The Effect of a Jumping Exercise Intervention on Bone Mineral Density in Postmenopausal Women

Ann Newstead, PT, MS, NCS,[1] Kristen I. Smith, PhD,[1] Jan Bruder, MD,[2] Colleen Keller, RN, PhD[3]

University of Texas Health Sciences Center at San Antonio, Texas
[1]School of Allied Health Sciences,[2]School of Medicine, [3]School of Nursing

ABSTRACT

Purpose: The purpose of this study was to determine the effect of a 12-month jumping exercise intervention on bone mineral density (BMD) and biomarkers of bone turnover, N-telopeptide (NTX), and alkaline phosphatase (ALK PHOS) in a group of postmenopausal women. **Subjects**: Fifty-three postmenopausal women (50 to 65 years) were recruited to participate and randomized into an exercise (EX) and a non-exercise control (CON) group. **Methods**: Exercisers performed progressive atypical, multidimensional jumping on the floor and from aerobic steps (4 inch and 6 inch) a minimum of 2 days per week at 25 to 200 jumps per session. Bone mineral density of the femoral neck, total hip, and lumbar spine was measured at baseline and 12 months using dual x-ray absorptiometry (DXA). Urinary NTX and serum ALK PHOS concentrations were assayed at baseline, 6 months, and 12 months. A mixed model (group X time) multivariate analysis of variance (MANOVA) procedure was performed for each set of dependent variables BMD (3) and biomarkers (2). **Results**: Forty-nine subjects completed the study, EX (N=23) and CON (N=26). Neither MANOVA showed a significant interaction between group and time. **Conclusion**: Participants in the jumping intervention in our study did not show improvement in BMD or biomarkers relative to nonparticipants.

Key Words: postmenopausal, bone mineral density, jumping, exercise, prevention

INTRODUCTION

Each year more than 250,000 Americans, 1 in 3 women, fracture their hips.[1,2] The risk of hip fracture approximately doubles for every one standard deviation reduction in bone mineral density (BMD), and loss of BMD doubles for every 10 years after menopause.[3,4] An increase in femoral neck BMD can directly reduce the risk for hip fractures that are normally associated with low femoral neck BMD.[5] Many different types of exercise intervention programs have been studied for their effect on BMD in postmenopausal women, including walking, strength training, and combinations of the two.[6-14] While walking has long been promoted as an exercise intervention designed to improve BMD, its benefits are not well supported with empirical evidence. Swezey[6] demonstrated that while weight-bearing exercise such as walking and jogging have some positive effect on bone mass, site-specific resistive exercise might have a more consistent effect. Other investigators[15-17] noted no significant increase in spinal BMD in women after a walking program, and concluded that walking did not provide the progressive increase in skeletal loading required for increases in BMD.

Address correspondence to: Ann Newstead, PT, MS, NCS, 7703 Floyd Curl Drive; Mail Code 6247 Department of Physical Therapy, School of Allied Health Sciences, University of Texas Health Sciences Center at San Antonio, Phone: 210-567-8766 work, Fax: 210-567-8774 (newstead@uthscsa.edu).

Specific exercise parameters have been described to prevent bone loss, with the appropriate mode, frequency, intensity, and duration of physical activity increasing BMD up to 50%.[18] Kohrt and colleagues[19] compared the effect of 2 different exercise interventions: ground reaction forces (GRF) such as walking, jogging, and stairs; and joint reaction forces (JRF) such as weight lifting and rowing in postmenopausal women between 60 and 74 years of age. Both exercise groups showed significant and similar increases in BMD of the whole body (2.0 ± 0.8%) and lumbar spine (1.8 ± 0.7%), whereas significant improvements were noted for GRF exercises in the femoral neck (3.5 ± 0.8%). Bassey and Ramsdale[20] described increased femoral BMD in premenopausal women with intermittent high-impact exercise, but not low-impact exercise. Heinonen et al[21] found increased BMD at the femoral neck (1.6%) with high impact exercise performed 3 times per week in premenopausal women (35-45 y), while Welsh and Rutherford[22] reported increased BMD at the greater trochanter in postmenopausal women and older men (50 to 73 y) following 12 months of high impact exercise (2.2 ± 0.9%). Bassey and colleagues[23] compared a vertical jumping exercise regimen and BMD response in pre- and postmenopausal women. Premenopausal women showed a significant increase (2.8%) in femoral BMD after 12 months of performing 50 jumps, 6 days a week, whereas the postmenopausal women showed no change through 18 months of jumping when HRT was controlled.[23]

A common element in these studies is production of an error strain. Error strain describes dynamic, atypical loading through weight bearing, or impact with the ground, that produces architectural changes in bone.[24,25] Dynamic loading is important for both prevention and treatment of osteoporosis and bone development.[4-6,18] Low intensity, low impact exercise prescriptions may achieve decreases in bone loss relative to higher intensity exercise.[26] Other studies indicate exercise must be high impact to prevent bone loss, but not necessarily high intensity.[20-23] Intensity is related to the amount of physical exertion compared with impact, which implies quantity of ground reaction forces.

There remains controversy on what constitutes the best form of exercise to improve bone mineral density and decrease bone turnover in postmenopausal women. The purpose, therefore, of this study of postmenopausal women was

to determine the effect of a progressive atypical, multidirectional jumping intervention program on BMD on bone turnover as measured by bone biomarkers.

METHODS

Subjects

Over 250 women from a Southwestern metropolitan community responded to advertisements through area interest groups, posted notices, and physician referral. Women were invited to participate in the study if the following criteria were determined by a phone screening to be present: (1) no co-morbidity, such as diagnosed diabetes, coronary heart disease, peripheral vascular disease, pulmonary or orthopedic dysfunctions that preclude jumping; (2) not currently taking alendronate (Fosamax®), tamoxifen, calcitonin (Miacalcin®), raloxifene (Avista®), glucocorticoids, residronate (Actonel®); (3) no current involvement in regular aerobic and/or weight training exercise; (4) no reported history of osteoporotic fracture; (5) body mass index (BMI) between 21-31 kg/m^2; and (6) on hormone replacement therapy (HRT) if more than 5 years postmenopausal. There were 59 women who fulfilled the screening criteria and had BMD measured. They were accepted into the study if the BMD T-score was >-1.5 SD at hip and lumbar spine and if their primary care physician cleared them to exercise. Fifty-three postmenopausal women were selected and randomly assigned to one of two groups, an experimental intervention group (N=25) and a control group (N=28).

Measurements

Bone mineral density of the femoral neck (Neck), total hip (Total), and lumbar spine (LS) was assessed at months 0 and 12 for all participants. Urine and blood concentrations of the biomarkers of bone turnover were assessed at month 0, 6, and 12. The BMD and biomarker testing were performed in the mornings at the General Clinical Research Center (GCRC) in the Audie Murphy Veterans Administration Hospital.

Osteoporosis is defined by BMD measurement as a T-score less than 2.5 SD below the normal mean for a young, healthy adult.[28] Dual x-ray absorptiometry (DXA) of the lumbar spine and hip represents the 'gold standard' for diagnosing osteoporosis and predicting related fracture risk.[29] All BMD measurements were obtained by the same technician with the pencil beam DXA bone densitometer, QDR 1500 series (Hologic, Inc, Waltham, Mass). The scan mode was adjusted for trunk thickness. Neck, total, and lumbar spine (L1-L4) BMD were all measured. All measurements were obtained and analyzed using standard protocols provided by the manufacturer. The short-term in vivo precision of the BMD was determined on 27 subjects performed in duplicate on the same day. The precision of the lumbar spine was 0.009 gm/cm^2 (CV = 1.0%). The precision of the total hip was 0.007 gm/cm^2 (CV = 0.87%). The precision of the manufacturer's spine phantom was 0.0017gm/cm^2 (CV = 0.17%).

Urine N-telopeptide (NTX) and serum bone specific alkaline phosphatase (ALK PHOS) reflect bone turnover. These markers represent a more sensitive indicator of bone resorption than DXA and can indicate bone turnover as early as 3 months from the beginning of a pharmaceutical intervention.[30-32] A trained technician collected urine (second void of the day) and blood (nonfasting) samples on 3 separate occasions, and these samples were processed by the GCRC. Urinary cross-linked N-telopeptide of type I collagen (NTX) was measured by ELISA (Osteomark®, Ostex International, Seattle, WA). The intra-assay coefficients of variation for NTX were 5.5%, and inter-assay coefficients of variation for NTX were 7.8%. Desired values of NTX that reflect low bone turnover are < 38 nM BCE/mM creatinine. Serum bone specific alkaline phosphatase was measured by radioimmunoassay (Ostase Assay Procedure; Beckman Coulter, Fullerton, Calif). A study of bone specific ALK PHOS showed mean values 8.7 ± 2.9 ug/L (N=228) in premenopausal women and 13.2 ± 4.7 ug/L (N=529) in postmenopausal women.

Procedures

The University's Institutional Review Board approved the study. An orientation session was held where the purpose, procedures, requirements, and benefits/risks were described to each participant, who then signed a consent form. From similar studies we concluded that by thorough screening, using proper warm-up, exercise techniques, and cool-down, postmenopausal women could participate in a jumping exercise program with little risk of injury.[21-23]

All participants in the exercise group received one pair of cross training type shoes. A certified instructor was hired to ensure proper exercise protocol, and was supervised by a licensed physical therapist. Both groups received calcium supplementation[33] of 800 mg per day and verified receipt through a sign out log and verbal acknowledgement of regular compliance. Oral consumption of estrogen was recorded at intake, but the investigators did not closely monitor compliance.

The intervention included 3 jumping sessions per week for 12 months, 2 with an instructor and 1 without supervision. For ease of scheduling, 5 different classes were scheduled 3 days per week; participants were able to select any 2 class sessions to attend. The exercise impact was slowly increased over the 12-month period by increasing the jump height from tile flooring (weeks 1-24) to a 4-inch step (weeks 25-41) to a 4-inch step with a 2-inch riser (6 inch step; weeks 42-56). The steps employed are commonly found in step aerobics classes. Exercise intensity was slowly increased by the addition of jump repetitions from a minimum of 25 to a maximum of 200 per session over 12 months. A unilateral jump was counted as one jump, whereas a bilateral jump was one-half jump. Jumps were performed while following the exercise instructor; however, subjects were not required to jump simultaneously with the instructor. A jump was performed in various directions to simulate error strain (ie, forward/backward, right/left, and in diagonals). Gradual increases in exercise impact and intensity were used to generate a progressive overload to prevent injury as participants became better skilled at the jumping activity. All exercise classes were performed to slow aerobics music. For safety, participants could be near a stable surface to lightly hold, if needed, and there were no combined bending and trunk rotation motions. In addition to jumping, the women were instructed in a 5 to10 minute warm-up and cool-down period that consisted of walking, stretching, upper extremity band exercises, and wall pushups.

The instructor counted jumps during each exercise session and participants recorded the total on an exercise log. The exercise log was submitted weekly. Each participant was required to keep a journal of all physical activities performed other than the specific jumping protocol. In addition, each participant recorded the number of jumps performed each week at home. Control subjects also completed a journal of physical activities and turned these in at 6 and 12 months.

Statistical Analyses

Based on Welsh and Rutherford's[22] studies of BMD and high impact aerobics in postmenopausal women, we expected a medium to high effect size. With a medium effect size, alpha of 0.05 and a power of 0.80, we estimated 20 participants per group would be needed to detect changes in outcome parameters.

Statistical analyses were performed using SPSS version 11.5 statistical program.[34] Independent t-tests were used to compare groups at the initiation of the study to ensure similarity in demographics and anthropometric measures.[35,36] Risk factors were compared using a chi square test. Mixed-model multivariate analysis of variance (MANOVA) procedures were performed to assess the effect of group and time on the dependent variables. One MANOVA included the 3 BMD measures (neck, total, and LS) as dependent variables. The other MANOVA included the 2-bone turnover markers (NTX and ALK PHOS) as dependent variables. Compliance was measured by recording the percentage of exercise classes attended and comparisons between variables were evaluated.

RESULTS

Subject Characteristics

Forty-nine out of 53 persons completed the study. The baseline characteristics of the subjects who completed the study are shown in Table 1. The subjects in the exercise (N=23) and control (N=26) groups did not differ significantly in age, height, weight, body mass index, menopausal years, years on hormone replacement therapy, and risk factors (smoking status, alcohol, coffee, and cola consumption). Our study population included 69.4% Caucasians, 26.5% Hispanic, and 4.1% other (Asian and Indian) who were comparably distributed between the exercise and control groups.

Table 1. Summary of Demographics and Risk Factors for Subjects Completing Study*

Demographics and risk factors	Control (n=26)	Exercise (n=23)
Age (years)	56.6 ± 4.1	56.7 ± 3.2
Height (cm)	161.7 ± 6.6	163.3 ± 4.4
Weight (kg)	68.1 ± 10.5	69.0 ± 12.4
BMI (kg/m2)	26.1± 3.9	25.9 ± 4.4
Post menopausal (years)	9.7 ± 6.5	10.0 ± 6.5
Hormone Therapy (years)	6.4 ± 6.1	5.1 ± 5.9
Smoking	2 (7.7)	2 (8.7)
Alcohol	13 (50.0)	11 (47.8)
Coffee	20 (76.9)	20 (87.0)
Cola	19 (73.1)	14 (60.9)

*Values are presented as mean ± SD or as N (%)

Bone Mineral Density

Mean (± SEM) BMD values for baseline and 12 months are shown in Table 2 for EX and CON groups. The MANOVA for BMD (gm/cm^2) showed a significant time effect but no significant interaction between group and time. Consequently, the jumping intervention did not result in increases in BMD that were significantly better than those realized by the control group.

Biomarkers of bone turnover

Mean (± SEM) biomarker values for the EX and CON groups at baseline, 6 months, and 12 months are presented in Table 2. The MANOVA showed a significant time effect but no significant interactions between group and time. Planned polynomial contrast testing showed that the time effect was quadratic in nature for both ALK PHOS ($F(2, 92)=24.08$, $p<0.000$) and NTX ($F(2, 92)=18.03$, $p=0.000$). Thus, while biomarkers decreased in both groups, the decrease was not significantly greater in the group participating in the jumping intervention.

Compliance

Exploratory analyses were performed for the effect of compliance with the exercise program. The exercise group was subdivided into high and low compliance groups to investigate possible effects on our dependent measures. Average compliance was 82% for the whole exercise group at month 6 and 75% by month 12. A cut off of 68% was used as a natural division between low and high compliance rates. The high compliance group was defined as attending 68% or more of the exercise sessions (N=15), and the low compliance group attended less than 68% (N=7). No significant differences were found; therefore, data were not presented.

DISCUSSION

In this study we examined the effects of an atypical, multidirectional jumping intervention on BMD and bone turnover in postmenopausal women. Although bone outcomes tended to improve overall, the jumping intervention did not result in superior outcomes (whether indicated by BMD or biomarkers). We attribute these changes in part to calcium supplement intake.

Bone Mineral Density and Biomarkers

Wolfe et al[14] noted a 0.9% reversal of bone loss per year via a meta-analysis of exercise training regimens, whereas others[19,22,37,38] have described greater increases in BMD (1.5% to 2.2%). A 12-month randomized investigation of exercise (aerobic, weight bearing, and weight lifting) in calcium-replete postmenopausal women with (N=159) and without HRT (N=161) demonstrated 1% to 2% improvements in BMD in women (40-65 y) who exercised and took calcium and HRT compared with those who did not.[37] Snow et al[38] showed that postmenopausal women wearing weighted vests while jumping (3 times per week, for 32 weeks per year, over 5 years) achieved greater improvements at the femoral neck (+1.5% ± 2.4%) than similar women in a control group (-4.4% ± 0.9%) when calcium and HRT were not controlled. In contrast, our findings agree with Bassey and colleagues[23] who described no significant changes in BMD in postmenopausal women on HRT who exercised for 18 months. Our largest BMD increase in the exercise group was noted in the lumbar spine (0.7 ± 0.4%). Since decreases in NTX of more than 30% are considered clinically significant[30-32] (Lab Corp, San Antonio,

Table 2. Descriptive Statist.ics (Mean±SEM) and MANOVA Comparison of 5 Dependent Variables by Group and Time

Dependent Variable	Time	Control (n=26)	Exercise (n=23)	Combined (n=49)	MANOVA Source	F	p
Neck BMD (gm/cm^2)	baseline	0.79±0.02	0.73±0.01	0.76±0.01	Group (G)	2.099	0.114
	12-month	0.78±0.02	0.73±0.01	0.76±0.01	Time (T)	3.272	0.030
Total BMD (gm/cm^2)	baseline	0.92±0.02	0.88±0.02	0.90±0.01	G X T	0.799	0.501
	12-month	0.92±0.02	0.89±0.02	0.91±0.01			
LS BMD (gm/cm^2)	baseline	1.03±0.02	1.01±0.02	1.02±0.02			
	12-month	1.04±0.02	1.02±0.02	1.03±0.02			
NTX (nM BCE/mM)	baseline	19.82±1.72	20.60±3.29	20.19±1.78	Group (G)	0.716	0.337
	6-month	13.38±0.99	14.86±1.51	14.07±0.88	Time (T)	11.358	<0.001
	12-month	12.30±0.83	12.90±0.94	12.58±0.62	G X T	1.484	0.224
ALK PHOS (ug/L)	baseline	40.73±6.72	38.17±4.29	39.53±4.06			
	6-month	27.23±3.57	22.04±2.24	24.80±2.17			
	12-month	22.68±3.33	26.17±3.47	24.35±2.39			

Tex), we view favorably our finding that biomarkers of bone turnover decreased more than 30% in both groups from initial intake to 6 months. A more progressive or intensive program, or a longer program (eg, for 2 years) may have yielded significant improvements in BMD and bone turnover in the exercise group. In addition, better control of HRT, calcium supplementation, and involvement in other outside activities across our study population may have created improved outcomes. Whether the jumping improves the BMD, bone turnover, or the strength of related muscle groups[39-43] in combination with calcium supplementation is an area to be explored further in postmenopausal women over an extended prospective period of time.

Exercise intensity and limitations of the study

Most of the women were able to perform the atypical loading (jumping) in all directions without much difficulty. Some, however, demonstrated minimal ability to vary their jumps, and one woman fell but was not injured.

Several women in each group were not on HRT (N=6 exercise; N=4 control), although mean HRT years were similar between groups. Dietary intake and calcium compliance were other factors that were not well controlled. Fifty three percent of the exercise group and 44% of the control group consumed calcium prior to the start of the study. The amount of intake prior to the study varied from none to more than 1000 mg/day. We distributed the calcium supplements prior to the study, and the participants were instructed to begin taking these supplements on the same date at the initiation of the exercise program. This may have affected our results, since most of the biomarker changes occurred in the first 6 months with fewer changes noticed in the second 6-month period. Calcium supplementation can improve BMD and biomarker turnover by 1% to 2% and could therefore be attenuating differences in our groups.[28-33]

The majority of the control group performed walking exercises (N= 20) at least 3 days per week, while the rest performed no exercises. One reported stair climbing and another 'rowing' and 'hiking.' Differences in physical activity levels may have had a direct effect on outcomes of BMD and biomarker turnover. Therefore, the control group improvements may have been due to the effects of calcium supplementation and walking activities.

Compliance, adherence, or self efficacy[44-47] was another issue of importance. During the first 24 weeks, compliance was high at over 80%. Over the course of the intervention, overall compliance declined to 75% which is comparable to others (69-85%).[22,23] We measured compliance as the number of classes attended and did not include the home log information since each subject appeared to be counting jumps differently. Therefore, the overall intensity of jumping may be higher than we have reported.

While all subjects were screened carefully prior to initiation in this study, minor 'painful conditions' were noted in 2 of the exercise participants. The primary complaints were ankle and knee joint pain and initial muscle discomfort. We had 2 subjects drop out of the exercise study from both the control and exercise group because of time commitments or a move, yet only one woman dropped out because of the inability to jump secondary to previous knee problems not reported during initial intake. Persons should be carefully screened prior to participation in such a program, and monitored closely during the intervention.

Finally, our sample size may not have had sufficient power to detect effect of the jumping intervention. Future studies also should involve larger samples to allow for examination of key, prespecified variables such as compliance and ethnicity.

CONCLUSIONS

An atypical, multidirectional jumping intervention remains controversial, but may be beneficial for select postmenopausal women to maintain BMD and decrease biomarker turnover in combination with calcium supplementation. Maintaining bone health through weight bearing activities is important to achieve long-term benefits and lessen the potential effects of osteoporosis in postmenopausal women. The ease of performing this program at home may improve long-term compliance; however, careful screening for preexisting injury and close monitoring of jumping intervention to ensure proper form to prevent injury is essential.

ACKNOWLEDGEMENTS

The investigators acknowledge Kelly Sanders, Bruce Paper, and the graduate physical therapy students in the preparation of this manuscript. This study was funded by Frederic C. Bartter General Clinical Research Center #MO1RR01346, a Grant from the Aging and Research and Education Center, and an Institutional Review Grant; University of Texas Health

Sciences Center at San Antonio. Mission Pharmaco, San Antonio, Texas, provided calcium supplementation.

REFERENCES

1. Greenspan SL, Myers ER, Maitland LA, Resnick NM, Hayes WC. Fall severity and bone mineral density as risk factors for hip fracture in ambulatory elderly. *JAMA*. 1994;271:128-133.
2. New SA. Exercise bone and nutrition. *Proceedings of Nutrition Society*. 2001;60:265-274.
3. Nguyen TB, Sambrook PN, Eisman JA. Bone loss, physical activity and weight change in elderly women: The Dubbo osteoporosis epidemiology study. *J Bone Miner Res*. 1998;13:1458-1467.
4. Hayes WC, Myers ER, Robinowitch SN, Van Den Kroonenberg A, Courtney AC, McMahon TA. Etiology and prevention of age-related hip fractures. *Bone*. 1996;18:37-44S.
5. Cummings SR, Black DM, Nevitt MC, et al.Bone density at various sites for prediction of hip fractures. *Lancet*. 1993;341:72-75.
6. Swezey RL. Exercise for osteoporosis-is walking enough? The case for site specificity and resistive exercise. *Spine*. 1996;21:2809-2813.
7. Nelson ME, Fiatarone MA, Morganti CM, Trice I, Greenber RA, Evans WJ. Effects of high-intensity strength training on multiple risk factors for osteoporotic fractures. A randomized control study. *JAMA*. 1994;272:1909-1914.
8. Kerr D, Ackland T, Maslen B, Morton A, Prince R. Resistance training over 2 years increases bone mass in calcium-replete postmenopausal women. *J Bone Miner Res*. 2001;16:175-181.
9. Iwamoto J, Takeda T, Ichimura S. Effect of exercise training and detraining on bone mineral density in post-menopausal women with osteoporosis. *J Orthop Sci*. 2001;6:128-132.
10. Ito M, Nakamura T, Ikeda S, et al. Effects of lifetime volleyball exercise on bone mineral densities in lumbar spine, calcaneus and tibia for pre-, peri-, and postmenopausal women. *Osteoporos Int*. 2001;12:104-111.
11. Uusi-Rasi K, Sievanen H, Pasanen M, Oja P, Vuori I. Maintenance of body weight, physical activity and calcium intake helps preserve bone mass in elderly women. *Osteoporos Int*. 2001;12:373-379.
12. Revel M, Mayoux-Benhamou MA, Rabourdin JP, Bagheri F, Roux C. One-year psoas training can prevent lumbar bone loss in post-menopausal women. *Calcif Tissue Int*. 1993;53:307-311.
13. Winett RA, Carpinelli RN. Potential health-related benefits of resistance training. Review. *Prev Med*. 2001;33:503-513.
14. Wolff I, van Croonenborg JJ, Kemper HCG, Kostense PJ, Twisk JWR. The effect of exercise training programs on bone mass: A meta-analysis of published controlled trials in pre- and postmenopausal women. *Osteoporos Int*. 1999;9:1-12.
15. Nelson ME, Fisher EC, Dilmanian FA, Dallal GE, Evans WJ. A 1-y walking program and increased dietary calcium in postmenopausal women: Effects on bone. *Am J Clin Nutr*. 1991;53:1304-1311.
16. Blumenthal JA, Emery CF, Madden DJ, et al. Effects of exercise training on bone density in older men and women. *J Am Geriatr Soc*. 1991;39:1065-1070.
17. Cavanaugh DJ, Cann CE. Brisk walking does not stop bone loss in postmenopausal women. *Bone*. 1988;9:201-204.
18. Kannus P, Sievanen H, Vuori I. Physical loading, exercise, and bone. *Bone*. 1996;18:1S-3S.
19. Kohrt WM, Ehsani AA, Birge SJ. Effects of exercise involving predominantly either joint-reaction or ground-reaction forces on bone mineral density in older women. *J Bone Miner Res*. 1997;12:1253-1261.
20. Bassey EJ, Ramsdale SJ. Increase in femoral bone density in young women following high-impact exercise. *Osteoporos Int*. 1994;4:72-75.
21. Heinonen A, Kannus P, Sievanen H, et al. Randomized controlled trial of effect of high-impact exercise on selected risk factors for osteoporotic fractures. *Lancet*. 1996;348:1343-1347.
22. Welsh L, Rutherford OM. Hip bone mineral density is improved by high-impact aerobic exercise in post-menopausal women and men over 50 years. *Eur J Appl Physiol*. 1996;74:511-517.
23. Bassey EJ, Rothwell MC, Littlewood JJ, Pye DW. Pre- and postmenopausal women have different bone mineral density responses to the same high-impact exercise. *J Bone Min Res*. 1998;13:1805-1813.
24. Cheng S, Sipila S, Taaffe DR, Pulolakka J, Suominen H. Change in bone mass distribution induced by hormone replacement therapy and high-impact physical exercise in post-menopausal women. *Bone*. 2002;31:126-135.
25. Sugiyama T, Yamaguchi A, Kawai S. Effects of skeletal loading on bone mass and compensation mechanism in bone: A new insight into the "mechanostat" theory. *J Bone Miner Metab*. 2002;20:196-200.
26. Layne JE, Nelson ME. The effects of progressive resistance training on bone density: a review. *Med Sci Sports Exerc*.1999;31:25-30.
27. Bassey, EJ, Ramsdale SJ. Weight-bearing exercise and ground reaction forces: a 12-month randomized controlled trial of effects on bone mineral density in healthy postmenopausal women. *Bone*. 1995;16:469-476.
28. National Osteoporosis Foundation. *Nof.org*. Osteoporosis: Bone Density. 1232 22nd Street NW, Washington, DC, 20037-1292. (202) 223-2226.
29. NIH Consensus Development Panel on Osteoporsis Prevention, Diagnosis and Therapy. *JAMA*. 2001;285:785-795.
30. Garnero P, Hausherr E, Chapuy MC, et al. Markers of bone resorption predict hip fracture in elderly women: The OPIDOS prospective study. *J Bone Miner Res*. 1996;11:1531-1538.
31. Ott S. Osteoporosis and bone physiology. Markers of bone cell activity. Available at: http://uwcme.org/courses/bonephys/markers.html 1998. Accessed March 2, 2004.
32. Chapurlat RD, Garnero P, Breart G, Meunier PJ, Delmas PD. Serum type I collagen breakdown product (serum CTX) predicts hip fracture risk in elderly women: The EPIDOS study. *Bone*. 2000;27:283-286.
33. Mission Pharmacal. 10999 IH 10 West, San Antonio, Texas, 78230.
34. SPSS Inc. Headquarters. 233 S. Wacker Drive, 11th Floor, Chicago, IL 60606.
35. Portney LG, Watkins MP. *Foundations of Clinical Research: Application to Practice*. ed 2. Prentice Hall; 2000.

36. Tabachnick BG, Fidel LS. *Using Multivariate Statistics.* Ed 4. Allyn and Bacon; 2001.
37. Going S, Lohman T, Houtkooper L, et al. Effects of exercise on bone mineral density in calcium-replete post-menopausal women with and without hormone replacement therapy. *Osteoporos Int*. 2003;14:637-643.
38. Snow CM, Shaw JM, Winters KM, Witzke KA. Long-term exercise using weighted vests prevents hip bone loss in postmenopausal women. *J Gerontol Biol Sci Med Sci*. 2000;55A:M489-M491.
39. McArdle WD, Katch FI, Katch VL. *Exercise Physiology*. ed 4. 1996:418-419
40. Kisner C, Colby LA. *Therapeutic Exercise. Foundations and Techniques*. ed 4. FA Davis; 2002:72-75.
41. Lewis CB. Musculoskeletal changes with age: Clinical implications. In: Lewis CB, ed. *Aging: The Health Care Challenge: An Interdisciplinary Approach to Assessment and Rehabilitative Management of the Elderly*. Philadelphia, Pa: F. A. Davis Company; 2002:110-113.
42. Puntila E, Kroger H, Lakka T, Tuppurainen M, Jurvelin J, Honkanen R. Leisure time physical activity and rate of bone loss among peri- and postmenopausal women: A longitudinal study. *Bone*. 2001;29:442-446.
43. Feskanich D, Willett W, Colditz G. Walking and leisure-time activity and risk of hip fracture in postmenopausal women. *JAMA*. 2002;288:2300-2306.
44. McAuley E, Blissmer B. Self-efficacy determinants and consequences of physical activity. *Exerc Sport Sci Rev*. 2000;28:85-88.
45. McAuley E, Courtneya KS, Rudoph DL, Lox CL. Enhancing exercise adherence in middle-aged males and females. *Prev Med*. 1994;23:298-506.
46. Estabrooks PA. Sustaining exercise participation through group cohesion. *Exerc Sport Sci Rev*. 2000;28:63-67.
47. Papaioannou A, Adachi JD, Winegard K, et al. Efficacy of home-based exercise for improving quality of life among elderly women with symptomatic osteoporosis-related vertebral fractures. International Osteoporosis Foundation and National Osteoporosis Foundation; 2003.