |
| C6 | 1 | 2 | 72 | 65 | 137 | 73.8 | 73.75 | 147.5 | 10.5 | 7.664 | 60 | 60 | 120 | -27.5 | -18.64 | -17 | -12.41 |
| C7 | 1 | 2 | 75 | 70 | 145 | 55 | 60 | 115 | -30.2 | -20.8 | 50 | 47.5 | 97.5 | -17.5 | -15.22 | -47.7 | -32.85 |
| C8 | 1 | 2 | 55 | 55 | 110 | 55 | 55 | 110 | 0 | 0 | 50 | 50 | 100 | -10 | -9.091 | -10 | -9.091 |
| C9 | 1 | 2 | 40 | 40 | 80 | 62.5 | 57.5 | 120 | 40 | 50 | 50 | 50 | 100 | -20 | -16.67 | 20 | 25 |
| C10 | 1 | 1 | 50 | 50 | 100 | 50 | 47.5 | 97.5 | -2.5 | -2.5 | 45 | 45 | 90 | -7.5 | -7.692 | -10 | -10 |

## Unilateral Arm Curl

| | | | Baseline | | | 2 Years | | | Change (0-2yr) | | 5 years | | | Change (2-5yr) | | Change (0-5yr) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject | Gender | Age | Right | Left | Sum | Right | Left | Sum | abs | % | Right | Left | Sum | abs | % | abs | % |
| A1 | 1 | 2 | 5.75 | 6.60 | 12.35 | 9.50 | 9.60 | 19.10 | 6.75 | 54.66 | 8.750 | 8.10 | 16.85 | -2.25 | -11.78 | 4.5 | 36.44 |
| A2 | 1 | 2 | 4.25 | 3.60 | 7.850 | 8.00 | 7.35 | 15.35 | 7.50 | 95.54 | 7.250 | 6.60 | 13.85 | -1.50 | -9.772 | 6 | 76.43 |
| A3 | 1 | 2 | 6.50 | 5.85 | 12.35 | 11.75 | 9.60 | 21.35 | 9.00 | 72.87 | 11.00 | 11.1 | 22.10 | 0.75 | 3.513 | 9.75 | 78.95 |
| A4 | 1 | 2 | 6.50 | 5.85 | 12.35 | 11.0 | 9.60 | 20.60 | 8.25 | 66.8 | 11.00 | 8.10 | 19.10 | -1.50 | -7.282 | 6.75 | 54.66 |
| A5 | 1 | 2 | 5.75 | 6.60 | 12.35 | 8.00 | 8.85 | 16.85 | 4.50 | 36.44 | 6.500 | 7.35 | 13.85 | -3.00 | -17.8 | 1.5 | 12.15 |
| A6 | 2 | 2 | 11.0 | 11.1 | 22.10 | 21.75 | 22.95 | 44.70 | 22.60 | 102.3 | 16.25 | 15.6 | 31.85 | -12.9 | -28.75 | 9.75 | 44.12 |
| A7 | 2 | 1 | 13.3 | 11.1 | 24.35 | 26.75 | 28.85 | 55.70 | 31.35 | 128.7 | 16.25 | 15.6 | 31.85 | -23.9 | -42.82 | 7.5 | 30.80 |
| A8 | 2 | 2 | 14.0 | 12.6 | 26.60 | 46.25 | 36.35 | 82.60 | 56.00 | 210.5 | 39.00 | 39.1 | 78.10 | -4.50 | -5.448 | 51.5 | 193.6 |
| A9 | 2 | 2 | 9.60 | 9.50 | 19.10 | 37.20 | 36.20 | 73.40 | 54.30 | 284.3 | 30.25 | 30.35 | 60.60 | -12.8 | -17.44 | 41.5 | 217.3 |
| A10 | 2 | 2 | 12.6 | 11.0 | 23.60 | 34.25 | 19.95 | 44.20 | 20.60 | 87.29 | 20.95 | 21.25 | 42.00 | -2.20 | -4.977 | 18.4 | 77.97 |
| B1 | 2 | 2 | 9.5 | 9.6 | 19.1 | 16.25 | 15.6 | 31.85 | 12.75 | 66.75 | 13.25 | 13.35 | 26.6 | -5.25 | -16.48 | 7.50 | 39.27 |
| B2 | 2 | 1 | 34.17 | 33.49 | 67.66 | 31.7 | 31.8 | 63.5 | -4.16 | -6.148 | 35.82 | 36.05 | 71.87 | 8.37 | 13.18 | 4.21 | 6.222 |
| B3 | 2 | 2 | 14 | 13.35 | 27.35 | 34 | 31 | 65 | 37.65 | 137.7 | 25.5 | 18.6 | 44.1 | -20.9 | -32.15 | 16.75 | 61.24 |
| B4 | 2 | 2 | 15.5 | 14.85 | 30.35 | 27.6 | 25.4 | 53 | 22.65 | 74.63 | 20.75 | 16.35 | 37.1 | -15.9 | -30 | 6.75 | 22.24 |
| B5 | 2 | 2 | 14.75 | 14.1 | 28.85 | 39.2 | 41.58 | 80.78 | 51.93 | 180 | 12.5 | 25.35 | 37.85 | -42.9 | -53.14 | 9.00 | 31.2 |
| B6 | 1 | 2 | 5 | 4.35 | 9.35 | 9.5 | 8.85 | 18.35 | 9 | 96.26 | 5.75 | 5.1 | 10.85 | -7.5 | -40.87 | 1.50 | 16.04 |
| B7 | 1 | 2 | 5.75 | 4.35 | 10.1 | 9.5 | 8.1 | 17.6 | 7.5 | 74.26 | 6.5 | 5.1 | 11.6 | -6.0 | -34.09 | 1.50 | 14.85 |
| B8 | 1 | 1 | 8 | 5.85 | 13.85 | 9.6 | 8.75 | 18.35 | 4.5 | 32.49 | 8 | 5.85 | 13.85 | -4.5 | -24.52 | 0 | 0 |
| B9 | 1 | 2 | 5.75 | 5.1 | 10.85 | 11 | 11.1 | 22.1 | 11.25 | 103.7 | 7.25 | 7.35 | 14.6 | -7.5 | -33.94 | 3.75 | 34.56 |
| B10 | 1 | 2 | 8 | 5.85 | 13.85 | 11.75 | 10.35 | 22.1 | 8.25 | 59.57 | 8.75 | 7.35 | 16.1 | -6.0 | -27.15 | 2.25 | 16.25 |
| C1 | 2 | 2 | 18.25 | 14.85 | 33.1 | 14 | 13.35 | 27.35 | -5.75 | -17.37 | 12.5 | 12.6 | 25.1 | -2.25 | -8.227 | -8 | -24.2 |
| C2 | 2 | 1 | 16.25 | 18.6 | 34.85 | 14.75 | 15.6 | 30.35 | -4.5 | -12.91 | 15.5 | 13.35 | 28.85 | -1.5 | -4.942 | -6 | -17.2 |
| C3 | 2 | 1 | 15.5 | 18.85 | 34.35 | 18.75 | 18.85 | 37.6 | 3.25 | 9.461 | 14.75 | 11.85 | 26.6 | -11 | -29.26 | -7.75 | -22.6 |
| C4 | 2 | 1 | 14.25 | 14.35 | 28.6 | 20.75 | 16.35 | 37.1 | 8.5 | 29.72 | 12.5 | 11.85 | 24.35 | -12.8 | -34.37 | -4.25 | -14.9 |
| C5 | 2 | 1 | 11.75 | 11.85 | 23.6 | 9.5 | 9.6 | 19.1 | -4.5 | -19.07 | 9.5 | 9.6 | 19.1 | 0 | 0 | -4.5 | -19.1 |
| C6 | 1 | 2 | 7.35 | 7.35 | 14.6 | 8.75 | 8.1 | 16.85 | 2.25 | 15.41 | 6.5 | 4.35 | 10.85 | -6 | -35.61 | -3.75 | -25.7 |
| C7 | 1 | 2 | 7.25 | 7.35 | 14.6 | 8.75 | 8.1 | 16.85 | 2.25 | 15.41 | 3.5 | 3.6 | 7.1 | -9.75 | -57.86 | -7.5 | -51.4 |
| C8 | 1 | 2 | 5.75 | 5.85 | 11.6 | 3.5 | 4.35 | 7.85 | -3.75 | -32.33 | 5.75 | 5.85 | 11.6 | 3.75 | 47.77 | 0 | 0 |
| C9 | 1 | 2 | 7.25 | 8.1 | 15.35 | 7.25 | 6.6 | 13.85 | -1.5 | -9.772 | 8 | 5.1 | 13.1 | -0.75 | -5.415 | -2.25 | -14.7 |
| C10 | 1 | 1 | 5 | 5.1 | 10.1 | 4.25 | 4.35 | 8.6 | -1.5 | -14.85 | 5 | 5.1 | 10.1 | 1.5 | 17.44 | 0 | 0 |

## Bone Density

| | Total Body | | | | | | | | Lumbar Spine | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | BMD | | | | BMC | | | | BMD | | | | BMC | | | |
| **Subject** | **Baseline** | **5 years** | **Change** | **%** | **Baseline** | **5 years** | **Change** | **%** | **Baseline** | **5 years** | **Change** | **%** | **Baseline** | **5 years** | **Change** | **%** |
| **A1** | 0.966 | 1.126 | 0.16 | 16.56 | 2535 | 2088 | -447 | -17.63 | 1.058 | 1.072 | 0.014 | 1.32 | 43.79 | 45.82 | 2.03 | 4.64 |
| **A2** | 0.951 | 1.128 | 0.177 | 18.61 | 2076 | 1944 | -132 | -6.36 | 0.962 | 0.9 | -0.062 | -6.44 | 42.79 | 42.64 | -0.15 | -0.35 |
| **A3** | 0.894 | 0.935 | 0.041 | 4.59 | 2295 | 1760 | -535 | -23.31 | 0.977 | 0.887 | -0.09 | -9.21 | 42.69 | 38.46 | -4.23 | -9.91 |
| **A4** | 0.973 | 0.81 | -0.163 | -16.75 | 1490 | 1276 | -214 | -14.36 | 0.822 | 0.745 | -0.077 | -9.37 | 41 | 37.5 | -3.5 | -8.54 |
| **A5** | 0.928 | 0.932 | 0.004 | 0.43 | 2029 | 1514 | -515 | -25.38 | 0.904 | 0.889 | -0.015 | -1.66 | 44.9 | 34.67 | -10.23 | -22.78 |
| **A6** | 0.759 | 1.031 | 0.272 | 35.84 | 2207 | 2108 | -99 | -4.49 | 1.008 | 0.849 | -0.159 | -15.77 | 53.65 | 49.19 | -4.46 | -8.31 |
| **A7** | 0.988 | 1.168 | 0.18 | 18.22 | 2800 | 2438 | -362 | -12.93 | 1.166 | 1.104 | -0.062 | -5.32 | 56.19 | 59.07 | 2.88 | 5.13 |
| **A8** | 1.024 | 1.14 | 0.116 | 11.33 | 2614 | 2297 | -317 | -12.13 | 1.263 | 0.974 | -0.289 | -22.88 | 62.55 | 50.09 | -12.46 | -19.92 |
| **A9** | 0.935 | 1.14 | 0.205 | 21.93 | 2513 | 2297 | -216 | -8.60 | 1.119 | 0.941 | -0.178 | -15.91 | 54.33 | 46.26 | -8.07 | -14.85 |
| **A10** | 1 | 1.093 | 0.093 | 9.30 | 2544 | 2182 | -362 | -14.23 | 1.316 | 0.925 | -0.391 | -29.71 | 61.3 | 42.44 | -18.86 | -30.77 |
| **B1** | 0.968 | 1.22 | 0.252 | 26.03 | 2889 | 2647 | -242 | -8.38 | 1.026 | 1.069 | 0.043 | 4.19 | 68.59 | 64.12 | -4.47 | -6.52 |
| **B2** | 1.07 | 1.3 | 0.23 | 21.50 | 3071 | 2866 | -205 | -6.68 | 1.513 | 1.473 | -0.04 | -2.64 | 84.57 | 77.84 | -6.73 | -7.96 |
| **B3** | 1.055 | 1.208 | 0.153 | 14.50 | 3136 | 2814 | -322 | -10.27 | 1.42 | 1.261 | -0.159 | -11.20 | 72.95 | 75.87 | 2.92 | 4.00 |
| **B4** | 1.016 | 1.171 | 0.155 | 15.26 | 2789 | 2677 | -112 | -4.02 | 1.198 | 0.999 | -0.199 | -16.61 | 59.3 | 61.73 | 2.43 | 4.10 |
| **B5** | 1.48 | 1.109 | -0.371 | -25.07 | 3096 | 2488 | -608 | -19.64 | 1.292 | 1.155 | -0.137 | -10.60 | 72.9 | 71.15 | -1.75 | -2.40 |
| **B6** | 0.875 | 0.895 | 0.02 | 2.29 | 1845 | 1428 | -417 | -22.60 | 0.617 | 0.538 | -0.079 | -12.80 | 28.22 | 23.26 | -4.96 | -17.58 |
| **B7** | 0.916 | 1.089 | 0.173 | 18.89 | 2425 | 2079 | -346 | -14.27 | 1.297 | 1.103 | -0.194 | -14.96 | 53.93 | 48.46 | -5.47 | -10.14 |
| **B8** | 0.929 | 0.995 | 0.066 | 7.10 | 1992 | 1636 | -356 | -17.87 | 1.043 | 0.912 | -0.131 | -12.56 | 41.61 | 37.76 | -3.85 | -9.25 |
| **B9** | 0.925 | 0.944 | 0.019 | 2.05 | 2086 | 1729 | -357 | -17.11 | 0.804 | 0.818 | 0.014 | 1.74 | 34.27 | 38.96 | 4.69 | 13.69 |
| **B10** | 1.145 | 1.234 | 0.089 | 7.77 | 2676 | 2276 | -400 | -14.95 | 1.526 | 1.42 | -0.106 | -6.95 | 73.15 | 68.61 | -4.54 | -6.21 |
| **C1** | 0.929 | 1.214 | 0.285 | 30.68 | 2781 | 2754 | -27 | -0.97 | 1.111 | 1.127 | 0.016 | 1.44 | 58.93 | 65.06 | 6.13 | 10.40 |
| **C2** | 1.057 | 1.225 | 0.168 | 15.89 | 3246 | 2899 | -347 | -10.69 | 1.227 | 1.003 | -0.224 | -18.26 | 66.38 | 54.79 | -11.59 | -17.46 |
| **C3** | 0.91 | 1.159 | 0.249 | 27.36 | 2678 | 2590 | -88 | -3.29 | 1.116 | 1.02 | -0.096 | -8.60 | 62.29 | 54.67 | -7.62 | -12.23 |
| **C4** | 1.269 | 1.434 | 0.165 | 13.00 | 3516 | 3310 | -206 | -5.86 | 1.647 | 1.307 | -0.34 | -20.64 | 86.18 | 74.04 | -12.14 | -14.09 |
| **C5** | 0.949 | 1.116 | 0.167 | 17.60 | 2267 | 2140 | -127 | -5.60 | 1.072 | 0.972 | -0.1 | -9.33 | 49.46 | 47.03 | -2.43 | -4.91 |
| **C6** | 1.083 | 1.064 | -0.019 | -1.75 | 2990 | 2170 | -820 | -27.42 | 1.123 | 1.04 | -0.083 | -7.39 | 46.96 | 53.54 | 6.58 | 14.01 |
| **C7** | 0.977 | 1.014 | 0.037 | 3.79 | 2289 | 1714 | -575 | -25.12 | 0.991 | 0.812 | -0.179 | -18.06 | 41.32 | 32.94 | -8.38 | -20.28 |
| **C8** | 1.14 | 1.115 | -0.025 | -2.19 | 2297 | 2116 | -181 | -7.88 | 0.974 | 1.188 | 0.214 | 21.97 | 50.09 | 56.85 | 6.76 | 13.50 |
| **C9** | 0.784 | 1.094 | 0.31 | 39.54 | 2238 | 1861 | -377 | -16.85 | 1.239 | 1.197 | -0.042 | -3.39 | 52.69 | 48.89 | -3.8 | -7.21 |
| **C10** | 0.937 | 0.993 | 0.056 | 5.98 | 2123 | 1713 | -410 | -19.31 | 0.905 | 0.834 | -0.071 | -7.85 | 36.39 | 36.35 | -0.04 | -0.11 |

## Treadmill Time to Exhaustion

| | | | Pre | 2 years | Change (0-2yr) | | 5 years | Change (2-5yr) | | Change (0-5yr) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Subject | Sex | Age | | | Abs | % | | Abs | % | Abs | % |
| A1 | 1 | 2 | 15.12 | 14.17 | -0.95 | -6.28 | 11.28 | -2.89 | -20.40 | -3.84 | -25.40 |
| A2 | 1 | 2 | 13 | 14.8 | 1.8 | 13.85 | 15.75 | 0.95 | 6.42 | 2.75 | 21.15 |
| A3 | 1 | 2 | 10.05 | 8.1 | -1.95 | -19.40 | 5.28 | -2.82 | -34.81 | -4.77 | -47.46 |
| A4 | 1 | 2 | 35 | 45 | 10 | 28.57 | 16.25 | -28.75 | -63.89 | -18.75 | -53.57 |
| A5 | 1 | 2 | 2.35 | 5.08 | 2.73 | 116.17 | 6.58 | 1.5 | 29.53 | 4.23 | 180.00 |
| A6 | 2 | 2 | 11.9 | 17 | 5.1 | 42.86 | 15.28 | -1.72 | -10.12 | 3.38 | 28.40 |
| A7 | 2 | 1 | 14.03 | 15.17 | 1.14 | 8.13 | 10 | -5.17 | -34.08 | -4.03 | -28.72 |
| A8 | 2 | 2 | 9.52 | 15.83 | 6.31 | 66.28 | 14.67 | -1.16 | -7.33 | 5.15 | 54.10 |
| A9 | 2 | 2 | 27.82 | 28.02 | 0.2 | 0.72 | 17.33 | -10.69 | -38.15 | -10.49 | -37.71 |
| A10 | 2 | 2 | 11 | 12.05 | 1.05 | 9.55 | 7.95 | -4.1 | -34.02 | -3.05 | -27.73 |
| B1 | 2 | 2 | 16.82 | 16.12 | -0.7 | -4.16 | 9.17 | -6.95 | -43.11 | -7.65 | -45.48 |
| B2 | 2 | 1 | 18.83 | 41.57 | 22.74 | 120.76 | 40.28 | -1.29 | -3.10 | 21.45 | 113.91 |
| B3 | 2 | 2 | 16.82 | 16 | -0.82 | -4.88 | 10.28 | -5.72 | -35.75 | -6.54 | -38.88 |
| B4 | 2 | 2 | 16.88 | 30.07 | 13.19 | 78.14 | 17.83 | -12.24 | -40.71 | 0.95 | 5.63 |
| B5 | 2 | 2 | 33.65 | 16 | -17.65 | -52.45 | 12.45 | -3.55 | -22.19 | -21.2 | -63.00 |
| B6 | 1 | 2 | 5.83 | 14.07 | 8.24 | 141.34 | 9.32 | -4.75 | -33.76 | 3.49 | 59.86 |
| B7 | 1 | 2 | 4.57 | 6.03 | 1.46 | 31.95 | 3.25 | -2.78 | -46.10 | -1.32 | -28.88 |
| B8 | 1 | 1 | 26.28 | 25.08 | -1.2 | -4.57 | 15.17 | -9.91 | -39.51 | -11.11 | -42.28 |
| B9 | 1 | 2 | 17.58 | 14.05 | -3.53 | -20.08 | 9 | -5.05 | -35.94 | -8.58 | -48.81 |
| B10 | 1 | 2 | 7.58 | 7.77 | 0.19 | 2.51 | 6.5 | -1.27 | -16.34 | -1.08 | -14.25 |
| C1 | 2 | 2 | 65.18 | 60 | -5.18 | -7.95 | 22.25 | -37.75 | -62.92 | -42.93 | -65.86 |
| C2 | 2 | 1 | 30.33 | 15.15 | -15.18 | -50.05 | 13.1 | -2.05 | -13.53 | -17.23 | -56.81 |
| C3 | 2 | 1 | 19.13 | 14.05 | -5.08 | -26.56 | 10.28 | -3.77 | -26.83 | -8.85 | -46.26 |
| C4 | 2 | 1 | 30 | 50 | 20 | 66.67 | 17.23 | -32.77 | -65.54 | -12.77 | -42.57 |
| C5 | 2 | 1 | 45 | 40 | -5 | -11.11 | 23.3 | -16.7 | -41.75 | -21.7 | -48.22 |
| C6 | 1 | 2 | 16.48 | 13 | -3.48 | -21.12 | 17.13 | 4.13 | 31.77 | 0.65 | 3.94 |
| C7 | 1 | 2 | 14.07 | 14 | -0.07 | -0.50 | 14.5 | 0.5 | 3.57 | 0.43 | 3.06 |
| C8 | 1 | 2 | 7.28 | 6.18 | -1.1 | -15.11 | 6.02 | -0.16 | -2.59 | -1.26 | -17.31 |
| C9 | 1 | 2 | 4 | 7.05 | 3.05 | 76.25 | 6.18 | -0.87 | -12.34 | 2.18 | 54.50 |
| C10 | 1 | 1 | 11.28 | 13.18 | 1.9 | 16.84 | 17.28 | 4.1 | 31.11 | 6 | 53.19 |

# Appendix C:

## Data Summary Tables

**Unilateral Arm Curl (Sum of Both Arms): Mean(Standard Deviation)**

**1 RM**

| **FEMALES** | **PRE** | **2 y** | **5 y** |
|---|---|---|---|
| TR | 11.45(2.01) | 18.65(2.52) | 17.15(2.54) |
| DETR | 11.60(2.12) | 19.70(2.21) | 13.40(2.16) |
| CON | 13.25(2.27) | 12.80(4.36) | 10.55(2.22) |
| **MALES** | **PRE** | **2 y** | **5 y** |
| TR | 23.15(2.79) | 60.12(17.26) | 48.88(20.11) |
| DETR | 34.66(18.95) | 58.83(18.05) | 43.50(17.05) |
| CON | 30.90(4.77) | 30.30(7.64) | 24.80(3.62) |
| **COMBINED** | **PRE** | **2 y** | **5 y** |
| TR | 17.30(6.58) | 39.38(24.76) | 33.02(21.56) |
| DETR | 23.13(17.59) | 39.26(23.92) | 28.45(19.57) |
| CON | 22.08(9.95) | 21.55(10.93) | 17.68(8.03) |

**Change in Strength (kg)**

| **FEMALES** | **0-2 y** | **2-5 y** | **0-5 y** |
|---|---|---|---|
| TR | 7.2(1.73) | -1.5(1.4) | 5.7(3.03) |
| DETR | 8.1(2.45) | -6.3(1.25) | 1.8(1.36) |
| CON | -0.45(2.63) | -2.25(5.54) | -2.7(3.12) |
| **MALES** | **0-2 y** | **2-5 y** | **0-5 y** |
| TR | 36.97(17.09) | -11.24(8.53) | 25.73(19.71) |
| DETR | 24.16(21.7) | -15.32(19.08) | 8.84(4.74) |
| CON | -.06(6.22) | -5.5(5.91) | -6.1(1.76) |
| **COMBINED** | **0-2 y** | **2-5 y** | **0-5 y** |
| TR | 22.08(19.42) | -6.37(7.72) | 15.72(16.98) |
| DETR | 16.13(16.86) | -10.81(13.61) | 5.32(4.96) |
| CON | -0.52(4.50) | -3.88(5.66) | -4.4(2.98) |

**Change in Strength (%)**

| **FEMALES** | **0-2 y** | **2-5 y** | **0-5 y** |
|---|---|---|---|
| TR | 65.26(21.91) | -8.62(7.82) | 51.72(28.11) |
| DETR | 73.25(28.74) | -32.11(6.44) | 16.34(12.26) |
| CON | -5.22(20.61) | -6.73(41.85) | -18.34(21.40) |
| **MALES** | **0-2 y** | **2-5 y** | **0-5 y** |
| TR | 162.62(83.01) | -19.89(16.13) | 82.24(68.78) |
| DETR | 90.58(71.40) | -23.92(17.42) | 24.19(17.90) |
| CON | -2.03(21.72) | -11.05(30.07) | -18.96(14.30) |
| **COMBINED** | **0-2 y** | **2-5 y** | **0-5 y** |
| TR | 113.94(76.87) | -14.26(13.34) | 82.24(68.78) |
| DETR | 81.92(52.12) | -27.92(17.42) | 24.19(17.90) |
| CON | -3.63(19.75) | -11.05(30.07) | -18.96(14.30) |

**Unilateral Leg Press (Sum of Both Legs): Mean (Standard Deviation)**

1 RM

| **FEMALES** | **PRE** | **2 y** | **5 y** |
|---|---|---|---|
| TR | 11.45(2.01) | 18.65(2.52) | 17.15(3.54) |
| DETR | 11.6(2.12) | 19.70(2.21) | 13.4(2.16) |
| CON | 13.25(2.27) | 12.8(4.36) | 10.55(2.22) |
| **MALES** | **PRE** | **2 y** | **5 y** |
| TR | 23.15(27.9) | 60.12(17.27) | 48.88(20.12) |
| DETR | 34.66(18.95) | 58.83(18.05) | 43.50(17.05) |
| CON | 30.9(4.77) | 30.3(7.64) | 24.8(3.62) |
| **COMBINED** | **PRE** | **2 y** | **5 y** |
| TR | 128.95(36.00) | 163.75(46.90) | 150.13(42.22) |
| DETR | 135.25(35.83) | 178.75(52.80) | 153.60(41.48) |
| CON | 155.77(49.54) | 148.75(38.23) | 137.45(39.78) |

**Change in Strength (kg)**

| **FEMALES** | **0-2 y** | **2-5 y** | **0-5 y** |
|---|---|---|---|
| TR | 29.75(16.64) | -12.55(9.62) | 17.5(8.29) |
| DETR | 24.0(15.27) | -15.8(1.99) | 8.2(13.64) |
| CON | 3.56(25.32) | -16.5(8.02) | -12.94(24.12) |
| **MALES** | **0-2 y** | **2-5 y** | **0-5 y** |
| TR | 40.75(20.03) | -15.0(14.71) | 25.75(22.67) |
| DETR | 63.00(8.13) | -34.5(22.41) | 28.50(24.47) |
| CON | -17.6(7.33) | -6.1(10.36) | -23.7(12.26) |
| **COMBINED** | **0-2 y** | **2-5 y** | **0-5 y** |
| TR | 35.25(18.30) | -13.63(11.81) | 21.62(16.67) |
| DETR | 43.5(23.57) | -25.15(17.94) | 18.35(21.52) |
| CON | -7.02(20.82) | -11.3(10.31) | -18.32(18.91) |

**Change in Strength (%)**

| **FEMALES** | **0-2 y** | **2-5 y** | **0-5 y** |
|---|---|---|---|
| TR | 28.12(14.56) | -8.43(6.30) | 16.66(7.32) |
| DETR | 23.90(17.23) | -12.06(1.65) | 8.82(13.92) |
| CON | 6.87(26.27) | -13.46(4.81) | -7.87(20.80) |
| **MALES** | **0-2 y** | **2-5 y** | **0-5 y** |
| TR | 27.61(13.27) | -7.32(7.36) | 18.20(14.53) |
| DETR | 39.86(9.89) | -14.71(8.82) | 19.59(17.66) |
| CON | -9.02(3.72) | -2.80(5.84) | -11.61(5.53) |
| **COMBINED** | **0-2 y** | **2-5 y** | **0-5 y** |
| TR | 27.86(13.13) | -7.58(6.49) | 17.43(10.88) |
| DETR | 31.88(15.69) | -13.38(6.14) | 14.20(16.03) |
| CON | -1.07(19.57) | -8.13(7.55) | -9.74(14.49) |

**Bilateral Bench Press: Mean (Standard Deviation)**

**1 RM**

| **FEMALES** | **PRE** | **2 y** | **5 y** |
|---|---|---|---|
| TR | 20.0(3.54) | 33.5(5.18) | 29.55(5.92) |
| DETR | 21.15(3.94) | 33.5(4.10) | 23.5(6.27) |
| CON | 26.5(4.54) | 30.1(3.49) | 2.6(2.24) |
| **MALES** | **PRE** | **2 y** | **5 y** |
| TR | 43.0(11.10) | 62.75(21.55) | 50.01(23.99) |
| DETR | 51.2(9.63) | 75.5(10.85) | 51.9(10.63) |
| CON | 52.5(5.30) | 53.25(4.47) | 46.0(5.18) |
| **COMBINED** | **PRE** | **2 y** | **5 y** |
| TR | 31.5(14.40) | 48.13(21.35) | 39.78(19.69) |
| DETR | 36.35(17.12) | 54.5(23.45) | 37.7(17.08) |
| CON | 39.5(14.47) | 41.67(12.77) | 36.0(11.19) |

**Change in Strength (kg)**

| **FEMALES** | **0-2 y** | **2-5 y** | **0-5 y** |
|---|---|---|---|
| TR | 13.5(4.71) | -3.95(3.71) | 9.55(7.36) |
| DETR | 12.0(5.36) | -10.0(2.34) | 2.0(6.70) |
| CON | 3.6(4.65) | -4.1(3.35) | -0.5(4.47) |
| **MALES** | **0-2 y** | **2-5 y** | **0-5 y** |
| TR | 19.75(12.82) | -12.7(8.68) | 7.01(16.06) |
| DETR | 24.3(12.37) | -23.6(13.38) | 0.7(18.90) |
| CON | 0.75(1.11) | -7.25(6.98) | -6.5(8.02) |
| **COMBINED** | **0-2 y** | **2-5 y** | **0-5 y** |
| TR | 16.63(9.68) | -8.35(7.82) | 8.28(11.85) |
| DETR | 18.15(11.08) | -16.8(11.55) | 1.35(13.39) |
| CON | 2.18(3.53) | -5.68(5.42) | -3.5(6.89) |

**Change in Strength (%)**

| **FEMALES** | **0-2 y** | **2-5 y** | **0-5 y** |
|---|---|---|---|
| TR | 70.24(28.11) | -11.8(12.66) | 52.67(43.3) |
| DETR | 60.8(39.74) | -30.9(10.50) | 12.01(34.23) |
| CON | 15.61(20.65) | -12.9(10.63) | 0.03(16.64) |
| **MALES** | **0-2 y** | **2-5 y** | **0-5 y** |
| TR | 45.46(25.12) | -21.8(12.53) | 14.54(31.47) |
| DETR | 50.46(30.72) | -30.4(14.45) | 5.80(33.24) |
| CON | 1.59(2.45) | -13.1(13.52) | -11.4(16.10) |
| **COMBINED** | **0-2 y** | **2-5 y** | **0-5 y** |
| TR | 57.85(28.32) | -16.8(12.98) | 33.6(40.96) |
| DETR | 55.63(33.93) | -30.6(11.91) | 8.90(31.98) |
| CON | 8.60(15.70) | -13.0(11.46) | -5.7(16.58) |

**Treadmill (minutes): Mean (Standard Deviation)**

**Time to Exhaustion**

| **FEMALES** | **PRE** | **2 y** | **5 y** |
|---|---|---|---|
| TR | 15.10(12.13) | 17.43(15.95) | 11.03(5.06) |
| DETR | 12.37(9.32) | 13.4(7.47) | 8.65(4.38) |
| CON | 10.62(5.04) | 10.68(3.74) | 12.22(5.70) |
| **MALES** | **PRE** | **2 y** | **5 y** |
| TR | 14.85(7.43) | 17.61(6.10) | 13.05(3.91) |
| DETR | 20.6(7.35) | 23.95(11.57) | 18.00(12.89) |
| CON | 37.93(17.79) | 35.84(20.64) | 17.23(5.64) |
| **COMBINED** | **PRE** | **2 y** | **5 y** |
| TR | 14.98(9.48) | 17.52(11.38) | 12.04(4.39) |
| DETR | 16.48(9.02) | 18.68(10.74) | 13.32(10.33) |
| CON | 24.28(18.93) | 23.26(19.27) | 14.73(5.96) |

**Change in Time to Exhaustion (min.)**

| **FEMALES** | **0-2 y** | **2-5 y** | **0-5 y** |
|---|---|---|---|
| TR | 2.33(4.7) | -6.40(12.66) | -4.08(9.10) |
| DETR | 1.03(4.43) | -4.75(3.27) | -3.72(5.98) |
| CON | 0.06(2.56) | 1.54(2.4) | 1.6(2.74) |
| **MALES** | **0-2 y** | **2-5 y** | **0-5 y** |
| TR | 2.76(2.75) | -4.57(3.80) | -1.81(6.27) |
| DETR | 3.35(15.39) | -5.95(4.13) | -2.60(15.64) |
| CON | -2.09(13.1) | -18.61(16.32) | -20.7(13.33) |
| **COMBINED** | **0-2 y** | **2-5 y** | **0-5 y** |
| TR | 2.54(3.64) | -5.48(8.86) | -2.94(7.46) |
| DETR | 2.19(10.75) | -5.35(3.56) | -3.16(11.18) |
| CON | -1.01(8.97) | -8.53(15.29) | -9.55(14.84) |

**Change in Time to Exhaustion (%)**

| **FEMALES** | **0-2 y** | **2-5 y** | **0-5 y** |
|---|---|---|---|
| TR | 26.58 | -16.63 | 14.94 |
| DETR | 30.23 | -34.33 | -14.87 |
| CON | 11.27 | -10.30 | 19.48 |
| **MALES** | **0-2 y** | **2-5 y** | **0-5 y** |
| TR | 25.51 | -24.74 | -2.33 |
| DETR | 27.48 | -28.97 | -5.56 |
| CON | -5.80 | -42.11 | -51.94 |
| **COMBINED** | **0-2 y** | **2-5 y** | **0-5 y** |
| TR | 26.04(40.17) | -20.68(26.4) | 6.30(70.68) |
| DETR | 28.86(63.76) | -31.65(13.59) | -10.22(56.08) |
| CON | 2.74(40.19) | -15.90(34.19) | -16.23(43.88) |

**Bone Density: Mean(standard deviation)**

**Lumbar Spine BMD**

| Females | Baseline | 5 years |
|---|---|---|
| TR | 0.9446(0.0879) | 0.8986(0.1161) |
| DETR | 1.057(0.3658) | 0.9582(0.3289) |
| CON | 1.046(0.1429) | 1.014(0.1855) |
| **Males** | **Baseline** | **5 years** |
| TR | 1.1744(0.1212) | 0.9586(0.0933) |
| DETR | 1.2898(0.3658) | 1.1914(0.1854) |
| CON | 1.2346(0.2376) | 1.0858(0.1367) |

**Lumbar Spine BMC**

| Females | Baseline | 5 years |
|---|---|---|
| TR | 43.03(1.45) | 39.82(4.41) |
| DETR | 46.24(17.84) | 43.41(16.72) |
| CON | 45.49(8.37) | 45.71(10.56) |
| **Males** | **Baseline** | **5 years** |
| TR | 57.60(4.07) | 49.41(6.17) |
| DETR | 71.66(9.11) | 70.14(7.07) |
| CON | 64.64(13.56) | 59.11(10.52) |

**Total Body BMD**

| Females | Baseline | 5 years |
|---|---|---|
| TR | 0.9424(0.032) | 0.9862(0.138) |
| DETR | 0.958(0.107) | 1.0314(0.134) |
| CON | 0.9244(0.117) | 1.056(0.052) |
| **Males** | **Baseline** | **5 years** |
| TR | 0.9412(0.107) | 1.2818(0.366) |
| DETR | 1.1178(0.206) | 1.2016(0.070) |
| CON | 1.0228(0.149) | 1.2296(1.224) |

**Total Body BMC**

| Females | Baseline | 5 years |
|---|---|---|
| TR | 2085.0(388.54) | 1716.4(326.61) |
| DETR | 2204.8(338.88) | 1829.6(342.91) |
| CON | 2366.6(353.8) | 1914.8(217.68) |
| **Males** | **Baseline** | **5 years** |
| TR | 2535.6(214.83) | 2264.4(126.01) |
| DETR | 2996.2(149.60) | 2698.4(149.01) |
| CON | 2897.6(490.73) | 2738.6(428.04) |

# Appendix D:

## Consent Form

## CONSENT FORM

## LONG-TERM RESISTANCE TRAINING IN THE ELDERLY: EFFECTS OF DETRAINING ON DYNAMIC STRENGTH, EXERCISE CAPACITY, AND BONE

I, ______________________________, consent to take part in a study conducted by Dr. N. McCartney, and K.M.Smith. The study will examine the effects of resistance training on dynamic muscle strength, exercise capacity, and bone mineral density and content in the elderly population. The results of this study will be made available to the scientific community but participation in this study will offer no direct benefit to me.

For the purposes of this study, I will be asked to perform a series of resistance exercises including: unilateral arm curl, unilateral leg press, unilateral military press, and bilateral supine bench press, to assess dynamic strength. This will be measured as the heaviest weight that can be lifted once throughout the complete range of movement (1RM). I will also be asked to perform a progressive treadmill walking test to assess my exercise capacity. During this test, I will be asked to assess my leg and breathing effort as described by the attending investigator (K.M. Smith) at the end of each minute of the walking test. Exercise may cause slight muscle strains and as with all exercises there is a slight risk of cardiovascular complications. A supervised adequate warm-up should alleviate the complication of muscle strains, and all of the attending personnel are trained in CPR and emergency procedures.

I understand that I will be asked to attend a subsequent session to measure my bone density which will be conducted in Nuclear Medicine at the McMaster University Medical Centre; during this assessment, I understand that I will be subjected to a radiation dosage equivalent to about one tenth (1/10) of a chest x-ray.

I understand that I may withdraw from the study at any time, even after signing this form, without prejudice. Any information that is collected about me during this study will be kept confidential and if the results are published, I will not be identified in any way. If I wish, the results of my test will be made available to me.

| | | |
|---|---|---|
| ______________________ | ______________________ | __________ |
| Name (print) | Signature | Date |
| ______________________ | ______________________ | __________ |
| Witness (print) | Signature | Date |

I have explained the nature of the study to the subject and believe that he/she has understood it.

| | | |
|---|---|---|
| ______________________ | ______________________ | __________ |
| Name (print) | Signature | Date |

# Appendix E:

## Questionnaires

## Medical Questionnaire

Name: ______________________________
Address: ______________________________
Phone #: ______________________________
Date of Birth: ______________________________
Age: ______________________________

Physician: ______________________________
Phone #: ______________________________

## Screening Questions

1. Approximate height and weight

   ______________________________

2. History of heart disease

   ______________________________

3. High blood pressure

   ______________________________

4. Lung disease (asthma, bronchitis, emphysema)

   ______________________________

5. Medications (specify)

   ______________________________

6. Smoking history

   ______________________________

7. High cholesterol

   ______________________________

8. Diabetes

   ______________________________

9. Arthritis

   ______________________________

10. Other orthopedic problems

    ______________________________

11. Current exercise habits

    ______________________________

12. Past exercise habits

13. Transportation

________________________________________________

14. Time commitments

________________________________________________

15. Holiday plans

________________________________________________

16. Additional comments

________________________________________________

# PHYSICAL ACTIVITY QUESTIONNAIRE

*Questionnaire, codes, and methods of calculation of scores on habitual physical activity in elderly people.*

## PART I: HOUSEHOLD ACTIVITIES

1) Do you do the light household work? (dusting, washing dishes repairing clothes, etc.)?

___

0. Never (<once a month)
1. Sometimes (only when partner or help is not available
2. Mostly (sometimes assisted by partner or help)
3. Always (alone or together with partner)

2) Do you do the heavy housework? (washing floors and windows, carrying trash disposal bags, etc.)?

___

0. Never (<once a month)
1. Sometimes (only when partner or help is not available)
2. Mostly (sometimes assisted by partner or help)
3. Always (alone or together with partner)

3. For how many people do you keep house? (including yourself; fill in "0" if you answered "never" in Q1 and Q2.)

___

4. How many rooms do you keep clean, including kitchen, bedroom, garage, cellar, bathroom, ceiling, etc.?

___

0. Never do housekeeping
1. 1-6 rooms
2. 7-9 rooms
3. 10 or more rooms

5. If any rooms, on how many floors? (fill in "0" if you answered "never" in Q4.)

___

6. Do you prepare warm meals yourself, or do you assist in preparing?

___

0. Never
1. Sometimes (once or twice a week)
2. Mostly (3-5 times a week)
3. Always (more than 5 times a week)

7. How many flights of stairs do you walk up per day? (one flight of stairs is 10 steps.)

___

0. I never walk stairs
1. 1-5
2. 6-10
3. More than 10

8. If you go somewhere in your hometown, what kind of transportation do you use?

___

0. I never go out
1. Car
2. Public transportation
3. Bicycle
4. Walking

9. How often do you go out shopping?

___

0. Never or less than once a week
1. Once a week
2. Twice to four times a week
3. Every day

10. If you go out shopping, what kind of transportation do you use?

___

0. I never go out shopping
1. Car
2. Public transportation
3. Bicycle
4. Walking

**Household score = (Q1 + Q2 +...+ Q10)/10** ____________________

## PART II: SPORT ACTIVITIES

Do you play a sport?

Sport 1: name ____________________
intensity (code) ____________
hours per week (code) _______
period of the year (code) ______

Sport 2: name ____________________
intensity (code) ____________
hours per week (code) _______
period of the year (code) ______

Sport 3: name ____________________
intensity (code) ____________
hours per week (code) _______
period of the year (code) ______

Sport 4: name ____________________
intensity (code) ____________
hours per week (code) _______
period of the year (code) ______

**Sport score:** $\sum_{i=1}^{2} (ia*ib*ic)$ ________________________________

## PART III: LEISURE TIME ACTIVITIES

Do you have any other physical activities?

Activity 1: name ________________
intensity ________________
hours per week __________
period of the year ________

Activity 2: name ________________
intensity ________________
hours per week __________
period of the year ________

Activity 3: name ________________
intensity ________________
hours per week __________
period of the year ________

Activity 4: name ________________
intensity ________________
hours per week __________
period of the year ________

Activity 5: name ________________
intensity ________________
hours per week __________
period of the year ________

Activity 6: name ________________
intensity ________________
hours per week __________
period of the year ________

**Leisure time activity score:** $\sum_{j=1}^{6} (ja^{*}jb^{*}jc^{*})$ ________________________

**QUESTIONNAIRE SCORE = HOUSEHOLD SCORE + SPORT SCORE + LEISURE TIME ACTIVITY SCORE.**

## CODES:

Intensity codes:

| | |
|---|---|
| 0: lying, unloaded | code 0.028 |
| 1: sitting, unloaded | code 0.146 |
| 2: sitting, movements hand or arm | code 0.297 |
| 3: sitting, body movements | code 0.703 |
| 4: standing, unloaded | code 0.174 |
| 5: standing, movements hand or arm | code 0.307 |
| 6: standing, body movements, walking | code 0.890 |
| 7. walking, movements arm or hands | code 1.368 |
| 8. walking, body movements, cycling, swimming | code 1.890 |

Hours per week:

| | |
|---|---|
| 1: < 1 hr/wk | code 0.5 |
| 2: 1-2 hrs/wk | code 1.5 |
| 3: 2-3 hrs/wk | code 2.5 |
| 4: 3-4 hrs/wk | code 3.5 |
| 5: 4-5 hrs/wk | code 4.5 |
| 6: 5-6 hrs/wk | code 5.5 |
| 7: 6-7 hrs/wk | code 6.5 |
| 8: 7-8 hrs/wk | code 7.5 |
| 9: > 8 hrs/wk | code 8.5 |

Months a year:

| | |
|---|---|
| 1: < 1 month/yr | code 0.04 |
| 2: 1-3 months/yr | code 0.17 |
| 3: 4-6 months/yr | code 0.42 |
| 4: 7-9 months/yr | code 0.67 |
| 5: > 9 months/yr | code 0.92 |

# Appendix F:

## Analysis of Variance Summary Tables

(i) Unilateral Arm Curl-1RM

1-Group, 2-Gender, 3-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 933.79968 | 24 | 210.07512 | 4.445075 | 0.02279 |
| 2 | 1 | 14262.204 | 24 | 210.07512 | 67.890976 | 1.865E-08 |
| 3 | 2 | 1189.3325 | 48 | 48.876331 | 24.333506 | 5.048E-08 |
| 12 | 2 | 438.14102 | 24 | 210.07512 | 2.0856397 | 0.1461693 |
| 13 | 4 | 418.14108 | 48 | 48.876331 | 8.5550833 | 2.699E-05 |
| 23 | 2 | 434.98883 | 48 | 48.876331 | 8.899785 | 0.0005157 |
| 123 | 4 | 156.1524 | 48 | 48.876331 | 3.1948471 | 0.020947 |

(ii) Unilateral Arm Curl- Absolute change from Baseline (Kg)

1- Group, 2- Gender, 3-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 1349.214 | 24 | 96.6529 | 13.95937 | 0.000095 |
| 2 | 1 | 622.626 | 24 | 96.6529 | 6.44188 | 0.018052 |
| 3 | 2 | 2952.983 | 48 | 98.30254 | 30.03974 | 0.000001 |
| 12 | 2 | 459.271 | 24 | 96.6529 | 4.75176 | 0.018258 |
| 13 | 4 | 579.816 | 48 | 98.30254 | 5.89828 | 0.000606 |
| 23 | 2 | 993.653 | 48 | 98.30254 | 10.10812 | 0.000217 |
| 123 | 4 | 238.822 | 48 | 98.30254 | 2.42945 | 0.060375 |

(iii) Unilateral Arm Curl- Relative Change from Baseline (%)

1- Group, 2- Gender, 3-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 38740.496 | 24 | 2243.5894 | 17.267197 | 2.257E-05 |
| 2 | 1 | 9189.1396 | 24 | 2243.5894 | 4.0957313 | 0.054262 |
| 3 | 2 | 50562.238 | 48 | 1084.0737 | 46.640961 | 5.594E-12 |
| 12 | 2 | 5158.3706 | 24 | 2243.5894 | 2.2991598 | 0.122025 |
| 13 | 4 | 12397.482 | 48 | 1084.0737 | 11.436015 | 1.341E-06 |
| 23 | 2 | 3624.9014 | 48 | 1084.0737 | 3.3437777 | 0.0436984 |
| 123 | 4 | 2082.2036 | 48 | 1084.0737 | 1.9207214 | 0.1222048 |

### (iv) Unilateral Leg Press-1RM

1-Group, 2-Gender, 3-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 718.53 | 24 | 1685.439 | 0.42632 | 0.657756 |
| 2 | 1 | 96730.6 | 24 | 1685.439 | 57.39188 | 0.000001 |
| 3 | 2 | 4512.02 | 48 | 132.175 | 34.13678 | 0.000001 |
| 12 | 2 | 1487.09 | 24 | 1685.439 | 0.88232 | 0.426822 |
| 13 | 4 | 2135.6 | 48 | 132.175 | 16.15739 | 0.000001 |
| 23 | 2 | 176.44 | 48 | 132.175 | 1.33486 | 0.272788 |
| 123 | 4 | 568.26 | 48 | 132.175 | 4.2993 | 0.004714 |

### (v) Unilateral Leg Press- Absolute change from Baseline (Kg)

1- Group, 2- Gender, 3-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 6557.82 | 24 | 466.5026 | 14.05741 | 0.000091 |
| 2 | 1 | 351.65 | 24 | 466.5026 | 0.7538 | 0.393875 |
| 3 | 2 | 12493.98 | 48 | 163.2731 | 76.52197 | 0.0000001 |
| 12 | 2 | 817.39 | 24 | 466.5026 | 1.75217 | 0.192859 |
| 13 | 4 | 3127.89 | 48 | 163.2731 | 19.15741 | 0.0000001 |
| 23 | 2 | 353.48 | 48 | 163.2731 | 2.16497 | 0.12583 |
| 123 | 4 | 1296.08 | 48 | 163.2731 | 7.93812 | 0.000054 |

### (vi) Unilateral Leg Press- Relative Change from Baseline (%)

1- Group, 2- Gender, 3-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 3259.5283 | 24 | 298.31885 | 10.926324 | 0.0004228 |
| 2 | 1 | 82.608345 | 24 | 298.31885 | 0.2769129 | 0.6035613 |
| 3 | 2 | 6520.5264 | 48 | 96.891136 | 67.297447 | 1.186E-14 |
| 12 | 2 | 235.78577 | 24 | 298.31885 | 0.7903817 | 0.4651285 |
| 13 | 4 | 1136.4901 | 48 | 96.891136 | 11.729557 | 1.006E-06 |
| 23 | 2 | 24.000463 | 48 | 96.891136 | 0.2477055 | 0.7815815 |
| 123 | 4 | 325.53934 | 48 | 96.891136 | 3.3598464 | 0.0167083 |

### (vii) Bilateral Bench Press-1RM

1-Group, 2-Gender, 3-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 121.12 | 24 | 206.2966 | 0.58713 | 0.563707 |
| 2 | 1 | 16261.86 | 24 | 206.2966 | 78.82758 | 0.0000001 |
| 3 | 2 | 1307.14 | 48 | 42.3137 | 30.89164 | 0.0000001 |
| 12 | 2 | 239.02 | 24 | 206.2966 | 1.15865 | 0.330857 |
| 13 | 4 | 244.15 | 48 | 42.3137 | 5.76992 | 0.000711 |
| 23 | 2 | 138.32 | 48 | 42.3137 | 3.26887 | 0.046672 |
| 123 | 4 | 38.1 | 48 | 42.3137 | 0.90047 | 0.471171 |

### (viii) Bilateral Bench Press- Absolute change from Baseline (Kg)

1- Group, 2- Gender, 3-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 467.202 | 24 | 177.4378 | 2.633 | 0.092503 |
| 2 | 1 | 107.671 | 24 | 177.4378 | 0.6068 | 0.443604 |
| 3 | 2 | 3837.968 | 48 | 38.2222 | 100.4121 | 0.0000001 |
| 12 | 2 | 19.767 | 24 | 177.4378 | 0.1114 | 0.896036 |
| 13 | 4 | 498.839 | 48 | 38.2222 | 13.051 | 0.0000001 |
| 23 | 2 | 361.119 | 48 | 38.2222 | 9.4479 | 0.000347 |
| 123 | 4 | 104.423 | 48 | 38.2222 | 2.732 | 0.039676 |

### (ix) Bilateral Bench Press- Relative Change from Baseline (%)

1- Group, 2- Gender, 3-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 5987.541 | 24 | 1336.7808 | 4.4790745 | 0.0222321 |
| 2 | 1 | 3647.3611 | 24 | 1336.7808 | 2.7284663 | 0.1115995 |
| 3 | 2 | 27798.631 | 48 | 247.09473 | 112.50192 | 7.616E-19 |
| 12 | 2 | 768.70929 | 24 | 1336.7808 | 0.5750452 | 0.5702434 |
| 13 | 4 | 3279.8779 | 48 | 247.09473 | 13.273768 | 2.344E-07 |
| 23 | 2 | 518.4967 | 48 | 247.09473 | 2.0983722 | 0.1337666 |
| 123 | 4 | 94.559082 | 48 | 247.09473 | 0.3826835 | 0.8199211 |

(x) Treadmill-Time to Exhaustion (min)

1-Group, 2-Gender, 3-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 288.66 | 24 | 231.3993 | 1.247453 | 0.305201 |
| 2 | 1 | 2129.848 | 24 | 231.3993 | 9.204212 | 0.005725 |
| 3 | 2 | 352.186 | 48 | 42.3969 | 8.306863 | 0.000798 |
| 12 | 2 | 642.917 | 24 | 231.3993 | 2.778386 | 0.082158 |
| 13 | 4 | 35.279 | 48 | 42.3969 | 0.832118 | 0.511451 |
| 23 | 2 | 102.573 | 48 | 42.3969 | 2.419338 | 0.099757 |
| 123 | 4 | 141.305 | 48 | 42.3969 | 3.332914 | 0.017335 |

(xi) Treadmill Time to Exhaustion- Absolute change from baseline (min)

1- Group, 2- Gender, 3-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 187.7903 | 24 | 130.5688 | 1.438248 | 0.257077 |
| 2 | 1 | 397.152 | 24 | 130.5688 | 3.041707 | 0.093947 |
| 3 | 2 | 512.3539 | 48 | 61.9064 | 8.276268 | 0.000816 |
| 12 | 2 | 640.6145 | 24 | 130.5688 | 4.906336 | 0.016352 |
| 13 | 4 | 11.9427 | 48 | 61.9064 | 0.192915 | 0.940939 |
| 23 | 2 | 109.1416 | 48 | 61.9064 | 1.76301 | 0.182453 |
| 123 | 4 | 103.6087 | 48 | 61.9064 | 1.673635 | 0.171539 |

(xii) Treadmill Time to Exhaustion- Relative Change from Baseline (%)

1- Group, 2- Gender, 3-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 1424.4192 | 24 | 4339.4067 | 0.328252 | 0.723364 |
| 2 | 1 | 6712.7075 | 24 | 4339.4067 | 1.5469183 | 0.2256028 |
| 3 | 2 | 13449.486 | 48 | 1020.5624 | 13.178505 | 2.742E-05 |
| 12 | 2 | 5268.0898 | 24 | 4339.4067 | 1.2140115 | 0.3146 |
| 13 | 4 | 1322.5131 | 48 | 1020.5624 | 1.295867 | 0.2849599 |
| 23 | 2 | 719.94098 | 48 | 1020.5624 | 0.7054356 | 0.4989413 |
| 123 | 4 | 720.57916 | 48 | 1020.5624 | 0.7060609 | 0.59173 |

### (xiii) Lumbar Spine-Bone Mineral Density

1-Group, 2-Gender, 3-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 0.09212 | 24 | 0.0744 | 1.2377 | 0.30791 |
| 2 | 1 | 0.43879 | 24 | 0.0744 | 5.8953 | 0.02305 |
| 3 | 1 | 0.16506 | 24 | 0.0068 | 24.422 | 0.000048 |
| 12 | 2 | 0.01442 | 24 | 0.0744 | 0.1937 | 0.82515 |
| 13 | 2 | 0.00277 | 24 | 0.0068 | 0.4103 | 0.66802 |
| 23 | 1 | 0.03665 | 24 | 0.0068 | 5.4233 | 0.02862 |
| 123 | 2 | 0.00987 | 24 | 0.0068 | 1.4602 | 0.25209 |

### (xiv) Lumbar Spine- Bone Mineral Content

1- Group, 2- Gender, 3-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 540.533 | 24 | 184.2556 | 2.9336 | 0.07248 |
| 2 | 1 | 5282.441 | 24 | 184.2556 | 28.669 | 1.698E-05 |
| 3 | 1 | 125.397 | 24 | 29.6125 | 4.2346 | 0.050626 |
| 12 | 2 | 246.4089 | 24 | 184.2556 | 1.3373 | 0.281417 |
| 13 | 2 | 32.0578 | 24 | 29.6125 | 1.0826 | 0.35469 |
| 23 | 1 | 71.9415 | 24 | 29.6125 | 2.42943 | 0.132166 |
| 123 | 2 | 36.60996 | 24 | 29.6125 | 1.2363 | 0.3083 |

### (xv) Total Body- Bone Mineral Density

1- Group, 2- Gender, 3-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 0.00773 | 24 | 0.0304 | 0.2359 | 0.77785 |
| 2 | 1 | 0.33481 | 24 | 0.0304 | 11.002 | 0.00289 |
| 3 | 1 | 0.32267 | 24 | 0.0189 | 17.078 | 0.00038 |
| 12 | 2 | 0.00107 | 24 | 0.0304 | 0.0351 | 0.96552 |
| 13 | 2 | 0.01804 | 24 | 0.0189 | 0.9546 | 0.39912 |
| 23 | 1 | 0.06093 | 24 | 0.0189 | 3.2248 | 0.08513 |
| 123 | 2 | 0.02819 | 24 | 0.0189 | 1.4922 | 0.245 |

### (xvi) Total Body- Bone Mineral Content

1- Group, 2- Gender, 3-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 633215.43 | 24 | 184441.48 | 3.43315 | 0.04883 |
| 2 | 1 | 6712077 | 24 | 184441.48 | 36.39136 | 3.146E-05 |
| 3 | 1 | 1541765.4 | 24 | 14437.842 | 106.786 | 2.579E-05 |
| 12 | 2 | 137054.61 | 24 | 184441.48 | 0.743079 | 0.048627 |
| 13 | 2 | 1210.85 | 24 | 14437.842 | 0.083866 | 0.9198223 |
| 23 | 1 | 91104.073 | 24 | 14437.842 | 6.31009 | 0.019136 |
| 123 | 2 | 17703.816 | 24 | 14437.842 | 1.2262 | 0.3111359 |

### (xvii) Unilateral Leg Press-1RM

1-Group, 2-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 718.53418 | 27 | 5190.9341 | 0.138421 | 0.871346 |
| 2 | 2 | 4512.021 | 54 | 166.11661 | 27.16177 | 6.872E-09 |
| 12 | 4 | 2135.5991 | 54 | 166.11661 | 12.856025 | 2.026E-07 |

### (xviii) Unilateral Leg Press-Absolute Change from Baseline

1-Group, 2-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 6557.8169 | 27 | 488.2406 | 13.431527 | 8.933E-05 |
| 2 | 2 | 12493.976 | 54 | 254.22951 | 49.144478 | 6.96E-13 |
| 12 | 4 | 3127.8892 | 54 | 254.22951 | 12.303408 | 3.515E-07 |

### (xix) Unilateral Leg Press-Relative Change from Baseline

1-Group, 2-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 3259.5283 | 27 | 285.69748 | 11.40902 | 0.0002563 |
| 2 | 2 | 6520.5264 | 54 | 111.12839 | 58.675613 | 2.882E-14 |
| 12 | 4 | 1136.4901 | 54 | 111.12839 | 10.226821 | 3.085E-06 |

### (xx) Unilateral Arm Curl-1RM

1-Group, 2-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 933.79968 | 27 | 747.41809 | 1.2493672 | 0.3027368 |
| 2 | 2 | 1189.3325 | 54 | 71.123169 | 16.722153 | 2.228E-06 |
| 12 | 4 | 418.14108 | 54 | 71.123169 | 5.8791118 | 0.0005301 |

### (xxi) Unilateral Arm Curl-Absolute Change from Baseline

1-Group, 2-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 1349.214 | 27 | 142.99402 | 9.4354572 | 0.000781 |
| 2 | 2 | 2952.9832 | 54 | 141.8725 | 20.814344 | 1.99E-07 |
| 12 | 4 | 579.81622 | 54 | 141.8725 | 4.0868826 | 0.0057638 |

### (xxii) Unilateral Arm Curl-Relative Change from Baseline

1-Group, 2-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 38740.496 | 27 | 2716.7417 | 14.259912 | 5.934E-05 |
| 2 | 2 | 50562.238 | 54 | 1252.114 | 40.3815 | 1.889E-11 |
| 12 | 4 | 12397.482 | 54 | 1252.114 | 9.9012413 | 4.404E-06 |

### (xxiii) Bilateral Bench Press-1RM

1-Group, 2-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 121.12345 | 27 | 803.37152 | 0.1507689 | 0.8607655 |
| 2 | 2 | 1307.1392 | 54 | 45.557446 | 28.69211 | 3.239E-09 |
| 12 | 4 | 244.1467 | 54 | 45.557446 | 5.3590956 | 0.0010425 |

(xxiv) Bilateral Bench Press-Absolute Change from Baseline

1-Group, 2-Time

|  | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 467.20215 | 27 | 163.17459 | 2.863204 | 0.0745218 |
| 2 | 2 | 3837.9678 | 54 | 55.085037 | 69.673508 | 1.105E-15 |
| 12 | 4 | 498.83905 | 54 | 55.085037 | 9.0557995 | 1.133E-05 |

(xxv) Bilateral Bench Press-Relative Change from Baseline

1-Group, 2-Time

|  | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 5987.541 | 27 | 1380.2784 | 4.3379226 | 0.0232465 |
| 2 | 2 | 27798.631 | 54 | 245.8477 | 113.07256 | 4.958E-20 |
| 12 | 4 | 3279.8779 | 54 | 245.8477 | 13.341097 | 1.26E-07 |

(xxvi) Treadmill Time to Exhaustion-Minutes

1-Group, 2-Time

|  | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 1424.4192 | 27 | 4496.0981 | 0.3168123 | 0.7311388 |
| 2 | 2 | 13449.486 | 54 | 987.20728 | 13.623772 | 1.621E-05 |
| 12 | 4 | 1322.5131 | 54 | 987.20728 | 1.3396509 | 0.2671812 |

(xxvii) Treadmill Time to Exhaustion-Absolute Change from Baseline

1-Group, 2-Time

|  | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 187.79033 | 27 | 178.22343 | 1.0536792 | 0.3625543 |
| 2 | 2 | 512.35388 | 54 | 66.744911 | 7.6762996 | 0.001164 |
| 12 | 4 | 11.942653 | 54 | 66.744911 | 0.1789298 | 0.9483302 |

(xxviii) Treadmill Time to Exhaustion-Relative Change from Baseline

1-Group, 2-Time

| | df Effect | MS Effect | df Error | MS Error | F | p-level |
|---|---|---|---|---|---|---|
| 1 | 2 | 1424.4192 | 27 | 4496.0981 | 0.3168123 | 0.7311388 |
| 2 | 2 | 13449.486 | 54 | 987.20728 | 13.623772 | 1.621E-05 |
| 12 | 4 | 1322.5131 | 54 | 987.20728 | 1.3396509 | 0.2671812 |