AN ABSTRACT OF THE THESIS OF

Karen W. Protiva for the degree of Doctor of Philosophy in Human Performance presented on May 9, 1996. Title: Weighted Vest Exercise Improves Functional Ability in Women Over 75 years of age.

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Christine Snow

The purpose of this study was to determine the effects of long-term weighted vest exercise on hip bone mass, functional ability and static balance in elderly women. This was a within subject exercise intervention study and included a 6-month control period. Twenty-three subjects (age 85 ± 6) were recruited and observed for 6-months, then deban a 9-month exercise program. Due to attrition during the control period, five subjects were recruited to add to the exercise group. Training entailed three supervised exercise sessions per week for nine-months designed to overload the lower extremity neuromuscular system. Training stimulus was one of two sets of six to twelve repetitions using weighted vests for progressive resistance. Measurements for bone mineral density (BMD) were assessed using dual energy x-ray absorptiometry (Hologic QDR-1000/W). Static balance measurements were made using the Biodex Stability System. Functional ability tests consisted of: leg strength and power (chair raises and sit to stand) and gait speed (tandem, wide and narrow gait and circular path) and was assessed monthly for six months. Comparisons were conducted using repeated measures analysis of variance. Significant improvements were observed for chair raises 13%, sit to stand 13%, tandem gait 30%, wide gait 22%, narrow gait 20% and circular path 20% following the exercise period. No significant changes were detected ($p>0.05$) for BMD at the femoral neck and trochanter, but BMD was maintained during the exercise period. Further, there was a trend for improved body composition in the exercise versus the control period. Static balance did not change following the observational or exercise period. In conclusion, a practical exercise program of lower extremity training using weighted vests for resistance improves functional ability in women over 75 years of age. Since improved may function transfer to improved postural stability, these results have important implications for design of exercise programs to reduce fall risk in the elderly.

Weighted Vest Exercise Improves Functional Ability in Women Over 75 years of Age

by

Karen W. Protiva

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I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

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CONTRIBUTION OF AUTHORS

Dr. Christine Snow was involved in the design, analysis and writing of the manuscript. Scott Macdonald assisted with exercise training and data collection for the study.

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INTRODUCTION

Osteoporosis is a major health concern in this country. Low bone mass results in 1.5 million fractures per year costing millions of dollars in medical care and lost wages. Two primary factors play important roles in osteoporotic fractures - bone loss and falls. Bone loss and increased risk of falling accompany women as they age, particularly after menopause. Weakness in bone and fear from falling decreases confidence resulting in decreased physical activity. Reduction in physical activity reduces bone mass, muscle strength and postural stability. Muscle weakness in the elderly has been linked to recurrent falls (Anniansen et al., 1984). A decline in muscle strength and low bone mass has been associated with falls leading to hip fractures (Hayes et al., 1996).

Bone mineral density (BMD) decreases with age. This decrease is accelerated during the menopause when estrogen levels are reduced and osteoclastic activity is greater than osteoblastic activity which causes deficits in both cortical and trabecular bone, increasing the incidence of fractures due to low bone mass (Snow-Harter, 1991). Low reproductive hormone production accompanied by bed rest or disuse causes decrements in both trabecular and cortical bone. Issekutz and coworkers (1966) examined the effect of prolonged bed rest to bone mass. The increase in urinary calcium output following prolonged inactivity indicated an uncoupling effect between formation and resorption of bone. The result of prolonged bed rest was low bone mass.

Physical activity is beneficial to bone. Rubin and Lanyon (1985) examined the effect of the magnitude of a stimulus and continuous versus intermittent loading on bone mass. Results indicated that dynamic intermittent loading above the "genetically programmed" or "normal" strain effectively stimulated bone remodeling. In support of these results, Robinson and colleagues (1995) observed elite gymnasts who were exposed to high forces and had an above average BMD at the hip and spine which were significantly higher when compared to elite runners (>30 miles per week). Similar results were observed when comparing gymnasts to swimmers with gymnasts having significantly higher BMD. The most profound difference was at the hip. Walking, a form of exercise often prescribed for the elderly population to increase bone mass has not proven osteogenic (Cavanaugh and Cann, 1988).

Weight-training exercises produce a loading effect shown to benefit bone mass (Snow-Harter et al., 1992), but not more than running. This is useful information considering a decline in muscle strength accompanies the aging process (Fiatarone et al., 1990). Normal aging is accompanied by a 20 to 40% decrease in strength by the age of 60 to 80 years (Hindmarsh et al., 1989). Knee extensor strength is reported to decrease 1-2% per year after the age of 65 years (Skeleton et al., 1995). Theoretically, it should be possible to intervene in the decrease in muscle strength associated with age and disuse. Strength training in the form of weight-training is an option that may be beneficial and appropriate for the elderly. Fiatarone and associates (1990) found weight-training improved strength in the frail elderly after 10 weeks of training. Skeleton and colleagues (1995) observed increases in isokinetic knee extension strength in healthy women aged 75-93 years following a 12-week resistance training program. Neither of these studies examined the effects on bone, whereas Nelson (1994) and Dalsky (1988) observed an association with strength and bone in healthy, young postmenopausal women. In addition to possibly affecting bone, increases in muscle strength may increase postural stability resulting in a higher quality of life, something that should not be dismissed.

Hindmarsh and coworkers (1989) define falls as "events which lead to the conscious subject coming to rest inadvertently on the ground." Falls are the leading cause of death in individuals over the age of 65 years (Hindmarsh et al., 1989). Death due to falls in this age group was 33% in 1987 (Hindmarsh et al., 1989). Almost 90% of hip fractures result from falls (Myers et al., 1996). Falls resulting in fractures are compounded by an increased fear of falling and lack of confidence, which may lead to reduction of daily activities and independence. This fear of falling and reduction in daily activities begins a cycle that is detrimental to overall health. From 20-30% of community dwelling individuals over the age of 65 years experience a fall each year, and half of these persons report multiple falls (Tinetti et al., 1993). The fear of falling and the inability to get up from a fall lead to further restrictions of functional activities (Tinetti et al., 1993). Falls in the elderly are a result of decreased strength in the lower extremity (knee extensors, hip abductors and ankle plantar and dorsi flexors) and changes in vision, proprioception, gait and balance abnormalities (Whipple et al., 1987). Tinetti and associates (1986) found gait and balance as good predictors of fallers. Fallers tend to have difficulty with rising and sitting down, stability when first standing, turning and stepping (Tinetti et al., 1986). Remaining physically active decreases the risk of falls by maintaining or improving balance, flexibility, muscle strength, coordination and reaction time to counteract instability, yet also increases the risk of falls by increasing the exposure to the opportunity to fall (Myers et al., 1996).

Functional ability tests are used to assess agility, balance, gait and strength. This form of testing is very useful when working with elderly individuals. Skeleton and coworkers (1995) evaluated functional ability following a 12-week resistance training program in healthy women aged 75-93 years. There were trends for improvements in rising from a chair and the floor, functional reach and walking. Tinetti and coworkers (1994) observed that men and women living in the community who were at least 70 years of age reduced the number of falls following a resistance exercise program concentrating on muscle strength of the hip, ankle and knee, balance, transfer skills and gait training. Falling is a multifactorial problem which must take into consideration the circumstances of the fall. Therefore, physical activity programs for the older population must be specific to improve the areas associated with falls.

The outcome and success of an exercise program depends on its ability to alter the multiple factors related to fracture risk. Few studies have evaluated exercise in individuals over 75 years. Further interventions to date have not investigated effects on multiple factors.

HYPOTHESIS

The specific hypotheses tested in this study included:

H_O1: Lower body resistance training will not significantly change BMD of the proximal femur.

H_A1: Lower body resistance training will significantly change BMD of the proximal femur.

H_O2: Lower body resistance training will not significant change strength of the ankle plantar and dorsiflexors and knee extensors.

H_A2: Lower body resistance training will significant change strength of the ankle plantar and dorsiflexors and knee extensors.

H_O3: Lower body resistance training will not significant change static balance.

H_A3: Lower body resistance training will significant change static balance.

H_O4: Lower body resistance training will not significant change functional ability as measured by chair raises, sit to stand, tandem, wide and narrow gait and circular path.

H_A4: Lower body resistance training will significant change functional ability as measured by chair raises, sit to stand, tandem, wide and narrow gait and circular path.

DELIMITATIONS

The following were measures taken in order to confine the focus of the study:

1. Individuals living in residential care facilities were recruited to participate. Individuals unable to ambulate without personal assistance were excluded from the study.
2. Bone mineral density was the only index of bone strength.
3. Data collection took place immediately before, during and after the six-month training.
4. The exercise program was a modified weight-training program, utilizing weighted vests to alter resistance in place of traditional equipment such as universal weight machines or free weights.

LIMITATIONS

The following may limit the findings of the study.

1. The subjects were volunteers and therefore could leave the program at any time.

2. There was no control over the effort exerted by the subjects during strength and functional ability tests. Subjects were encouraged to perform to their fullest potential and were provided with detailed descriptions of test protocols.

3. Assessments were not always conducted at the same time of day due to subject schedule and equipment availability. Strength, balance and functional ability may be affected by time of day.

4. The balance measure required subjects to wear a harness for safety which may have introduced a fear factor while performing this measurement.

5. The majority of the participants in this study were not low mobility which contributes to selection bias. Studies that advertise for volunteers for an exercise program are not as likely to recruit those less mobile.

6. Due to attrition, the design of the study was altered to increase subject number. Thus, there is one group who acted as their own controls and another control group that was matched with the exercise group.

7. Functional ability measurements were performed during the exercise period, but not during the control period. Thus, no control times were available for comparison.

Weighted Vest Exercise Improves Functional Ability in Women Over 75 Years of Age

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ABSTRACT

Objective: To determine the effects of long-term lower body resistance exercise using weighted vests on hip bone mass, static balance and functional ability in women over 75 years of age.

Design: This was a within subjects exercise intervention study which included a 6-month control and a 9-month exercise period.

Setting: Oregon State University, Regent Retirement Residence and Timberhill Place, Corvallis, Oregon.

Participants: Twenty-three (age 85 ± 6) subjects were recruited from a retirement facility and acted as their own controls. Over the 6-month control period, ten subjects dropped out due to illness, death and time commitment. Thus, 5 additional subjects were recruited. Attrition during the exercise period was 17%.

Intervention: Training entailed three supervised exercise sessions per week for 9-months. The exercises included, chair raises, lunges in anterior, posterior and lateral directions, squats, stepping, others mimicked daily activities, but also overload. Training stimulus was applied progressively by using weighted vests.

Measurements: Measurements for bone mineral density of the femoral neck and whole body and body composition were assessed by dual energy x-ray absorptiometry (Hologic QDR-1000/W) at baseline, 6 and 15 months. Stability index which included anterior/posterior and medial/lateral static balance measurements were made using the Biodex Stability System at baseline, 3, 6, 9, 12 and 15 months. Functional ability tests consisted of: gait assessments (tandem, wide and narrow gait and circular path) and leg strength and power (chair raises and sit to stand). Data were analyzed using one-way repeated measures of analysis of variance.

Results: Significant improvements were observed for chair raises (18%), sit to stand (5%), tandem gait (34%), wide gait (18%), narrow gait (17%) and circular path (35%) following the exercise period. No significant changes were detected for bone mineral density at the femoral neck or trochanter, but trochanteric BMD was maintained during the exercise versus the control period. Further, there was trend for improved body composition in the exercise versus the control period. Muscular strength and static balance did not change following the observational or exercise period.

Conclusion: A practical exercise program of lower extremity training using weighted vests for resistance improves functional ability in women over 75 years of age. Since physical function is related to fall risk, these result have important implications for design of exercise programs to reduce the incidence of falls in the elderly woman.

INTRODUCTION

As women age, declines in the neuromuscular function and skeletal integrity occur which can result in the development of hip fractures and reduced quality of life (Riggs & Melton, 1992; Lyles et al., 1993). Over 250,000 hip fractures occur annually in this country and carry serious consequences with respect to morbidity and mortality. Current annual costs to the U.S. health care system are estimated at over $10 billion, are expected to rise dramatically with the graying of America (Ray et al., 1997).

Although the etiology of hip fractures is complex, low bone mass and falls play key roles. With age, women suffer bone loss, particularly after menopause (Birkenhager-Frenkel et al., 1988) and an increased risk of falling (Nevitt et al., 1991). The combined effects of disuse and aging result in marked reductions in bone mass and physical function, including muscle strength and postural stability. Several investigators have reported a relationship between low bone mass and risk of fracture (Hui et al., 1988; Ross et al., 1991; Melton et al., 1988). A decline in musculoskeletal function is associated with an increase in falls and incidence of hip fracture (Amnianson et al., 1984; Nevitt et al., 1991). In a large epidemiological study over 7,000 individuals, Meunier and colleagues (1996) recently reported that the two most important predictors of falls were physical function and vision. These results support earlier data of Whipple et al. (1987) who reported that knee and ankle weakness (measured by isokinetic dynamometry) were related to an increase in falls in nursing home residents.

Aging alone has been shown to be negatively correlated with bone mass at the lumbar spine (Hui et al., 1988). Results from our laboratory demonstrate a strong negative association (-0.64, $p<0.001$) between femoral neck BMD and age in 220 women aged 20-82 years. Melton et al. (1988) reported a decline in femoral neck BMD between the ages 55 and 95 years. They concluded that a relatively small increase in BMD would disproportionately decrease hip fracture rates. To date, there are no reports on the exercise effects on hip bone mass in women over 75 years of age.

Studies which examine muscle function in the elderly report an adaptation as a result of resistance training demonstrated by significantly increases in both muscular strength and cross-sectional fiber area (Charette al., 1991; Frontera et al., 1988). Further, Fiatarone et al., (1990) observed a 48% increase in tandem gait speed in nonagenarians who experienced strength improvements averaging 174% after 8 weeks of high intensity strength training (80% of 1-RM). Tandem gait speed is a task that requires muscle strength and balance. The link of muscular strength to balance is most logically in the stabilization required for voluntary movements. Considerable dynamic postural adjustments are made during tests of gait speed.

Since bone mass and physical function are primary risk factors for hip fractures, we designed a study to evaluate the effect of a long-term exercise program targeting lower extremity function on hip bone mass and functional ability in women over 75 years of age. Of the three primary components of postural stability (maintenance of a position, stabilization for voluntary movement and reaction to external disturbances), the emphasis in this exercise intervention was on stabilization for voluntary movement and we expected changes in tests of gait speed will reflect this improvement in balance.

We evaluated the long-term effect of a progressive weight bearing resistance exercise training on bone mass, muscle strength and power (isokinetic dynamometry, chair raises and sit to stand), static balance and functional ability in women over 75 years of age. The training program was designed to progressively overload the skeletal and neuromuscular systems of the lower body by using exercises in the upright position that both mimicked daily activities and also required adaptations to uncustomary activities in the medial lateral direction. The exercise program used weighted vests rather than traditional weight machines to challenge the skeletal and neuromuscular systems.

METHODS

Subjects: Twenty-three subjects were recruited (age 74-94 years) from a local retirement community. This group represents a more frail elderly population since they are relieved of many household responsibilities (cooking, cleaning, gardening) but did enjoy some independence with respect to recreation activities and had no cognitive impairments. This group primarily engaged in walking type activities. A "sit and be fit" class was offered two times per week which subjects did not frequent. This class was structured to stretch while in the seated position. Subjects were asked to continue with regular daily activities throughout the study.

The first six months represented an observation/control period over which time these subjects were evaluated on bone, anthropometric variables and balance. During this time 10 subjects dropped out due to illness, death and time difficulties. The remaining 13 subjects began a 9-month progressive exercise program, but only 10 completed the program. To increase the subject numbers, an additional 5 women were recruited and data were collected at baseline, 3, 6 and 9 months then pooled with the ten original recruits. Due to unreliable strength measurements, tests of functional ability were added at the initiation of the exercise program and conducted monthly for 6 months.Thus, there were no control data for comparisons. The study was approved by the Oregon State University Institutional Review Board and all subjects gave written consent prior to participation.

Study Design: All tests were performed in the same order, with rests to avoid fatigue. BMD was measured at baseline and 6 months during the control period and the exercise group was measured at the beginning and end of the 9-month training. Static balance was measured every three months while functional ability was assessed monthly for 6-months. All assessments were performed by the same investigators. All tests were demonstrated and explained to the subjects.

Bone Mineral Density Measurements: Bone mineral density (BMD) was determined for the whole body, proximal femur and trochanter using dual energy x-ray absorptiometry (Hologic QDR-1000/W). The coefficients of variation for these procedures at the Oregon State University Bone Research Laboratory are 1.0% for whole body BMD and proximal femur BMD. Radiation doses to the subjects are very low: 2.0 to 5.0 milliRem for the regional scans and less than 1.5 milliRem for whole body scan.

Balance: Static balance measurements were assessed using the Biodex Stability System. The coefficients of variation for this measurement in our laboratory is 8%. At baseline the subject's center was established during the centering process where the subjects were asked to position themselves so the platform was flat and the cursor centered. This position was recorded and used for each additional measurements. Stability index (SI) represents the variance of platform displacement in degrees from level in all motions during a test. Anterior/posterior stability index represents the variance of platform displacement in degrees from level in the sagittal plane. Medial/lateral stability index represents the variance of platform displacement in degrees from level in the frontal plane.

Prior to assessing balance a support harness was attached to insure safety. Subjects were allowed two practice trials to become familiar with the test and to assure proper positioning. Subjects were instructed not to use the hand-rails unless necessary. The practice trials were followed by two test trials and the best score recorded. Balance was evaluated at baseline, month 3 and 6 in all subjects.

Functional Ability Tests:

Gait Speed: Tandem Gait, Wide and Narrow Gait and circular path:: To perform tandem gait test subjects were asked to walk, heel to toe for 19 feet 6 inches. The subjects were instructed to and assisted on proper technique. The investigator held onto one arm for safety purposes when needed. For wide and narrow gait test subjects walked, as quickly as possible, for ten feet with their feet 12 and 6 inches apart, respectively. To perform circular path test subjects were asked to follow a "s" shaped path, marked by a secured rope to assure proper foot placement, for twenty feet with their feet six inches apart. For the wide and narrow gait and circular path tests, a rope was used to standardize foot placement and subjects were instructed to keep their feet on the outside of the rope. The tests were performed once and time (sec.) recorded. The coefficient of variations for this measurement in our laboratory are 10-12%.

Leg Strength and Power: Chair Raises and Sit to Stand: To perform chair raises subjects were asked to sit on a hard back chair and at the given command stand as quickly as possible. The sit to stand test required the subjects to sit on a hard back chair, stand to full extension and return to the seated position as quickly as possible. Subjects were asked to perform these tests without use of hands. The tests were performed twice and the best score recorded. The coefficients of variation for these tests in our laboratory is 10-15%.

Training: Each class began with a warm-up and emphasized the muscles being worked, followed by an active session of lower body resistance exercises and ended with a cool-down period and stepping on a six inch step. The exercisers were asked to wear a vest so that additional weights, in 0.5 pound increments, could be easily increased during the 9-month training period. The program began with the subjects wearing the vests for comfort and concentrating on proper technique. Vest weight increased in increments of 1% of the participants body weight. If this weight was too high, the weight was reduced to accommodate individual ability. The exercise training program (Table 1) was based on progressive loading, but was individualized as needed. As the weights in the vest reached 6% of body weight, the exercise group experienced fatigue and technique was compromised. The repetitions and sets were lowered to help with compliance and to prevent injury. The group completed the training period with 6.5% of body weight added to the vests for resistance.

Each training period consisted of one to two sets of six to twelve repetitions. The exercises performed included chair raises, squats, toe raises, forward and side lunges, standing straight leg extensions and flexions, standing hamstring curls and stepping. Chair raises were conducted on hard back chairs that allowed for ~90 degree knee angle. Subjects were asked to perform this exercise without the use of hands. Initially the majority of the class was unable to perform chair raises without hands, therefore were allowed use of hands to stand. Squats were performed while holding onto the back of a chair for support. Subjects were encouraged to squat as low as possible, not to exceed ~90 degree knee angle. The majority of the class performed half squats (~120 degree knee angle). Toe raises were followed by asking subjects to rock back to the heels. Forward and side lunges were performed while holding onto the side of a chair. Subjects were encouraged to lunge as low as possible, not to exceed ~ 90 degree knee angle. Modifications were made for those who had knee trouble or could not perform this exercise. Standing straight leg raises were controlled and subjects were asked to concentrate on leg height (~ 90 degree hip angle), proper posture and stability while standing on one leg. The training period was completed with subjects stepping on a six inch step for three to six repetitions, depending on the weight in the vests.

Table 1. Exercise Training Program Outline

Weeks	Sets	Repetitions	Intensity *
1-4	1	8	0
5	1	10	0
6-7	2	6	0
8-10	2	10	0
11-14	2	6	2
15	1	6	5
16-17	2	6	5
18	2	10	5
19-20	1	6	6
21-22	2	6	6
23-24	2	10	6
25-27	2	6	6
28-30	2	10	6
31-34	1	8	6.5
35-36	1	10	6.5

* Intensity was defined as a percentage of body weight

The two instructors of the exercise class emphasized proper technique and safety. The 9-month training program was designed to increase strength of the lower extremities and was based on principles of progression, overload and specificity. Classes were held at the residence of the subjects three times per week with at least one day of rest between classes.

STATISTICAL ANALYSIS

All analyses were performed using Statview (Abacus, Inc.). Descriptive statistics were conducted to report means and standard deviations. The data were treated in two ways given the recruitment of additional subjects in the exercise intervention period. In the initial within group design, data were analyzed using repeated measures ANOVA. When additional subjects were added to the exercise group, the percent change scores were analyzed using one-way ANOVA's and Bonferroni adjustments were made to correct for multiple comparisons. Initial differences were evaluated using one-way ANOVA on scores at baseline for the newly-recruited exercise subjects (n=5) compared with values at exercise initiation for those subjects (n=10) who had completed the 6-month control period.

RESULTS

Of the initial twenty-three subjects recruited, ten stopped the study during the 6-month control period. There were two deaths, 5 left due to illness, one needed to care for her spouse and remaining had scheduling difficulties. Thirteen women began the exercise program and three dropped out for similar reasons, thus ten women from the original group (age 85 $\pm$ 6) completed 9-months of training. Five additional women were recruited and completed a 9-month training program following the same guidelines as the first training period. The recruited group had similar baseline characteristics as the initial group. Although not significant, the recruited group were lighter and had less fat than the initial group.

The 15 women who began and completed the study did not change their pre-training levels of physical activity. The typical form of physical activity was walking for pleasure or shopping, averaging approximately two hours per week. Meals were prepared and served for each individual. Variations were made on beverage selection and dessert denial. Subjects looked forward to spending meal times together and missed meals, only if they were ill or went out for a meal. Values for height, weight, percent fat, lean mass and fat mass did not significantly change during the control nor the exercise period (Table 2).

Table 2. Absolute Values During Control and Exercise Period

	Control Baseline	Month 6	Exercise Month 15
Wt. (kg)	58.1 (8)	59.4 (9)	60.2 (11)
% Fat	30.2 (4)	31.9 (4)	32.2 (5)
Lean (kg)	38.8 (5)	38.6 (5)	38.7 (5)
Fat (kg)	17.7 (4)	19.2 (5)	19.8 (6)

Average attendance to the training program was 86% (range 56 to 100%). During the holiday season many participants were absent due to familial responsibilities. Exercise training averaged 3 hours/week of weight-bearing exercises for 9-months. Exercises did not produce discomfort and participants complained about muscle soreness minimally and only after weights were added to the vests.

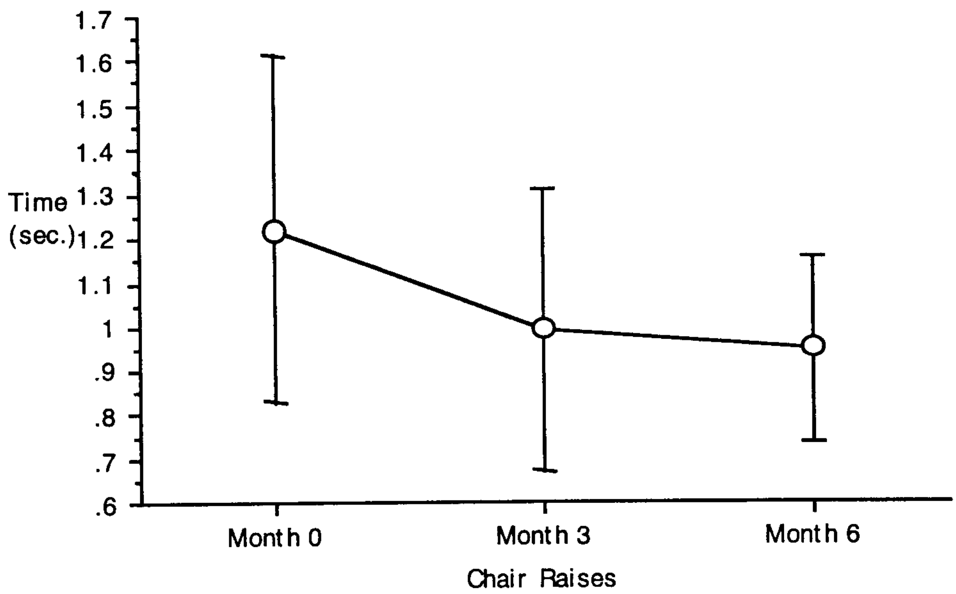
Monthly testing of lower extremity strength and power (chair raises 13% and sit to stand 13%) and gait speed (tandem gait 30%, wide gait 22%, narrow gait 20% and circular path 20%) significantly improved (p<0.05-0.001) (Table 3) (Figures 1-6).

Table 3. Functional Ability Absolute Values

	Exercise Month 0	Exercise Month 6	% Change
Chair Raises (sec.)	1.22 (1.2)	1.01 (0.2)#	13
Sit to Stand	2.40 (0.4)	2.11 (0.4)#	13
Tandem Gait (sec.)	27.2 (12.1)	17.68 (5.6)#	30
Wide Gait (sec.)	5.29 (3.1)	4.01 (1.9)#	22
Narrow Gait (sec.)	5.75 (4.4)	3.96 (1.7)#	20
Circular Path (sec.)	16.2 (14.7)	11.88 (10.6)#	20

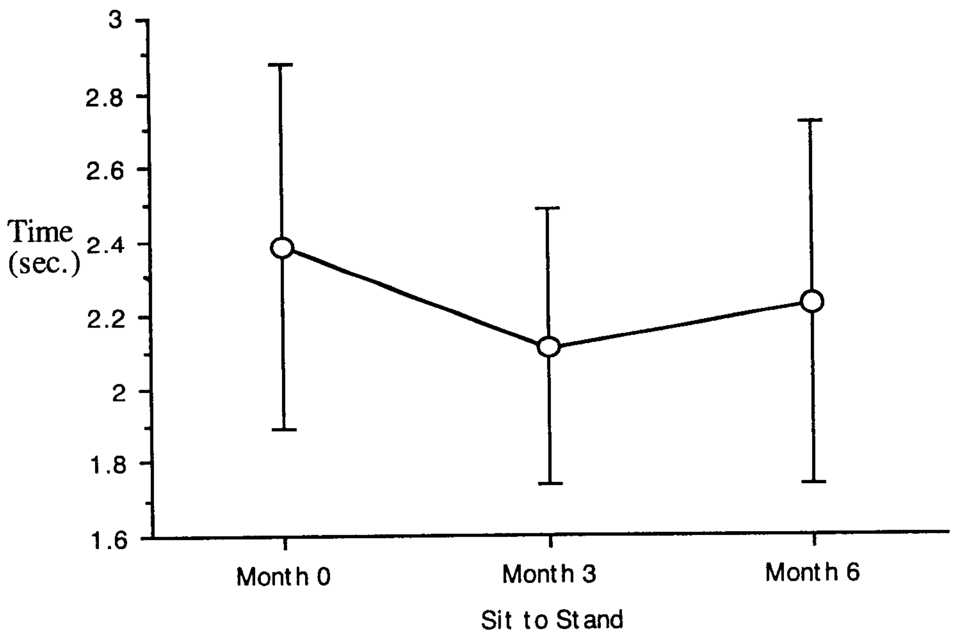
Post study values faster then baseline values p<0.05

Figure 1. Leg Strength: Chair Raises Month 0, 3 and 6



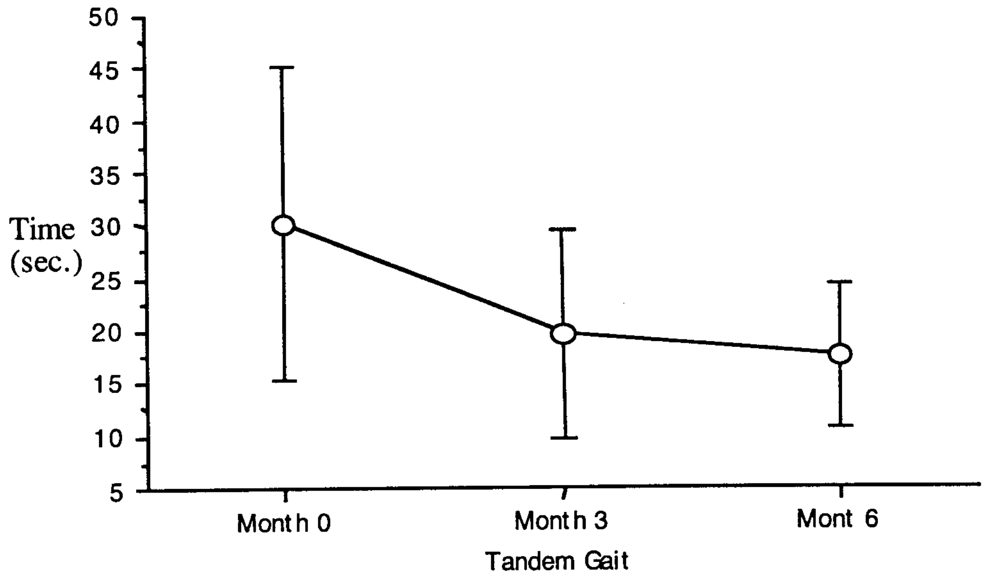
$p = 0.05$

Figure 2. Leg Strength: Sit to Stand Month 0, 3 and 6



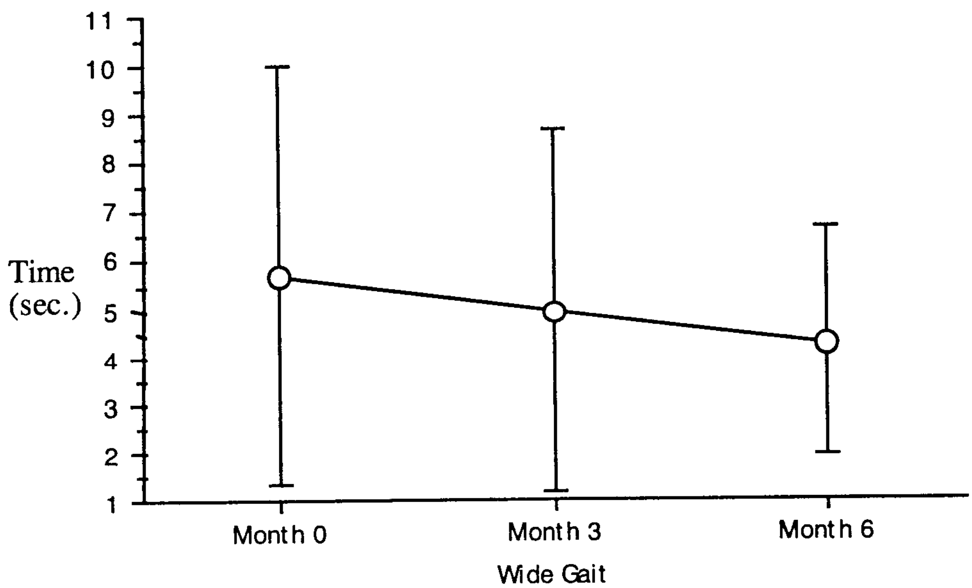
$p < 0.05$

Figure 3. Gait Speed: Tandem Gait Month 0, 3 and 6



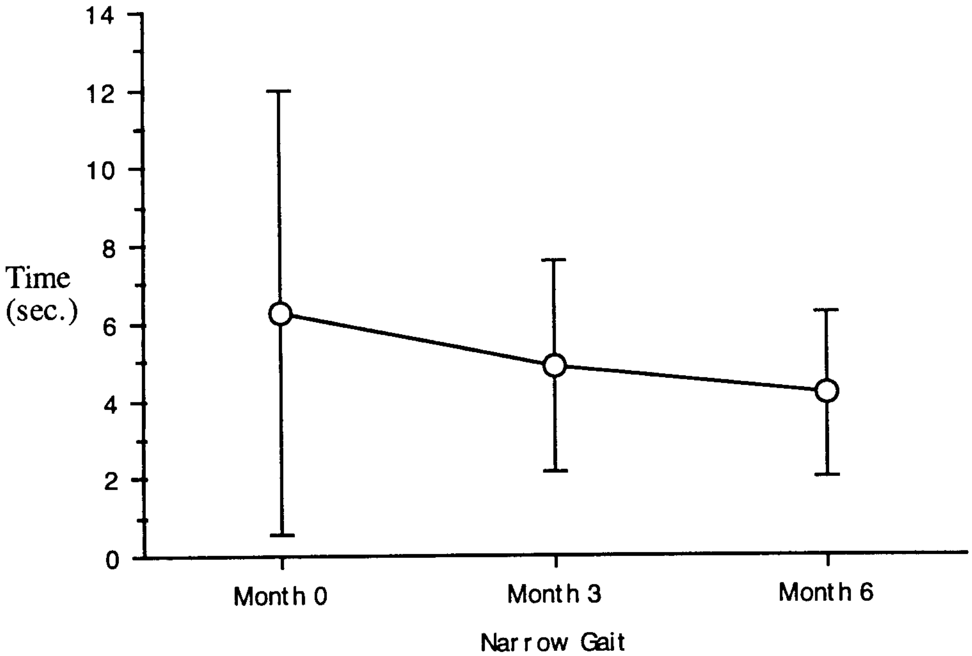
$p < 0.005$

Figure 4. Gait Speed: Wide Gait Month 0, 3 and 6



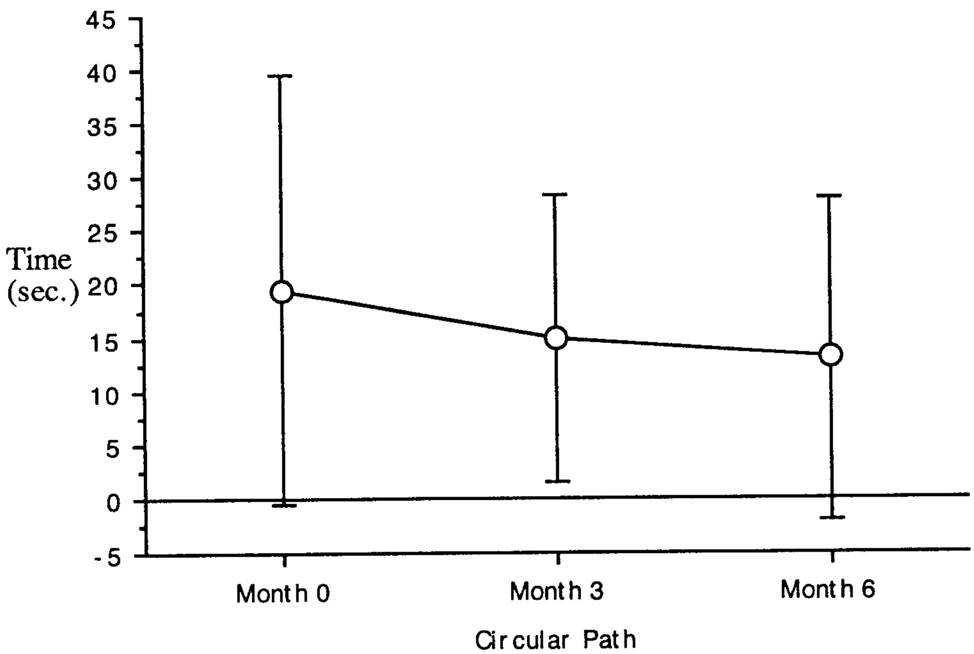
$p < 0.05$

Figure 5. Gait Speed: Narrow Gait Month 0, 3 and 6



p = 0.05

Figure 6. Gait Speed: Circular Path Month 0, 3 and 6



p = 0.01

Bone mass at the femoral neck, trochanter, hip and whole body did not significantly change following the control or exercise period, yet there was a trend for trochanter bone mass to increase during the exercise period (Table 4). Stability index, anterior/posterior and medial/lateral balance improved 11%, 14% and 6%, respectively following the 9-month intervention period, but values were not significantly different from the control ($p>0.05$) (Table 5).

Table 4. BMD During Control and Exercise Period

	Control Baseline	Month 6	Exercise Month 15
Fneck (BMD) g/cm^2	.533 (.095)	.542 (.093)	.544 (.115)
TR (BMD) g/cm^2	.455 (.061)	.444 (.060)	.441 (.058)
Hip (BMD) g/cm^2	.592 (.082)	.586 (.083)	.585 (.078)
WB (BMD) g/cm^2	.904 (.044)	.900 (.049)	.904 (.073)

Table 5. Stability Index During Control and Exercise Period

	Control Baseline	Month 6	Exercise Month 15
SI	2.9 (1.6	2.7 (1.5)	2.4 (1.4)
A/P	2.3 (1.4)	2.1 (0.9)	1.8 (0.9)
M/L	1.7 (1.2)	1.8 (1.4)	1.7 (1.3)

DISCUSSION

We evaluated the long-term effect of weight bearing resistance exercise using weighted vests on indices of fracture risk, i.e. bone mass, muscle strength, static balance and tests of functional ability, in women over 75 years of age. Although no changes in bone mass were observed, significant improvements in functional ability were seen after the 6-month training period. Specifically, exercisers improved on gait speed in a tandem test, on wide and narrow stances, and in a circular, S-shaped path. Further, improvements were observed in exercisers on chair raises and sit to stand tests. These results indicate a neuromuscular training response to the exercise program.

We are the first to report long-term effects of "weight-bearing" lower body resistance exercise on hip fracture risk factors in women over 75 years in age. We imposed overload using a weighted vest and two types of exercises. Some of the exercises mimicked daily activities, i.e. stair climbing, chair raises, squatting, while others involved more uncustomary movements to the side. Some exercises mimicked daily activities, therefore would have direct transfer into activities of daily living and also exercises that were uncustomary improved in static balance tests and time on the circular path gait test which increased by 35%. This test required significant postural adjustments in the lateral direction as individuals needed to follow an S-shaped curve.

While we had hypothesized that bone mineral density at the femoral neck and trochanter would improve from 9-months of lower extremity "loading", we speculate that the loads were not of sufficient magnitude to stimulate osteogenesis. During the control period, trochanteric bone mass declined, although not significantly and there was a trend for it to increase during the exercise period. It is likely that with greater subject numbers, this change would be significant. Further, "old" bone may not be as responsive to loading as is younger bone, thus a training response is not as likely. We consider these results to be a strength of the study in that exercise programs to reduce "osteoporosis" should not target bone changes, rather direct efforts on reducing fall risk. Since 90% of hip fractures occur from a fall to the side, and since the hip is not responsive to loads of the magnitudes imposed in this study, exercise programs should emphasize neuromuscular improvements, rather than bone changes.

We expected to observe improvements in stability index, but, following testing, were not surprised that no significant changes were demonstrated given problems with instrumentation. The platform on the Biodex stabilometer had a series of "sticking" problems, thus we cannot rely on these data to be reliable. Further, the harness that was used to "stabilize" the subjects proved uncomfortable and restrictive.

Results from the functional tests prove far more reliable and we observed significant improvements on each of these tests, the greatest of which occurred after the first 3-months of training. Exercise training in the side-to-side direction could improve reaction time and recovery from a stumble, thus be potentially effective in preventing a fall to the side. The exercisers did improve their time on the S-shaped curve gait test. This test required considerable postural adjustments in the medial lateral direction, thus could transfer to recovery from a side fall. This is merely speculative at this time and must be tested in a controlled trial evaluating the effect of this program on fall reduction.

It is unfortunate that attrition was so high, but, in all cases but 3, the causes were illness, death and unforeseen circumstances (such as taking care of an ailing spouse). Given the length of the program, it may not be surprising that the attrition rate was as high as we observed in this age group.

In this group of very elderly women, there was some resistance to increasing the weights in the vests initially, given the level of difficulty that accompanied this change. However, this attitude softened with time and toward the end, the women had no reluctance to wearing the vests. Time was the critical factor in this transition for our subjects. In fact, at the end of the program, there was sincere interest in continuing the exercises and the subjects wished to hire an instructor for their needs. We believe that the long-term nature of the program was responsible for the high level of compliance as well as the benefits gained.

Few investigations have evaluated functional ability response to a long-term resistance training program in women over 75 years of age. Skeleton and colleagues (1995) performed a short-term resistance training program in older women and reported trends for, but no significance in functional ability (time rising from a chair and floor, walking). Fiatarone and coworkers (1990) also performed a short-term resistance training program in older adults. This group reported significant improvements in functional ability. Neither group had control data for comparisons. The majority of functional ability tests include chair raises and gait speed. These activities measure leg strength, power, agility and balance, which are required to perform activities of daily living successfully.

Accurately measuring leg strength and power is important, particularly in this population since these two factors are reported as being associated with falls and fracture risks. Functional ability tests were not originally scheduled, but after the 6-month control period the decision to perform these tests on leg strength and power and gait speed was made primarily due to unreliable strength assessments. Accurate measurements on leg strength and power and gait speed may also transfer to improvements on activities of daily living. As a result of the delayed measurements on functional ability, there was no control data for comparisons. Another limitation was the low subject numbers which required a recruitment for additional subjects. These subjects were measured on the same functional ability test and time line and data were pooled.

To date, there are no reports on hip bone changes from exercise training in women over 75 years. The majority of physical activity programs for this group focus on chair exercises which emphasize stretching and muscle endurance or seated strength training activities. This form of exercise, while it can maintain and promote range of motion, does not place any load on the bones of the hip, nor does it challenge the neuromuscular system of the lower extremities. Further, the hips are unloaded in the sitting position, thus the current chair exercise programs do not induce bone strain at the hip. Nelson et al. (1995) reported increases in hip bone mass as a result of strength training at 80% of 1-RM on weight machines, but this was in a younger population of older women who could sustain higher loads than those reported in the present study.

There is a growing interest in promoting resistance exercise among the older, more frail population, but few reports and results are mixed (Fiatarone et al., 1990, Skeleton et al., 1995). Fiatarone and colleagues (1991) reported that nonagenarians improved tandem gait speed and muscle strength as a result of a machine-based strength training program. However, other programs have been unsuccessful in augmenting strength among more elderly individuals (Thompson JAGS, 1988; Morey JAGS, 1989). From these reports, it is clear that intensity is a key factor in promoting the most significant strength gains. However, no programs have emphasized activities that are weight bearing in nature and use progressive resistance. Since our strength assessments were unreliable, we evaluated the effect of the exercise on test that require relatively high levels of strength and power, such as chair raises and sit to stand. These tests proved to be appropriate for the population we were investigating in that they were non-threatening and familiar. These forms of measurements transfer to activities of daily living since they tend to mimic those activities used every day.

The ultimate success of an exercise intervention study aimed at reducing hip fractures is its effect on hip fracture risk. Prior to conducting a large clinical trial to test this hypothesis, it is important to determine the exercises that improve predictors of hip fractures, i.e. bone mass and falls. We studied the bone and neuromuscular response to lower extremity resistance exercise by using a weighted vest to load the legs and hips and by including weight bearing activities. During weight bearing activities, dynamic postural adjustments are continually required to stabilize the body in order to stay upright. In this program, the neuromuscular system was challenged and overloaded by including uncustomary movements to the side and by adding resistance using small weights in a vest. The exercises were chosen to challenge the neuromuscular system in anterior posterior (stair stepping, chair raises) as well as the medial lateral directions (lunges, steps to the side), thus were expected to improve strength, power and postural stability.

Results of this intervention indicate that the exercises were effective in improving postural stability, an important predictor of falls. More importantly, adjustments in stability in the lateral direction were increased, an improvement which could potentially reduce falls to the side. Since 90% of hip fractures occur from a fall to the side, exercise programs should emphasize neuromuscular improvements, rather than bone changes, since the neuromuscular system is clearly far more responsive to progressive training than is the skeletal system at this age. Further, the loads that would be necessary to elicit an significantly osteogenic response could prove injurious to this elderly population. The program is safe, non-threatening, easy to administer, progressive and could easily be taught to activity directors and their assistants. These results have implications for implementation of this practical exercise program in home, community and retirement and assisted living facilities and emphasize the importance of focusing on fall risk reduction rather than bone mass in reducing the incidence of hip fractures.

REFERENCES

Birkenhager -Frenkel DH, Courpron EA & Hupscher (1988). Age-related changes in concellous bone structure. Bone Mineral, 4, 197-216.

Dargent-Molina P, Favier F, Grandjean H, Baudoin C, Schott AM, Housherre, Meunier PJ & Breart G (1996). Fall-related factors and risk of hip fractures: the EPIDOS prospective study. Lancet, 348, 145-149.

Fiatarone MA, Marks EC, Ryan ND, Meredith CN, Lipsitz LA & Evans WJ (1990). High intensity strength training in nonagenarians. Journal of the American Medical Association, 262, 3029-3033.

Fiatarone MA, Evans WJ. (1993). The etiology and reversibility of muscle dysfunction in the aged. Journal of Gerontology, 48, 77-83.

Frontera WR, Meredith CN, O'Reilly KP, Knuttgen HG, & Evans WJ (1988). Strength conditioning in older men: skeletal muscle hypertrophy and improved function. Journal of Applied Physiology, 64, 1038-1044.

Hui SL, Slemenda CW & Johnston CC (1988). Age and bone mass as predictors of fracture in a prospective study. Journal of Clinical Investigation, 81, 1804-1809.

Lyles KW, Gold DT, Shipp KM, Pieper CF, Martinez S, Mulhausen PL. (1993). Association of osteoporotic vertebral compression fractures with impaired functional status. American Journal of medicine, 94, 595-601.

Melton III LJ, Kan SH, Wahner HW, Riggs BL. (1988). Lifetime fracture risk: an approach to hip fracture risk assessment based on bone mineral density and age. Journal of Clinical Epidemiology, 41, 985-994.

Morey MC, Cowper PA, Feussner JR, DePasquale RC, Crowley GM, Kitzman DW & Sullivan RJ (1989). Evulation of a supervised exercise program in a geriatric population. Journal of American Geriatric Society, 37, 348-354.

Nashner LM. (1989) Sensory, neuromuscular, and biomechanical contributes to human balance. In Duncan P, ed. Proceeding of the APTA Forum. Nashville, p 5-12.

Nevitt MC, Cummings SR, Hudes ES. (1991) Risk factors for injurious falls: a prospective study. Journal of Gerontology, 46, M164-170.

Pocock N, Eisman J, Gwinn T, Sambrook P, Kelly P, Freund J, Yeates M. (1989). Muscle strength, physical fitness and weight, but not age predict femoral neck bone mass. Journal of Bone Mineral Research, 4, 441-448.

Pruitt LA, Jackson RD, Bartles RL, Lehnhard HJ. ( ). Weight-training effects on bone mineral density in early postmenopausal women. Journal of Bone Mineral Research, 7, 179-185.

Ray NF, Chan JK, Thamer M, Melton LJ. (1997). Medical expenditures for the treatment of osteoporotic fractures in the United States in 1995: report from the National Osteoporosis Foundation. Journal of Bone Mineral Research, 12, 24-35.

Riggs BL, Melton III LJ. (1992). The prevention and treatment of osteoporosis. New England Journal of Medicine, 327, 620-627.

Robinson TL, Snow-Harter C, Taaffee DR, Gillis D & Shaw J (1995). Gymnasts exhibit higher bone mass than runners despite similar prevalence of amenorrhea and oligomenorrhea. Journal of Bone Mineral Research, 10, 26-35.

Ross PD, Davis JW & Epstein RS (1991). Pre-existing fractures and bone mass predict vertebral fracture incidence in women. Annals of Internal Medicine, 114, 919-923.

Skeleton DA, Young A, Greig CA & Malbut KE (1995). Effects of resistance training on strength, power, and selected functional abilities of women aged 75 and older. Journal of American Geriatric Society, 43, 1081-1087.

Thompson RF, Crist DM, Marsh M & Rsenthal M (1988). Effects of physical exercise for elderly patients with physical impairments. Journal of American Geriatric Society, 36, 130-135.

Whipple RH, Wolfson LI & Amerman PM (1987). The relationship of knee and ankle weakness to falls in nursing home residents: an isokinetic study. Journal of American Geriatric Society, 35, 13-20.

CONCLUSION

Physical activity used as interventions for fracture risk factors in the frail elderly population should remember that functional improvements are as important as improvements in bone mass, muscle strength and balance. A variety of physical activities need to be observed in the frail population to determine the type and duration of exercise that best benefits fracture risk factors. Although no interventions have proven effective for all indices of fracture risks, identifying those exercises that can change certain factors is critical. There may not be only one exercise program that fits this population and benefits all indices of fracture risks. More research is needed to identify intervention methods for benefiting BMD, muscle strength and improving balance and functional ability, and controlled, longitudinal trails are needed to assess the effectiveness of these interventions.

Since there are limited studies showing the effectiveness of specific interventions, recommendations for future research for the frail elderly population living with or without assisted care are as follows:

1. Establishing reliable and accurate testing procedures for the frail population. Particularly those measurements that assess fracture risk factors and are not intimidating to the frail population.
2. Interventions should observe frail individuals living with or without assisted care. The subjects should act as their own controls or a matched control group should be established. The intervention should concentrate on activities that can be performed in the place of residence as well as continued throughout life.
3. Interpretation of fundamental changes in daily tasks should be performed before, during and after a longitudinal exercise program.
4. Developing functional ability tests that measure common tasks found difficult to perform in daily routines should accompany a longitudinal lower body resistance exercise program.

The functional ability tests should be evaluated in the residence home and require minimum equipment.

5. Developing an exercise program(s) concentrating on muscle groups necessary to perform difficult tasks commonly associated with falls such as: stair ascending and descending, turning, gait speed and form and reaction time.

6. Assessment of muscle strength of the knee extensors, ankle plantar and dorsiflexors and hip abductors should be observed before, during and following a longitudinal lower body resistance exercise program. One group should have specific muscle groups assessed by the same or similar exercises and equipment that were used during the study, while another group should have muscle strength assessed by a machine not associated with the exercise program. Both exercise groups should be compared to a control group.

BIBLIOGRAPHY

Agre JC, Pierce LE, Raab DM, McAdams M & Smith EL (1988). Light resistance and stretching exercise in elderly women: Effect upon strength. Archives of Physical and Medical Rehabilitation, 69, 273-276.

Aloia JF, McGowan DM, Vaswani AN, Ross P, & Cohn SH (1991). Relationship of menopause to skeletal and muscle mass. American Journal of Clinical Nutrition, 53, 1378-1383.

Aloia JI, Cohn SH, Babu T & Ostani JA (1978). Skeletal mass and body composition in marathon runner. Metabolism, 27, 1793-1796.

Anonymous. (1992). QDR Insights, 3, 1-10.

Annianson A, Zitterber C & Hedber M. (1984).Impaired muscle function with aging. Clinical Orthopedic Rehabilitation Research, 191, 193-210.

Bergh U, Kanstrup IL & Ekblom B. (1986). Maximal oxygen uptake during exercise with various combinations of arm and leg work. Journal of Applied Physiology, 11, 191-196.

Bevier WC, Wiswell RA, Gisela P, Kozak KC, Newhall KM & Marcus R. (1989). Relationship of body composition, muscle strength, and aerobic capacity to bone mineral density in older men and women. Journal of Bone Mineral Research, 4, 421-432.

Beverly MC, Rider TA, Evans MJ & Smith R. (1989). Local Bone Mineral Response to Brief Exercise that Stressed the Skeleton. British Medical Journal, 299, 233-235.

Birkenhager -Frenkel DH, Courpron EA & Hupscher (1988). Age-related changes in concellous bone structure. Bone Mineral, 4, 197-216.

Burr DB, Martin RB, Schaffler MB & Radin EL (1985). Bone remodelling in response to in vivo fatigue microdamage. Journal of Biomechanics, 18, 711-714.

Cavanaugh DJ & Cann CE (1988). Brisk Walking Does Not Stop Bone Loss in Postmenopausal Women. Bone, 9, 201-204.

Capozzo A. (1983). Force Actions in the Human Trunk During Running. Journal of Sports Medicine, 23, 14-22.

Chow RK, Harrison JE, Brown CF & Hajek M. (1986). Physical Fitness effect on bone mass in premenopausal women. Archives of physical Medicine and Rehabilitation, 67, 231-234.

Dalsky G, Stocke KS & Ehsani AA (1988). Weight-Bearing Exercise Training and Lumbar Bone Mineral Content in Postmenopausal Women. Annual International Medicine, 108, 824-828.

Dalsky G (1990). Effect of exercise on bone: permissive influence of estrogen and calcium. Medicine and Science in Sport and Exercise, 22, 281-285.

Dargent-Molina P, Favier F, Grandjean H, Baudoin C, Schott AM, Housherre, Meunier PJ & Breart G (1996). Fall-related factors and risk of hip fractures: the EPIDOS prospective study. Lancet, 348, 145-149.

Donaldson CL, Hulley SB, Vogel JM, Harter RS, Bayers JH & McMillan DE (1970). Effect of prolonged best rest on bone mineral. Metabolism, 19, 1071-1084.

Duncan DW, Weiner DK, Chandler J & Studenson S. (1990). Functional Reach: a new clinical measure of balance. Journal of Gerontology, 45, M192-197.

Fiatarone MA, Marks EC, Ryan ND, Meredith CN, Lipsitz LA & Evans WJ (1990). High intensity strength training in nonagenarians. Journal of the American Medical Association, 262, 3029-303.

Fiatarone MA, Evans WJ. (1993). The etiology and reversibility of muscle dysfunction in the aged. Journal of Gerontology, 48, 77-83.

Forwood MR & Burr DB (1993). Physical activity and bone mass: exercise in futility. Bone Mineral, 21, 89-112.

Frontera WR, Meredith CN, O'Reilly KP, Knuttgen HG & Evans WJ (1988). Strength conditioning in older men: skeletal muscle hypertrophy and improved function. Journal of Applied Physiology, 64, 1038-1044.

Frost HM (1990). Skeletal structural adaptations to mechanical usage (SATMU): 1. Redefining Wolff's law: The bone modeling problem. The Anatomical Record, 226, 403-413.

Gehlsen GM & Whaley MH (1990). Falls in the elderly: PartII, balance, strength, and flexibility. Archives of Physical Medicine and Rehabilitation, 71, 739-741.

Gleeson PB, Protas EJ, LeBlanc AD, Schneider VS & Evans HJ (1990). Effects of weight lifting on bone mineral density in premenopausal women. Journal of Bone and Mineral Research, 5, 153-158.

Grove KA & Londeree BR (1992). Bone density in postmenopausal women: high impact vs low impact exercise. Medicine, Science, Sport and Exercise, 24, 1190-1194.

Hayes WC, Myers ER, Robinovitch SN, VanDen Kroonenber A, Courtney AC & McMahon TA (1996). Etiology and prevention of age-related hip fractures. Bone, 18, 77S-86S.

Hui SL, Slemenda CW & Johnston CC (1988). Age and bone mass as predictors of fracture in a prospective study. Journal of Clinical Investigation, 81, 1804-1809.

Hurgens AR (1994). Recent bed rest results and countermeasure development at NASA. Acta Physiologival Scandinavian, 616, 103-114.

Issekutz B, Blizzard JJ, Birkhead NC & Rodahl K. (1966). Effect of prolonged bed rest on urinary calcium output. Journal of Applied Physiology, 21, 1013-1020.

Kellie SE (1992). Measurements of bone density with dual-energy x-ray absorptiometry. Journal of American Medical Association, 267, 286-293.

Krohler B & Toft B (1983). Vetebral bone loss: An unheeded side effect of therapeutic bed rest. Clinical Science, 64, 537.

Lanyon LE (1987). Functional strain in bone tissue as an objective, and controlling stimulus for adaptive bone remodelling. Journal of Biomechanics, 20, 1083-1093.

Leach CS, Cintron NM & Krauhs JM (1991). Metabolic changes observed in astronauts. Journal of Clinical Pharmacology, 31, 921-927.

Lindsay R (1993). Hormone replacement therapy for prevention and treatment of osteoporosis. American Journal of Medicine, 95, 37S-39S.

Lyles KW, Gold DT, Shipp KM, Pieper CF, Martinez S, Mulhausen PL. (1993). Association of osteoporotic vertebral compression fractures with impaired functional status. American Journal of medicine, 94, 595-601.

Marcus R, Drinkwater B, Dalsky G, Dufek J, Raab D, Slemenda C et al., (1992). Osteoporosis and exercise in women. Medicine Science Sport and Exercise, 24, S301-7.

Marcus R (1987). Calcium intake and skeletal integrity: Is there a critical relationship? Journal of Nutrition, 117, 631-635.

Marcus R & Carter DR (1988). The role of physical activity in bone mass regulation. Advances in Sports Medicine Fitness, 1, 63-82.

Melton III LJ, Kan SH, Wahner HW, Riggs BL. (1988). Lifetime fracture risk: an approach to hip fracture risk assessment based on bone mineral density and age. Journal of Clinical Epidemiology, 41, 985-994.

Morey MC, Cowper PA, Feussner JR, DePasquale RC, Crowley GM, Kitzman DW & Sullivan RJ (1989). Evulation of a supervised exercise program in a geriatric population. Journal of American Geriatric Society, 37, 348-354.

Myers AH, Young Y & Langlois JA (1996). Prevention of falls in the elderly. Bone, 18, 87S-101S.

Nashner LM. (1989) Sensory, neuromuscular, and biomechanical contributes to human balance. In Duncan P, ed. Proceeding of the APTA Forum. Nashville, p 5-12.

Nelson ME, Fiatarone MA, Morganti CM, Trice I, Greenberg RA & Evans WJ (1994). Effects of high-intensity strength training on multiple risk factors for osteoporotic fractures. Journal of American Medical Association, 272, 1909-1914.

Nelson ME, Fisher EC, Dilmonian FA, Pallol GE & Evans WJ (1991). A 1-Y Walking Program and Increased Dietary Calcium in Postmenopausal Women: Effect a Bone. American Journal of Clinical Nutrition, 53, 1304-1322.

Nelson ME, Meredith CN & Dawson-Houghes B (1988). Hormone and Bone Mineral Statusin Endurance-Trained and Sedentary Postmenopausal Women. Journal of Clinical Endocrinology Metabolism, 66, 927-933.

Nevitt MC, Cummings SR, Hudes ES. (1991) Risk factors for injurious falls: a prospective study. Journal of Gerontology, 46, M164-170.

Nishimura Y, Fukuoka H, Kiriyaama M, Suzuki Y, Oyaama K, Ikaawaa S, Higurashi M, & Gunji A (1994). Bone turnover and calcium metabolism during 20 days bed rest in young healthy males and females. Acta Physiological Scandinavian, 616, 27-35.

O'Connor JA, Lanyon LE & MacFie H (1982). The influence of strain rate on adaptive bone remodeling. Journal of Biomechanics, 15, 767-781.

Orwoll ES, Ferar J, Oviatt SK, McClung MR & Huntington K (1989). The Relationship of Swimming Exercises to Bone Mass in Men and Women. Archives of International Medicine,14, 2197-2200.

Pocock NA, Eismon JA &Yeates MG (1986). Physical Fitness as a Major Determinant of Femoral Neck and Lumbar Spine Bone Mineral Density. Journal of Clinical Investigation, 78, 618-721.

Pocock N, Eisman J, Gwinn T, Sambrook P, Kelly P, Freund J & Yeates M (1989). Muscle strength, physical fitness, and weight but not age predict femoral neck bone mass. Journal of Bone Mineral Research, 4, 441-448.

Protiva KW, Snow-Harter C, Gillis DE, Connolly D & Robinson TL (1994). Aerobic Capacity correlates with femoral neck, but not hip spine or whole body mineral density. Medicine and Science in Sports and Exercise, 26, S165.

Pruitt LA, Jackson RD, Bartles RL, Lehnhard HJ. ( ). Weight-training effects on bone mineral density in early postmenopausal women. Journal of Bone Mineral Research, 7, 179-185.

Raisz LG & Smith J (1989). Pathogenesis, prevention, and treatment of osteoporosis. Annual Review of Medicine, 40, 251-267.

Ray NF, Chan JK, Thamer M, Melton LJ. (1997). Medical expenditures for the treatment of osteoporotic fractures in the United States in 1995: report from the National Osteoporosis Foundation. Journal of Bone Mineral Research, 12, 24-35.

Riggs BL, Melton III LJ. (1992). The prevention and treatment of osteoporosis. New England Journal of Medicine, 327, 620-627.

Rikle RE & McManis BG (1990). Effects of Exercise on Bone Mineral Content in Postmenopausal Women. Research Quarterly for Exercise and Sport, 61, 243-249.

Robinson TL, Snow-Harter C, Taaffee DR, Gillis D & Shaw J (1995). Gymnasts exhibit higher bone mass than runners despite similar prevalence of amenorrhea and oligomenorrhea. Journal of Bone Mineral Research, 10, 26-35.

Rockwell JC, Sorenson AM, Baker S, Leahey D, Stock JL, Michaels J & Baran DT (1990). Weight training decreases vertebral bone density in premenopausal women-a prospective study. Journal of Clinical Endocrinology Metabolism, 71, 988-993.

Ross PD, Davis JW & Epstein RS (1991). Pre-existing fractures and bone mass predict vertebral fracture incidence in women. Annals of Internal Medicine, 114, 919-923.

Shaw JM, Snow-Harter C & Protiva KW (1994). The effects of resistance training of fracture risk and psychological variables in postmenopausal women. Medicine and Science in Sport and Exercise, 26, S175.

Sinaki M, Wahner HW, Offord KP & Hodgson SF (1989). Efficacy of Nonloading Exercises in Prevention of Vertebral Bone Loss in Postmenopausal Women: A Controlled Trial. Mayo. Clinical Procedures, 64, 762-769.

Skeleton DA, Young A, Greig CA & Malbut KE (1995). Effects of resistance training on strength, power, and selected functional abilities of women aged 75 and older. Journal of American Geriatric Society, 43, 1081-1087.

Smith EL, Gilligan C, McAdam M, Ensign CP & Smith PE (1989). Deterring Bone Loss by Exercise Intervention in Premenopausal and Postmenopausal Women. Calcification Tissue International, 3, 312-321.

Snow-Harter C, Bouxsein ML, BT, Carter DR & Marcus R (1992). Effects of resistance and endurance exercise on bone mineral status of young women: A randomized exercise intervention trial. Journal of Bone and Mineral Research, 7, 761-769.

Snow-Harter C & Marcus R (1991). Exercise, Bone Mineral Density, and Osteoporosis. Exercise and Sport Science Review, 19, 351-388.

Snow-Harter C, Wegner M, Robinson T, Shaw J, Shelley A (1993). Determinants of femoral neck BMD in pre- and postmenopausal women. Medicine, Science, Sport and Exercise, 25, Supple S153.

Taaffee DR, Snow-Harter C, Connolly DA, Robinson TL, Brown MD & Marcus R (1995). Differential effects of swimming versus weight-training activity on bone mineral status of eumenorrheic athletes. Journla of Bone Mineral Research, 10, 586-593.

Thompson RF, Crist DM, Marsh M & Rsenthal M (1988). Effects of physical exercise for elderly patients with physical impairments. Journal of American Geriatric Society, 36, 130-135.

Tinetti ME, Baker DI, McAvay G, Claus EB, Garrett P, Gottschalk M, Koch M, Trainor K & Horwitz RI (1994). A multifactorial intervention to reduce the risk of falling among elderly people living in the community. New England Journal of Medicine, 331, 821-827.

Tinetti ME, Liu WL & Claus EB (1993). Predictors and prognosis of inability to get up after falls among elderly persons. Journal of American Medical Association, 269, 65-70.

Tinetti ME, Speechley M & Ginter SF (1988). Risk factors for falls among elderly persons living in the community. New England Journal of Medicine, 319, 1701-1707.

Tinetti ME (1986). Performance-oriented assessment of mobility problems in elderly patient. Journal of American Geriatric Society, 34, 119-126.

Vandervoot A, Hill K, Sandrin M & Vyse VM (1990). Mobility, impairment and falling in the elderly. Physiotherapy Canada, 42, 99-107.

Weiss NS, Ure CL, Ballard JH, Williams AR & Daling JR (1980). Decreased risk of fractures of the hip and lower forearm with postmenopausal use of estrogen. New England Journal of Medicine, 303, 1195-1198.

Whalen RT, Carter DR & Steele CR (1988). Influence of physical activity on the regulation of bone density. Journal of Biomechanics, 21, 825-837.

Whipple RH, Wolfson LI & Amerman PM (1987). The relationship of knee and ankle weakness to falls in nursing home residents: An isokinetic study. Journal of American Geriatric Society, 35, 13-20.

APPENDICES

APPENDIX A
REVIEW OF LITERATURE

Bone Mineral Density: Osteoporosis results in 1.5 million fractures annually (Myers et al., 1996). In addition to bone loss, another central factor to fracture risk is falls. Approximately 90% of fractures of the hip are a direct result from a fall (Myers et al., 1996). It is estimated that 30 million falls are reported annually (Hayes et al., 1996). Although falls typically do not result in serious injury, a fall may lead to fear of falling, decreased physical ability and loss of independence (Myers et al., 1996, & Hayes et al., 1996). Fractures which result from falls, are associated with increased disability, death and health care costs. It is estimated that 7-10 billion dollars are spent on medical and nursing services related to hip fractures (Hayes et al., 1996). As our society ages the incidence of fractures rise because fracture rates increase exponentially with age (Melton et al., 1996).

Bone Development and Aging: The functions of the skeleton system are to aid in movement and support loads against gravity, to protect vital organs, such as heart, brain and spinal cord and to store calcium to support blood levels if needed. Bone is composed of two types of osseous tissue--cortical and trabecular. Cortical bone constitutes 80% of the skeletal mass and is located primarily in the peripheral skeleton (e.g., the shafts of long, limb bones), has a solid structure and provides strength to the skeleton (Snow-Harter et al., 1991). Trabecular bone is a spongy material, which constitutes 70% of the axial skeleton (e.g., femoral neck, vertebrae), and gives the skeleton its flexibility (Snow-Harter et al., 1991). Trabecular bone has greater metabolic activity than does cortical bone such that 25% of all trabecular bone is remodeled annually compared to 2-3% of cortical bone (Nelson et al., 1991).

Trabecular bone architecture is like a honeycomb. There are horizontal and vertical arrangements that connect to provide strength to trabecular bone. The strength of trabecular bone is based on the support the horizontal arrangements contribute to the vertical structure (Snow-Harter et al., 1991). This vertical and horizontal structure tends to lose strength with age as the thickness of the trabeculae and the plates eventually disappear. These decreases in trabeculae are a result of deficits produced over the years of remodeling. The decrease in thickness and disappearance of trabeculae results in loss of bone strength and possibly increased risks of fractures. Due to the architecture and rate of turnover of trabecular bone (compared to cortical bone), changes in bone mass are evident earlier and to a greater extent in trabecular skeleton (Marcus, et al., 1987).

The percentage of bone which is remodeled annually may increase or decrease depending on mechanical demands. Recker and coworkers (1992) estimated that 60% of final bone is accumulated during adolescent growth and that peak bone is reached by the end of the second decade of life. The time at which bone is lost is controversial. Marcus and colleagues (1988) estimate that decreases in trabecular bone occur somewhere between the second and fifth decade of life. This bone loss accelerated during and immediately following menopause (Aloia et al., 1991) when estrogen levels decrease and the bone responds accordingly. Upon completion of menopause, the decline in bone returns to a similar loss as observed prior to menopause (Snow-Harter et al., 1991). Marcus (1988) reported an average of 0.7% of trabecular bone loss per year in women, adding up to a 25% decline over a 30 year span, prior to menopause. Numerous studies report a gradual loss of trabecular bone beginning somewhere in the third decade, but the majority of bone loss occurs immediately following menopause. Given the direct effect of estrogen on bone, it has become the primary therapy in treating osteoporosis. Estrogen increases the absorption of calcium by the intestine, allowing more efficient synthesis of vitamin D and increased calcitonin secretion (Raisz & Kream, 1983). Dalsky (1990) suggests that in the absence of estrogen or dramatic decreases in estrogen, bone becomes more sensitive to the resorption phase of bone remodeling. Estrogen decreases bone loss by reducing the rate of bone turnover (Lindsay, 1993). The use of estrogen decreases risks of fractures at the hip, wrist and spine regions (Weiss et al., 1980). Decreased fracture risk is greatest in women who currently use estrogen (Weiss et al., 1980). Lindsay (1993) recommends estrogen replacement therapy to last at least ten years if not lifelong.

Bone remodeling is a process which includes continuous removal of bone (bone resorption) and the replacement of old bone with new bone matrix and mineral (bone formation) (Kellie et al., 1992). This remodeling process is a function of bone forming cells called osteoblasts and bone-resorbing cells called osteoclasts (Frost, 1989). Osteoblasts form bone by removing calcium and phosphate from blood to form crystals (Kellie et al., 1992). Osteoclasts resorb bone by breaking down these crystals and returning calcium and phosphate to the blood (Kellie et al., 1992). During maintenance, remodeling tends to produce small deficits as a result of osteoclastic activity which is greater than osteoblastic activity. These deficits over the years contribute to bone loss often seen with age (Marcus et al., 1991). These deficits result in a decline in strength of bone.

Bedrest and Bone Mass: Immobilization or weightlessness is another factor which may contribute to rapid bone mineral loss (Pocock et al., 1986). Bed rest (immobilization) is associated with loss in bone mass and strength due to changes in mineral metabolism and bone remodeling. There appears to be a decrease in calcium balance and an increase in bone resorption associated with immobilization (Nirshimura et al., 1994). Loss of bone density reported by U.S. and Soviet space flight is believed to be a result of disuse and reduction of gravitational loading (Leach et al., 1991). When examining mineral balance in astronauts, substantial amounts of calcium and phosphate, found primarily in bone, are either found in the blood stream or lost through urine and feces (Leach et al., 1991). In an attempt to alter the reaction to reduced gravitational loading and disuse subjects were exercised in the supine position during bed rest. Exercising in the supine position does not correct the calcium imbalance associated with immobilization (Krohler, B., et al., 1983). However, Hurgens (1994) explains that a combination of static and inertial loads on the musculoskeletal system are necessary to mimic normal activities of daily living on Earth. The theory supporting the use of exercise states that bone mineral density is a function of the amount of mechanical demands made on bone (Grove & Londeree, 1992). Nishimura and colleagues (1994) examined women and men during 20 days of bed rest. This study reported tendencies of BMD at the lumbar and metacarpal bone to decrease. In addition to decreased BMD, markers for bone matrix resorption (deoxypyridinoline) increased during this period of bed rest, indicating bone loss.

The absence of external stress, with immobilization, leads to bone loss and decreased bone mineral density. The exercises performed in space have not included activities with enough load to stimulate bone formation and thus result in decreased bone mass following space flight. The loss of bone found in persons involved in spaceflight indicates the important role gravity plays in bone remodeling in addition to the need for appropriate strain. The loss of bone found with space flight is similar to the loss found with bed rest.

Skeletal Biomechanics: Bone has the unique capability of altering its state to meet equilibrium (bone modeling) (Snow-Harter et al., 1991). Bone modeling is most active prior to the completion of the second decade of life. Bone is able to change its shape in response to physiologic and/or mechanical influences imposed on it (Frost et al., 1990).The remodeling process may occur when exercises, such as jumping, produce an additional external stress or when non-weight bearing exercises, such as swimming, produce a force generated by muscle contraction, and bone is required to build new bone in order to meet the required demands.

Strength of bone is defined by Frost (1989) as " the fracture stress or fracture strain." Bone strength is not only dependent on the mass of bone, but also on bone's architecture. The bone mass distributed around its axis is important in determining the strength of bone. " The diameter of the bone reflects its strength which is exemplified in the long bone. Along the middle of the long bone is the medullary cavity. This cavity is similar to a hollow tube surrounded by bone mass. The larger the medullary cavity, the further stresses and strains are from the axis of the bone (Snow-Harter et al., 1991). A larger radius helps prevent fractures and aids in development of bone strength. The axis may change by the removal or addition of bone. Therefore, according to Wolff's law, bone will change shape to accommodate stress imposed on the bone. If in fact physical activity can produce the stress necessary to increase bone, then physical activity is an obtainable option to increase the diameter of the bone and potentially decrease the risk of fractures.

The biomechanical properties of bone include mechanical demands, such as stress and strain. Daily activities subject the bone to external forces (loading) as well as forces generated by muscle contractions. These forces lead to changes in bone shape and strength. If strain increases beyond the physiological demands, there is a greater chance of injury due to fracture. Yet if appropriate strain is consistently applied over time, bone will adapt to meet equilibrium. However, if strain is decreased over time, often seen to accompany the aging process, bone will adapt to meet the new state of equilibrium. Decrease in strain resulting in decreases in bone mass is observed in cases of immobilization and weightlessness. Immobilization, often a result of bed rest, result in a decrease in both trabecular and cortical bone (Donaldson, et al., 1970). Krohler & Toft (1983) reported a decrease in bone to be altered with an increase of weight-bearing activity which promoted the remodeling process. The optimal strain necessary to promote bone formation remains undefined.

Rubin and Lanyon (1985) tested the phenomenon of the optimal amount of strain necessary to maintain bone mass. Following 8 weeks of physiological loading on one wing of turkeys, Rubin and Lanyon (1985) observed greater bone mineral density as well as greater bone strength in the exercised wing. The results of this study support the hypothesis that magnitude is an important component of bone mass accretion. This hypothesis may be applied to general physical activity. Weight-bearing activities, such as weight training, where an external load is constantly applied through range of motion, might be a better form of exercise to encourage bone remodeling, versus activities which apply a lesser amount of external strain, such as swimming. Taaffee and associates (1995) examined the effects of both a weight-bearing activity, gymnastics, and a non-weight-bearing activity, swimming, had on bone mineral density. This studies findings support the influence weight-bearing activities have on bone over non-weight-bearing activities. Gymnastics involves high loads on the musculoskeletal system where as swimming does not seem to produce enough muscle pull sufficient to increase bone mineral density to protect bone. The ideal type(s) and amount of external stain, from physical activity, necessary to promote bone remodeling remains unclear.

O'Connor and associates (1981) examined the effect of different levels of strain on the radius and ulna of adult sheep. It was apparent that bone's remodeling was sensitive to different mechanical loading. Furthermore, the different amounts of strain affected areas of the skeleton differently. This supports the theory that training is site specific and if the femoral neck is to be altered, then the femoral neck needs to be challenged appropriately. Lanyon (1987), however, hypothesized that osteocytes, at first, become sensitive to the magnitude and distribution of strain within the bone matrix. Osteoblasts and osteoclasts respond accordingly in order to adapt to the amount of strain received.

Bone Mineral Density and Physical Activity: Pocock and coworkers (1989) reported muscle strength and physical fitness affected bone mass independent of age. This suggests that bone loss, often associated with aging, may be prevented by changes in loading through muscle contractions and physical fitness. Smith and colleagues (1989) observed pre and postmenopausal women who exercised three times per week for 45 minutes per session lost significantly less bone mineral content than non-exercisers. High levels of physical activity, as those seen in college and professional athletics, resulted in increased bone mass whereas immobilization, bed rest or space flight resulted in reversible bone loss (O'Connor et al., 1981) Cross-sectional studies have examined physically active and sedentary individuals and found a positive correlation between physical activity and bone mineral density (Snow-Harter et al., 1991). The type and amount of strain produced on the bone due to physical activity plays a crucial role in the remodeling cycle.

Physical training needs to progress continuously throughout life. Once equilibrium is reached, bone will no longer observe increases unless the program is changed; rather, bone maintenance and possibly bone decrements will be observed due to the natural loss of BMD seen with age. Progression of physical activity produces continuous added stress on the skeleton. This added stress, if efficient, is expected to reduce or eliminate the expected loss of BMD which accompanies age. Rikle and colleagues (1990) performed a study which separated groups into a general exercising group, a general exercising and weight training group and a non-exercising group. The individuals in both exercising groups maintained or increased overall bone mineral density, while subjects in the control group significantly loss BMD. This study demonstrated bone's ability to adapt to external stresses, and it speculated that exercises have a general as well as a localized effect on maintaining BMD.

Not only do physically active individuals tend to have higher bone density, they may have a lower rate of age-related bone loss. Smith and associates (1989) performed a four year program with women (average age 50 years). The exercise group participated in aerobic activities three times per week for 45 minutes at a training heart rate of 70-85% of maximal predicted heart rate, and the control group remained sedentary. The subject's bilateral radius, ulna and humerous bone mineral content were measured throughout the four year study. The exercise group lost less bone mass than the control group over this four year period. Smith and associates (1989) concluded that physical activity contributed to the reduction of bone loss associated with age. Shaw and coworkers (1994) perform a nine month weight-bearing training program with postmenopausal women. This program concentrated on exercises for the lower extremities. Although not significant, Shaw reported a trend for BMD to increase in the exercise group and decrease in the control group.

Sites selected for measurement from exercise interventions may play a crucial role in the outcome of the study. Physical activity may benefit bone primarily at the specific sites worked (Orwoll et al., 1989). Another consideration is the types of loading, weight-bearing versus non-weight-bearing or loading versus repetitive exercises. Rubin and Lanyon (1984, 1985) reported bone mass correlated with functional loading although the loading needs to be above a certain optimal level of strain in order to maintain bone mass. The effects of different exercises on bone mass are not the same and reflect the site to which the stress occurs (Rubin & Lanyon, 1985). The mode, duration, intensity and frequency of exercise need to be considered before drawing a conclusion on how physical activity aids in bone density. O'Connor and colleagues (1981) suggest that in order for physical activity to affect bone positively, the activity should involve high strain rate. Forwood & Burr (1993) suggest that the gains of bone mass observed during training are lost during de-training, and therefore, physical activity has to remain constant and life long to prevent returning to pre-training levels of bone mass.

Aerobic Capacity and Bone Mass: Research has shown that certain aspects of exercise play a role in preventing or slowing the process of bone mineral content loss. When considering the relationship between aerobic capacity and bone mineral content, it should be understood that aerobic capacity is directly found by performing tests which measure maximal oxygen consumption (VO_2max). Therefore, when exploring the relationship between aerobic capacity and bone mineral content, it is actually the examination of maximal oxygen consumption and its relationship with bone mineral content. Although aerobic exercise is important for cardiovascular function, the relationship between maximal aerobic capacity and bone mass is somewhat controversial. Both non-weight-bearing and weight-bearing aerobic activities promote cardiovascular health, but only weight-bearing is beneficial to bone.

While some investigators have examined premenopausal and postmenopausal women and found no relationship between spine mineral content and aerobic capacity (Bevier et al., 1989), others have reported significant relationships between aerobic capacity and bone mineral density at regional sites of both the femoral neck and lumbar spine in premenopausal and postmenopausal women (Pocock et al., 1986, Pocock et al., 1989, and Chow et al,. 1986).

Conflicting results may be attributed to the determination of aerobic capacity, found by a maximal graded treadmill exercise test or a submaximal bicycle ergometry test. Bergh and colleagues (1976) reported bicycle ergometry corresponds to 93% of true VO_2max in running. Submaximal bicycle ergometry traditionally under-predicts maximal oxygen consumption due to fatigue of quadriceps and calf muscle mass (Bergh et al,. 1986). VO_2max is inclined to be dependent on the exercising muscle mass (Bergh et al., 1986).

Pocock and associates (1986 and 1989) examined the relationship between aerobic capacity (via submaximal bicycle ergometry test) and bone mineral density at the femoral neck and lumbar spine regions in premenopausal and postmenopausal women. Results report femoral neck BMD to be positively correlated to VO_2max and negatively correlated to age. The findings suggest that as an individual ages, there may be decreases in bone mass at the femoral neck due to changes in aerobic fitness and body weight (loading). These data indicate that factors other than age contribute to bone maintenance at these regions. Pocock disregards adjusting for body weight and age in the calculations, leaving questions as to whether the increases in bone mineral content are due to aerobic capacity or due to the variables body weight and age.

Cavanaugh and coworkers (1988) reported less bone loss with physically active individuals than with sedentary individuals when examining individuals participating in endurance type exercises. Spinal trabecular mineral density was measured in postmenopausal women during a 52 week walking program. Exercisers walked three days a week for 15-40 minutes per session at 60-85% of predicted maximal oxygen consumption. Both the exercise group and the sedentary control group observed a significant bone loss over the 52 weeks. This indicated that the type of physical activity (walking), the time (15-40 minutes), the intensity (60-85%), and/or the duration of the study (52 weeks) were inadequate to produce an increase or maintenance in trabecular bone at the spine region for the exercisers, suggesting aerobic capacity does not affect BMD, yet loading may be a more critical factor necessary for bone metabolism. Other investigators have found body weight to be an important contributor to BMD (Bevier et al., 1989, Sinaki et al., 1989, Snow-Harter et al., 1991).

Nelson and associates (1988) and Dalsky and colleagues (1988) examined aerobic capacity, via maximal tests, and bone mineral content. Nelson (1988) evaluated BMD of the spine, femoral neck and radius in endurance-trained and sedentary postmenopausal women. The endurance-trained subjects had a higher VO_2max, yet no difference in BMD at the selected sites. However, when normalized for body weight, the bone mass of the spine and radius were higher in the endurance-trained than the sedentary women. These results suggest that the effect physical activity has on bone is more a factor of body weight than of aerobic capacity. Dalsky (1988) also reported no significant relationship between aerobic capacity and bone mineral content after examining individuals training 9 months by way of weight-bearing and non-weight-bearing exercises. According to Nelson and Dalsky, aerobic capacity should not be considered a reliable source in predicting bone density.

Nelson and coworkers (1991) examined the effects of a 42 week endurance activity program, where a weighted belt was added 24 weeks into the program. The intent of this study wanted to explore the effects aerobic capacity, as well as, added stress had on bone. There was a significant increase in aerobic capacity and bone at the femoral neck, yet no change in strength with the added weighted belt. The added weighted belt appears to make the individual work harder and thus improve aerobic capacity. Nelson and coworkers (1991) suggest that the added stress from the weighted belt caused the increase bone mineral content, not the increase in aerobic capacity. Nelson's study concluded that one's aerobic capacity does not correlate with bone mass.

Protiva and associates (1994) who evaluated the relationship between maximal aerobic capacity, measured via treadmill, and bone mineral density. Femoral neck BMD was significantly correlated with VO_2max and age. However, lumbar spine and whole body BMD did not significantly correlate with VO_2max. This study found that aerobic capacity had no association with bone mass at the spine or whole body, and the contribution of aerobic capacity, an outcome of progressive weight-bearing aerobic exercise which loads the femur, independently predicted bone mineral density of the femoral neck. This conclusion was supported by Nelson and Dalsky who observed added loads rather than aerobic capacity increased BMD.

The association between aerobic capacity and bone mineral content is more likely be the result of common factors which affect both of these parameters such age, body weight and mechanical loading of weight-bearing physical activity, rather than a direct correlation between maximal oxygen consumption and bone. Research has found as age increases, $V0_2$max decreases. Therefore, when exploring the relationship between aerobic capacity and bone mass, the $V0_2$max tests should be corrected for age. Currently, there is insufficient evidence to conclude the exact relationship aerobic capacity has with bone mass.

Some studies have found a relationship between maximal oxygen consumption and bone mineral content in healthy postmenopausal women. Whereas, other studies have found no relationship between maximal oxygen consumption and bone density when age and weight factors were removed. These studies indicate that weight and age may be common factors affecting the relationship between maximal oxygen consumption and bone. Therefore, the positive relationship between aerobic capacity and bone mineral content may be attributed to confounding variables.

Muscle Strength and Bone Mineral Density: Muscle mass, strength and contraction play a role in bone mass and bone mineral density by reflecting the forces exerted on bone (Rutherford & Jones, 1992). Loss in muscle strength and therefore, decreases in muscle contraction and forces exerted on bone, accompany immobilization and weightlessness and contribute to loss in bone so often observed with age. A study by Rutherford and Jones (1992) on muscle and bone loss with age in women indicated a progressive decline in strength from the third decade on, resulting in 70 to 80 year old women retaining only 60% of their strength at age 20 to 30 years. In addition to the loss in strength there is a 20% loss in force-generating capacity from age 20 to 80 years and a decrease in overall physical activity with age. Decreases not only in physical activity, but in activities of daily living are suggested to be the primary cause of loss in muscle strength and force-generation in the elderly population.

Muscle strength is a good predictor of bone mineral density, but the relationship between muscle strength, developed through muscle contraction, and bone mineral content is complex (Marcus et al., 1992). It appears that the type of loading, the intensity of the loading exercise and the duration of the study play a crucial role on the effects of muscle strength and bone mass.

Whalen and colleagues (1988) suggest that bone will adapt differently to the two main types of strain: impact loading (e.g., running and walking) and muscle contraction pulling on the bone (e.g., weight lifting). Both types of physical activities are beneficial to bone growth and maintenance, yet it remains unclear which type of exercise is the better of the two, or if they both contribute equally.

Bevier and colleagues (1989) observed the relationship of muscle strength to bone mineral density in older men and women. Since muscle activity is a major source of mechanical loading on the skeleton, it is feasible for muscle strength to have a significant relationship with bone remodeling. Bevier's study tested healthy active men and women over the age of 60 on back strength and dominant and non-dominant grip strength. This study observed a significant correlation with dominant and non-dominant grip strength and forearm bone density and back strength and spine density, in both men and women. Muscular action is a form of mechanical loading; therefore, it is not surprising that physical activities which increase muscle strength are recommended to increase bone strength. To some extent "function dictates form" (Frost, 1989), which can be observed when bone responds to physical activities creating a strain resulting in increases in muscular strength.

Charette and associates (1991) performed a 12 week training program with women (mean age 69 years), concentrating on the lower extremities. Subjects performed weight training exercises three times per week on weight machines. The exercised group witnessed increases in strength, while the control group observed neither increases nor decreases in strength. Charette's study suggested that elderly people can benefit from weight training programs. Fiatarone and colleagues (1990) evaluated individuals in their 90's on resistance exercises and reported increases in strength. Accompanying the strength increases was improved gait speed. Fiatarone concluded that improved gait speed required strength and balance.

Rockwell and colleagues (1990) investigated the effect of a nine-month weight training program for premenopausal women. Rockwell reported this period of time to be too short to observe an increase in bone mineral content, even though muscle strength increased. Gleeson and coworkers (1990) performed a 12 month weight training study and observed minimal increases in vertebral bone mineral content. Programs involving weight training machines (e.g., Nautilus), such as Rockwell's and Glesson's, may not stress the musculoskeletal system adequately enough to produce changes in bone. Snow-Harter and colleagues (1992) performed a study randomly assigning college aged women to either a jogging group, weight training group or control group. After 8 months, the jogging group observed an increase in lumbar spine bone mineral content (1.3%) and the weight training group reported an increases of 1.2% BMC, but no changes were observed in the control group. Shaw and associates (1994) developed an exercise program concentrating on lower extremity and weight-bearing type activities. The resistance was continually increased by adding lead weights to vests. The results of this study reported hip abductor, knee extensor and ankle plantarflexor strength to increase significantly while the control group's strength did not change over the nine-month period. Even though the bone mass did not significantly increase in the exercise group, there was a trend towards bone mass improvements with the exercise group when compared to the control group. Research suggests that the type of activity needed to change bone positively is weight-bearing and loaded. The intensity needs to continually increase so that the bone does not reach equilibrium. As far as the length of time needed to see positive changes in bone, it remains unclear. What is understood is that the physical activity needs to continue throughout life.

Postural Stability as a Fracture Risk Factors: Falls account for the vast majority of hip fractures, thus, postural stability is an important determinant of fracture risk. The incidence of fractures from falls may influence the elderly to reduce mobility due to fear of falling. The reduction of movement will ultimately result in decrements in strength and flexibility, leading to loss in bone mass and decreased stability. It is crucial that the type of exercise and training be determined to enhance those muscles associated with balance, at the same time strengthening those muscles most commonly linked to falls. Once this has been accomplished, presenting it to the elderly population in a useable fashion may bring our society one step closer to reducing fractures from falls. The limited function of the musculoskeletal system associated with disuse and aging ultimately results in decreased mobility (Vandervoort et al., 1990). Decreased functional ability has also been linked with increases in falls and fractures (Anniansson et al., 1984).

Loss of muscular strength and flexibility may be two factors contributing to reduced postural stability and falls. Muscle strength, particularly of the lower extremity is needed to compensate for a stumble or a fall, assist with maintaining balance and is necessary to perform activities of daily living. As muscle strength decreases with age so does balance and functional ability while there is an increase in falls. Whipple and coworkers (1987) reported weaknesses in the knee and ankle were related to increases in falls in nursing home residents. Additionally, Tinetti and associates (1988) identified decreased strength in the lower extremities, and changes in balance and gait as factors associated with falls. There is evidence that lower extremity muscle strength is associated with both BMD and postural stability. Specifically, dorsiflexion and hip muscle weakness are risk factors associated with falling and injuries in persons over age 65 (Grabiner et al., 1993).

Furthermore, hip strength has been shown to be a determinant of femoral neck BMD in older women (Snow-Harter et al., 1993). Shaw and coworkers (1994) reported hip abductor strength to be a predictor of lateral movement of time. The ability to adjust to lateral movements may contribute to decreased falls. Gehlsen and coworkers (1990) examined 25 individuals with a history of falls and 30 individuals with no history of falls on balance, muscle strength of the lower extremities (hip, knee, and ankle joints) and flexibility of the hip, knee and ankle joints. This study reported a significant difference between groups on one-leg balance stance with eyes open and closed, leg strength and flexibility of the hip and ankle dorsiflexion. Results indicated static balance as a good predictor to distinguish fallers from non-fallers. While other investigators (Whipple et al., 1987; Fiatarone et al., 1990; Skeleton et al., 1995) have reported significant correlation's between strength and balance, but Gehlsen's study did not reproduce these same findings. Gehlsen's results suggest strength does not relate to functional abilities and that reduction in flexibility and balance are the primary contributors to falls in the elderly. It is evident that the lower extremity strength contributes to balance; therefore, strengthening the muscles associated with the lower extremity appears to be desirable.

In general studies have reported older individuals respond positively to strength training exercises (Agre et al., 1988 & Frontera et al., 1988). Unfortunately the exercises used in most studies are not easily continued throughout life. Fiatarone and colleagues (1990) observed strength gains in the frail elderly following a 10 week machine-based resistance training. These gains were lost following a detraining period. Without continuance of training, strength will return to before training levels and eventually begin to decrease with age. Exercises geared towards the elderly population and nursing homes are essential to aid this growing population in preventing such drastic decreases in lower extremity strength, balance and bone mass.

APPENDIX B
MUSCULAR STRENGTH: ABSOLUTE VALUES

Muscle strength knee extensors and ankle plantar and dorsi flexors were determined using isokinetic dynamometry (KinCom 500H, Chattex Corp.). The coefficients of variation for these measurements in our laboratory are between 6-8%.

Each subject performed two warm-up trials. The warm-up was followed by three to four maximal strength tests. Subjects were given one minute rest periods between trials and instructed to "push as hard and as fast as possible" prior to and during each trial. The best of the trials was recorded (Appendix Table B).

Appendix Table B.Muscular Strength During Control and Exercise Period

	Control Baseline	Month 6	Exercise Month 9
Plantar Flexion (N)	260 (108)	296 (156)	271 (106)
Dorsi Flexion (N)	215 (27)	228 (34)	189 (57)
Knee Extension (N)	508 (184)	554 (182)	451 (165)

Strength measurements, via isokinetic dynamometry did not significantly change over the observation and exercise period. Accounts for these results include error of machine as well as subject intimidation. During the study the isokinetic dynamometer had to be recalibrated. This resulted in the baseline measures to be inaccurate. Subjects may not have reached maximal peak force at each testing period due to this intimidation factor, as well as having to relearn the procedures for testing. Utilizing a measurement technique familiar to the subject may be more accurate in measuring strength than using a novel machine which is intimidating and has to be relearned each testing period. Measurements which require exertion is best established by equipment or test procedures which are comfortable, an important consideration for older individuals.