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TITLE: Resistance exercise and bone turnover in elderly men and women

SOURCE: Medicine and Science in Sports and Exercise 34 no1 17-23 Ja 2002

ABSTRACT

Purpose: This investigation examined the effect of 6 months of high- or low-intensity resistance exercise (REX) on bone mineral density (BMD) and biochemical markers of bone turnover in adults aged 60-83 yr. Methods: Sixty-two men and women (68.4 +/- 6 yr) were stratified for strength and randomly assigned to a control (CON, N = 16), low-intensity (LEX. N = 24). or high-intensity (HEX. N = 22) group. Subjects participated in 6 months of progressive REX training. Subjects trained at either 50% of their one repetition maximum (1-RM) for 13 repetitions (LEX) or 80% of 1-RM for 8 repetitions (HEX) 3 times•wk[sup-1] for 24 wk. One set each of 12 exercises was performed. 1-RM was measured for eight exercises. BMD was measured for total body, femoral neck. and lumbar spine by dual energy x-ray absorptiometry (DXA). Serum levels of bone-specific alkaline phosphatase (BAP), osteocalcin (OC), and pyridinoline cross-links (PYD) were measured. Results: 1-RM significantly increased for all exercises tested for both the HEX and LEX groups (P [less or equal] 0.050). The percent increases in total strength (sum of all eight 1-RMs) were 17.2% and 17.8% for the LEX and HEX groups, respectively. Bone mineral density (BMD) of the femoral neck significantly ($P < 0.05$) increased by 1.96% for the HEX group. No other significant changes for BMD were found. OC increased by 25.1% and 39.0% for the LEX and HEX groups, respectively ($P < 0.05$). BAP significantly ($P < 0.05$) increased 7.1% for the HEX group. Conclusion: These data indicate high-intensity REX training was successful for improving BMD of the femoral neck in healthy elderly subjects. Also, these data suggest REX increased bone turnover, which over time may lead to further changes in BMD.

Key Words: RESISTANCE EXERCISE. ELDERLY. BMD. OSTEOCALCIN, ALKALINE PHOSPHATASE

Osteoporosis is a degenerative disease that is characterized by a decrease in bone mineral density (BMD). This loss makes the bones more susceptible to fractures. Hip fractures affect more than 250,000 Americans annually, with an associated cost of over $8 billion (6). Persons suffering hip fractures experience a loss of independence and have a 10-20% greater risk of mortality within the next year (19). Bone formation can be stimulated by placing strain on the bone as is experienced during resistance exercise (11,17). However, the data regarding the effects of resistance exercise on BMD are inconsistent. Some investigations have reported increases in BMD following resistance training (1,4,7-10,12), whereas others have not (14,18). Differences in exercise regimens, study duration, subject gender, and the health status of the subjects before study participation makes comparison of these investigations difficult. Also, evidence suggests that the intensity of the stimulus is more important than the frequency of application (11). This would seem to indicate that high-intensity resistance exercise may not only be an effective means of increasing BMD, but also would be more effective than low-intensity resistance training.

The American College of Sports Medicine (ACSM) currently recommends that adults over 50 yr of age perform resistance exercise consisting of one set of 8-10 exercises for 10-15 repetitions. However, to our knowledge, no studies have examined the effect of this protocol on BMD in elderly men and women. It is unknown if this volume or intensity of resistance exercise is sufficient to increase BMD, or reduce the age-related rate of decline of BMD in elderly adults. Therefore, the purposes of this investigation were to examine 1) if one set of resistance exercise would alter BMD and bone turnover in elderly adults, and 2) if the intensity of the exercise would affect the magnitude of change in BMD and bone turnover.

MATERIALS AND METHODS

SUBJECTS

Eighty-four apparently healthy men and women 60-83 yr old were recruited from the Gainesville area. Sixty-two of the volunteers completed the study protocol. Only participants that had not participated in regular resistance training for at least 1 yr were eligible. Participants also had to be free from any orthopedic or cardiovascular problems that would limit exercise. All participants received a comprehensive explanation of the proposed study, its benefits, inherent risks, and expected commitments with regard to time. After the explanation, all participants signed an informed consent document approved by the Institutional Review Board at the University of Florida and in accord with the policies of the ACSM.

MEASUREMENTS

Screening. Subjects were orientated to the study and signed the informed consent document, and underwent an initial screening via health history questionnaire during the first visit to the laboratory. One hundred fifteen potential participants were invited to the laboratory to participate in the initial screening. To be eligible for study participation, subjects underwent a medical examination performed by a physician specializing in geriatric medicine, a resting 12-lead electrocardiogram (ECG), and a graded exercise test to symptom-limited maximum (SL-GXT). Blood pressure, oxygen consumption, heart rate, and ECG were monitored during the SL-GXT. Thus, the subjects in this study were healthy, 60-83 yr old, with no signs of overt pathologic abnormalities that would confound or compromise their responses to exercise training. Female subjects were screened for the use of estrogen hormone replacement therapy or other medications used to increase bone density.

Strength. Baseline testing was performed before the 6-month training period and included assessment of BMD, dietary intake, blood collection, and muscular strength. Before the training period, each participant was instructed about the proper settings and movement techniques for each of the machines used during the 6-month training period.

Dynamic muscular strength was measured using the following eight resistance exercises: leg press, leg curl, knee extension, chest press, seated row, overhead press, triceps dip, and biceps curl. For each dynamic exercise, a one repetition maximum (1-RM) was determined. The participant began the test by lifting a light load on the machine, and incremental increases were then made according to the difficulty with which the participant executed the previous lift. The investigator continued to increase the weight lifted until reaching the maximum weight that could be lifted in one repetition with proper form. Maximal strength was defined as the maximum weight that could be lifted through a full range of motion with proper form. Total strength was calculated by summing the 1-RMs from the eight tested exercises. Lumbar extension strength was tested using a seven-angle isometric strength test using a MedX(R) (MedX (R) Corp., Ocala, FL) lumbar extension machine. The procedures for this test have been previously described by our laboratory (20).

BMD. Total body and regional BMD were assessed non-invasively using dual energy x-ray absorptiometry (DXA) (DXA model DPX-L, Lunar Radiation Corp., Madison, WI). Subjects were placed in a supine position or on their side while the x-ray scanner performed a series of transverse scans, moving from top to bottom of the region being measured at 1-cm intervals. Four separate scans were performed: 1) anteroposterior (AP) view of the total body with the subject supine; 2) AP view of the lumbar (L1-L4) spine; 3) AP view of the hips with the subject supine while the scanner moved across the right hip, providing information on the femur neck; and 4) lateral view of the lumbar (L2-L3) spine. Bone phantoms were scanned daily and were within expected values for the duration of the study. We previously demonstrated that regional and total body BMD measurements with this technique are highly reliable when subject positioning is carefully standardized (3).

Biochemical variables. Blood samples were collected from each subject at baseline and at 6 months. A 30-mL blood sample was collected via venipuncture of an antecubital vein. The sample was allowed to clot at room temperature for 10 min and then centrifuged for 15 min at 0°C. The serum was then pipetted into polystyrene tubes and stored at -80°C for later analysis. Bone-specific alkaline phosphatase (BAP) was measured in serum using an Alkphase-B(R) enzymatic immunoassay kit (EIA) (Metra Biosystems, Mountain View, CA). The assay is highly specific for BAP, cross-reacting [less or equal] 8% with liver alkaline phosphatase and not significantly with other alkaline phosphatase isoenzymes. Osteocalcin (OC) was measured with a NovoCalcin(R) EIA kit (Metra Biosystems) utilizing a murine monoclonal anti-OC antibody. Serum pyridinoline cross-links (PYD) were measured with Serum Pyd(R) EIA kit from Metra Biosystems utilizing a rabbit monoclonal anti-PYD antibody. To explore the possible influence of resistance training on the state of bone metabolism, ratios of OC and BAP (anabolic indicators) to PYD (catabolic indicator) were calculated.

Diet. Three-day diet records were completed before and after training. To ensure standardization of the dietary records, a registered dietician instructed the subjects individually how to fill out the diet records and assess food servings and sizes. Diet records were analyzed using Nutritionist IV Software (Nutritionist IV, First Data Bank, San Bruno, CA).

Group assignments. After baseline testing, the subjects were rank ordered by composite strength (chest press 1-RM plus leg press 1-RM) and randomly stratified to one of the two training groups or a control group that did not train. Subjects were randomly assigned to the control (CON, N = 20), low-intensity exercise (LEX, N = 34), or high-intensity exercise (HEX, N = 30) groups using a random numbers table. The CON group was instructed not to make any changes in their lifestyle during the study, and all groups were instructed not to change their diet.

Training program. The exercise training equipment used in this investigation was MedX(R) resistance machines. Subjects performed one set of each of the following exercises: abdominal crunch, leg press, leg extension, leg curl, calf press, seated row, chest press, overhead press, biceps curl, seated dip, leg abduction, leg adduction, and lumbar extensions. Participants in both the LEX and HEX groups were asked to report to the training facility 3 times•wk[sup-1] for 6 months to perform dynamic variable resistance exercise under the supervision of trained personnel. Isolated

lumbar extensions were performed under the supervision of personnel certified for the use of MedX(R) rehabilitation equipment. Each subject received appropriate instruction concerning warm-up and cool-down techniques, as well as how to monitor the intensity of the exercise using the RPE scale. Each subject performed one set on each of the resistance exercise machines. A 2-min rest period was allowed between each machine. Each set consisted of 8 repetitions for the HEX group and 13 repetitions for the LEX group at the appropriate resistance load. Each session lasted approximately 30 min. Training logs were kept for each session to monitor the progress of each participant and to adjust the resistance loads as necessary. To examine the effects of training intensity on the outcome variables and criterion measures, the LEX group trained at 50% of their 1-RM. whereas the HEX group used loads corresponding to 80% of their 1-RM. This allowed the groups to perform at different training intensities (defined by percentage of 1-RM) while completing comparable volumes of work. For the LEX and HEX groups, the load was increased by 5% when their RPE rating dropped below 18.

STATISTICAL ANALYSES

Statistical analyses were performed using the Statistical Package for the Social Sciences software (version 9.0) (SPSS Inc., Chicago, IL). Experimental analysis was performed with a 3 × 2 repeated-measures analysis of variance (ANOVA) model to determine differences within and between groups over time. If a significant (group × time) interaction was found, a Scheffé post hoc test was used to determine if and where there was a difference between the group means. Although no statistical differences were observed between groups at study entry, an ANCOVA was performed on outcome variables at the conclusion of the study. The covariate used was the baseline value for each subject for the particular outcome variable being analyzed. When the ANCOVA revealed that the covariate significantly contributed to the outcome, then the predicted means generated by the ANCOVA were analyzed with a Scheffé post hoc test. Pearson bivariate correlations were performed to examine the degree of association between variables. A priori alpha levels were set at 0.05.

RESULTS

Subjects. Sixty-two of the original 84 subjects completed the study (CON = 16, LEX = 24, HEX = 22). Of the 22 who did not finish, 11 (CON = 1, LEX = 6, HEX = 4) were dropped by the investigators for not adhering to the training protocol or they dropped out voluntarily for reasons of inconvenience. The other 11 (CON = 3, LEX = 6, HEX = 2) dropped out because of one of the following reasons: moved out of the area, financial difficulties, or surgery/injury (detached retina, atrial fibrillation, liver cancer, renal stenosis, prostate cancer) not related to the study protocol. Six of the training subjects experienced joint discomfort (three knee, two back, one elbow) and had to reduce training for 2 wk. The six subjects were distributed as follows: LEX. one knee and one back: HEX, two knee, one back, and one elbow. To be included in data analysis, participants in the two training groups must have completed greater than 85% of the possible exercise sessions during the 6-month period. Participants participating in less than 85% of the sessions were deemed noncompliant and dropped from the study. Characteristics of those subjects who completed the study are shown in Table 1. There were no statistically significant differences among groups for age, height, weight, body composition, and VO[sub2peak] at study entry (P [greater or equal] 0.05). Pre- and posttraining data for dietary calcium intake can be found in Table 1. There were no significant differences before or after the study whether dietary calcium was expressed as mg•d[sup-1] or was adjusted for total energy intake.

Muscular strength. Muscular strength did not differ among groups at study entry. The percent changes for muscular strength can be found in Table 2. No significant strength changes were noted in the control group. Muscular strength significantly increased in both training groups. ranging from 10.8% to 25.3% and from 14.6% to 27.6% for the LEX and HEX groups, respectively. Total strength values increased significantly from before to after training (P [less or equal] 0.05), but were not different between the two training groups (17.2% and 17.8% for the LEX and HEX groups, respectively). Total lumbar extension strength significantly (P [less or equal] 0.05) increased by 62.6% and 39.5% for the LEX and HEX groups, respectively (Table 2).

BMD. Pre- and poststudy values for total body (TB), femoral neck (FN), anteroposterior spine (APS), Ward's triangle (WT) and lateral spine (LS) BMD can be found in Table 3. There were no significant differences in BMD either between groups or from before to after training for TB, APS, WT, and LS ($P > 0.05$). Change in FN BMD from before to after the study is shown in Figure 1. The HEX group significantly ($P < 0.05$) increased (1.96%) BMD of the FN from before to after training.

Correlation coefficients relating TB, APS, LS, WT, and FN BMD to leg press (LP), overhead press (OP), total strength (TS), and total lumbar extension strength (LMB) can be found in Table 4. TB, LS, and APS BMD were significantly correlated ($P < 0.05$) to TS, LMB, LP, and OP, with r values ranging from 0.38 to 0.63. FN BMD was significantly correlated to TS, LP, and OP ($P < 0.05$).

Biochemical variables. The results for OC, BAP, and PYD are presented in Table 5. There were no significant differences between groups at study entry for OC, BAP, and PYD. OC significantly increased ($P < 0.05$) from before to

after training by 25.1% and 39.0% for the LEX and HEX groups, respectively. BAP increased significantly ($P < 0.05$) from 17.86 U•L[sup-1] to 19.15 U•L[sup-1] for the HEX group, but not for the remaining two groups. The prestudy ratios of OC to PYD were 8.9, 8.0, and 9.0 for the CON, LEX, and HEX groups, respectively (Fig. 2). After the study, the ratios were 8.2, 10.2, and 14.5 for the CON, LEX, and HEX groups, respectively, with LEX greater than CON ($P < 0.05$), and HEX greater than CON and LEX ($P < 0.05$). The prestudy ratios of BAP to PYD were 16.2, 12.8, and 14.3 for the CON, LEX, and HEX groups, respectively (Fig. 3). After the study, the ratios were 11.8, 13.8, and 17.2 for the CON, LEX, and HEX groups, respectively, with HEX greater than CON and LEX ($P < 0.05$).

DISCUSSION

This investigation was the first to examine the effects of one set of either high- or low-intensity resistance exercise on BMD and biochemical markers of bone turnover in healthy, elderly men and women. The results indicate that regional BMD can be increased via high-intensity resistance exercise even in healthy elderly persons. The results also indicate that both high- and low-intensity resistance exercise can change biochemical indices of bone turnover. As evidenced by increased OC/PYD and BAP/PYD ratios, these changes seemingly favor increased bone formation.

BMD. The exercise regimen used in this study was effective in increasing FN BMD in the HEX group. However, there were no other significant changes in BMD for any of the groups at the FN, TB, APS, WD, and LS sites. Previous investigations in older adults (50-61 yr) have shown that resistance exercise is an effective means for increasing BMD (1.12). However, the subjects in the Braith et al. (1) study were organ transplant recipients immunosuppressed with glucocorticoids that had significantly depressed BMD compared with healthy age-matched controls. Also, although the subjects in the Menkes et al. (12) study improved their FN and LS BMD, examination of their data shows that the training group had lower bone density values compared with the control group at the start of the study. It is possible that the significant increases reported in those two studies was a matter of the training groups regressing toward the mean and approaching normal levels of BMD.

In a follow-up to the Menkes et al. study, the same group tried to replicate their findings using a bigger sample size and subjects with higher initial BMD (18). Using the same exact regimen as in the Menkes et al. study. Ryan et al. reported similar increases in total strength (45% vs 39%) after 16 wk of resistance exercise. However, Ryan et al. only found increased BMD for the FN and not for any other site. Our data are in accord with those presented by Ryan et al., as we observed a significant increase only at the FN. Ryan et al. postulated that the discrepancy between their study and that of Menkes et al. was a consequence of the higher initial BMD values for their subjects as compared with those in the Menkes et al. study.

Pruitt et al. (15) examined the effects of 12 months of high-intensity (HI) (80% of 1-RM, three sets) versus low-intensity (LI) (40% 1-RM, three sets) resistance exercise on LS, FN, and WT BMD in 26 women between the ages of 65 and 79. Strength increased after the training but BMD did not. The authors attributed the lack of BMD changes to the fact that the subjects had normal BMD values before study participation. Nichols et al. (14) examined the effects of 12 months of HI (80% 1-RM, three sets) resistance exercise on BMD in older women (67.1 +/- 1.5 yr). No significant changes in BMD were observed. Again, the authors concluded that the lack of a training-induced improvement in BMD was attributable to the normal pretraining BMD values. The initial BMD values for the LS, FN, and TB were 96%, 105%, and 98%, respectively. The subjects in the present study also had normal levels of BMD before study participation. The mean percent of age-matched norms at the start of the study were 102%, 113%, 115%, 108%, and 102% for FN, APS, LS, TB, and WD, respectively. It is also noteworthy that at study entry the women had a significantly higher percentage of normal BMD compared with the men. The stringent screening process used in the present study may have resulted in selecting subjects that were very healthy and had higher BMD than would normally be expected in this population. Therefore, since the BMD values were at or above normal, it is not surprising that greater increases in BMD were not observed. However, it is important to note that one site that was impacted was the FN. Low BMD at the FN is a primary cause of fractures, disability, decreased independence, and death in the elderly (13). Therefore, interventions that can increase or prevent the age-related decrease of FN BMD are extremely important.

A purpose of the present study was to provide information that could be useful for resistance exercise program design. It is important to know not only what exercise intensity is necessary to improve BMD but also which exercises have the greatest impact on BMD. Table 4 indicates that, of the exercises in the current investigation, leg press, overhead press, and lumbar extensions had the greatest influence on both site-specific and TB BMD. Other exercises were not included because they did not affect BMD. If the amount of time exercising is a limiting factor, then this information could be used to design a program that maximizes the influence on BMD while helping to minimize the time spent exercising.

Biochemical markers of bone metabolism. In an attempt to examine the biochemical alterations underlying BMD changes with resistance training, several serum markers of bone metabolism were measured. Serum OC and BAP have

been shown to be sensitive to alterations in bone metabolism following disease, menopause, and hormone replacement therapy (2,5,16). We observed a significant increase in OC for both the LEX and the HEX groups, whereas only the HEX group demonstrated a significant increase in BAP. These data are in accord with Menkes et al. (12), who reported significant increases in OC and BAP following 16 wk of resistance training. However, neither the follow-up to that study (18) or Pruitt et al. (15) reported significant increases in either OC or BAP. Serum PYD are an indicator of bone resorption and should increase with increased bone resorption (2). The assay for serum PYD is new and has not been used in any published studies in this type of setting. Therefore, comparisons of the values from this study cannot be made to those of other resistance training studies. The interpretation of the biochemical results in the present study is unclear. Possibly, biochemical alterations were observed before measurable changes in the skeletal BMD. It may be that more time would be necessary to observe measurable alterations in BMD, and that the biochemical markers serve as precursors to skeletal changes.

Alterations in isolated markers of bone metabolism are useful for evaluating if a specific intervention has impacted the rate of bone turnover. However, these markers when viewed in isolation may not indicate whether increased turnover translates into bone anabolism or catabolism. Indeed, interpretation of the results can be clouded by the phase of bone metabolism (2,5,16). In an attempt to shed light on how the biochemical markers relate to each other and how they may serve as indicators of possible anabolism or catabolism, we calculated ratio scores of OC and BAP to PYD. Since OC and BAP are anabolic markers, and PYD is a catabolic marker, an increase in the OC/PYD or BAP/PYD ratio could indicate a state of bone turnover favoring increased bone formation. Likewise, a decrease in these ratios may indicate bone turnover favoring bone loss. We observed increases in the OC/PYD ratio in both training groups and an increase in the BAP/PYD ratio for the HEX group. These changes appear to be in accord with the BMD changes we observed. Increased BMD and the greatest increases in the OC/PYD and BAP/PYD ratios were both observed in the HEX group. It is possible that the biochemical markers indicate initial changes in bone metabolism that favor increased bone mass. However, measurable (by DXA) increases in regional BMD may lag behind alterations in biochemical markers of bone metabolism. Therefore, before definitive conclusions regarding these relationships can be made, further investigations of longer duration are necessary to determine if early biochemical changes are associated with delayed increases in BMD.

CONCLUSION

Study duration is an important consideration for investigations examining changes in BMD as a consequence of an intervention. We feel that because of the evidence reported in the literature, the current study duration of 6 months is appropriate. Typically, the magnitude of bone density change is influenced by the subject's bone density at baseline. Since the subjects in this study were very healthy and had adequate bone density levels at baseline, a duration longer than 6 months may be necessary for measurable changes in bone density. Studies using a similar population should be conducted for a longer duration so that bone density has more time to accumulate. The biochemical indices of bone turnover presented in this study seem to indicate that bone metabolism had increased. These increases may potentially lead to measurable alterations in bone density over time. Also, although it was not the purpose of this study to examine gender differences in adaptations to resistance training, we analyzed the data separated by gender to determine any unforeseen influences. No additional significant differences were noted that changed either the results or the interpretation of this investigation when the data were analyzed separated into men and women.

In summary, the results from this investigation indicate that one set of HI (80% of 1-RM) was effective for increasing BMD and biochemical indices of bone turnover. LI resistance exercise did not elicit significant increase in BMD, but was associated with alterations in biochemical indices of bone turnover. The ratio of anabolic (OC, BAP) to catabolic (PYD) markers of bone turnover was changed by resistance training to seemingly favor bone formation. It is possible that alterations in biochemical indices of bone turnover precede measurable changes in BMD. The relationship between measurable BMD and biochemical indices of bone turnover warrants further investigation.

ADDED MATERIAL

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The authors wish to thank Michael L. Pollock, Ph.D., for his assistance and guidance with the development of this project before his untimely passing. We also thank Drs. Paulo Gomes and Glen Duncan, and Peter Magyari, Ross Feldman, Ray Urquiza, Abigail Geslani, Abigail Updike, Lisa Porter, and Shannon Foster for their help with testing and training the subjects throughout this study. We also thank the staff at the University of Florida Living Well facility for their assistance with this study and all of the study participants who volunteered.

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TABLE 1. Characteristics of the study participants.

Variable	CON (N = 16)	LEX (N = 24)	HEX (N = 22)
Age	71 +/- 5	67.6 +/- 6	66.6 +/- 7
Height (cm)	169.9 +/- 10	167.2 +/- 11	167.1 +/- 9
Mass (kg)	71.0 +/- 14	74.4 +/- 16	74.8 +/- 15
Skin fold (% fat)	28.9 +/- 7	29.0 +/- 5	29.9 +/- 8
DXA (% fat)	34.4 +/- 7	34.1 +/- 8	36.2 +/- 9
Fat-free mass (kg)	46.0 +/- 10	47.8 +/- 13	47.9 +/- 12
VO[sub2peak] (mL•kg[sup-1]•min[sup-1])	22.6 +/- 3	20.2 +/- 4	20.9 +/- 6
Dietary calcium (mg•d[sup-1])			
Before	953.1 +/- 697	956.5 +/- 419	835.3 +/- 376
After	831.0 +/- 244	887.2 +/- 387	974.7 +/- 825
Dietary calcium (mg•1000 kcal[sup-1])			
Before	556.8 +/- 139	516.6 +/- 127	673.3 +/- 559
After	599.1 +/- 350	499.6 +/- 216	582.3 +/- 248

CON. control group: LEX. low-intensity group: HEX. high-intensity group: DXA. dual energy x-ray absorptiometry, where VO[sub2peak] = peak oxygen consumption. Means +/- SD are shown.

TABLE 2. Percent change in 1-RM values before and after 6 months of resistance training.

Variables	CON (N = 16)	LEX (N = 24)	HEX (N = 22)
Chest press	-1.2 +/- 20	17.5 +/- 14(FN*)	16.0 +/- 17(FN*)
Leg press	1.5 +/- 22	15.7 +/- 16	27.6 +/- 18(FN*)
Leg curl	-0.7 +/- 10	25.3 +/- 13(FN*)	17.3 +/- 10(FN*)
Biceps curl	-3.8 +/- 16	17.8 +/- 10(FN*)	24.6 +/- 14(FN*)
Seated row	6.5 +/- 16	19.2 +/- 11(FN*)	22.1 +/- 16(FN*)
Overhead press	-3.6 +/- 18	18.8 +/- 12(FN*)	16.1 +/- 10(FN*)
Seated dip	-0.7 +/- 6	18.5 +/- 9(FN*)	16.1 +/- 10(FN*)
Leg extension	-4.6 +/- 8	10.8 +/- 7(FN*)	14.6 +/- 12(FN*)
Total strength	-1.1 +/- 6	17.2 +/- 10(FN*)	17.8 +/- 8(FN*)
Lumbar extension	-8.0 +/- 23	62.6 +/- 44(FN*)	39.5 +/- 30(FN*)

CON. control group: LEX. low-intensity group: HEX. high-intensity group; Total strength. % change for all eight exercises. Values are mean +/- SD.

FOOTNOTE

* $P < 0.05$ vs CON.

TABLE 3. Changes in bone mineral density for the CON, LEX, and HEX groups following 6 months of resistance training or control period.

Site	CON (N = 16)		LEX (N = 24)	
	Before	After	Before	After
TB (g•cm[sup-2])	1.196 +/- 0.1	1.187 +/- 0.1	1.195 +/- 0.1	1.189 +/- 0.
TB % Delta		-0.73 +/- 1.9		-0.42 +/-
FN (g•cm[sup-2])	0.863 +/- 0.1	0.848 +/- 0.1	0.893 +/- 0.2	0.9 +/- 0.
FN % Delta		-1.59 +/- 4.89		0.68 +/-
APS (g•cm[sup-2])	1.228 +/- 0.2	1.222 +/- 0.2	1.186 +/- 0.2	1.182 +/- 0.
APS % Delta		-0.0251 +/- 4.1		-0.464 +/-
LS (g•cm[sup-2])	0.645 +/- 0.2	0.651 +/- 0.2	0.715 +/- 0.3	0.72 +/- 0.
LS % Delta		0.644 +/- 13.1		3.22 +/-
WT (g•cm[sup-2])	0.69 +/- 0.1	0.676 +/- 0.1	0.743 +/- 0.2	0.733 +/- 0.
WT % Delta		-1.94 +/- 8.3		-0.74 +/-

Site	HEX (N = 22)	
	Before	After
TB (g•cm[sup-2])	1.192 +/- 0.1	1.182 +/- 0.1

TB % Delta		-0.21 +/- 1.6
FN (g•cm[sup-2])	0.852 +/- 0.1	0.869 +/- 0.1(FN*)
FN % Delta		1.96 +/- 3.33
APS (g•cm[sup-2])	1.197 +/- 0.2	1.188 +/- 0.2
APS % Delta		-0.958 +/- 3.5
LS (g•cm[sup-2])	0.694 +/- 0.3	0.674 +/- 0.2
LS % Delta		-1.12 +/- 15.6
WT (g•cm[sup-2])	0.677 +/- 0.1	0.676 +/- 0.1
WT % Delta		-0.17 +/- 6.7

CON, control group; LEX, low-intensity group; HEX, high-intensity group; TB, total body; FN, femoral neck; APS, anteroposterior spine; LS, lateral spine; WT, Ward's triangle; %Delta, percent change from before to after.

Values are mean +/- SD.

FOOTNOTE

* P < 0.05 vs before.

TABLE 4. Correlations between absolute bone mineral density and select strength measures: r values are shown followed by significance value in parentheses.

Site	TS	LMB	LP	OP
TB	0.58 (0.00)(FN+)	0.48 (0.00)(FN+)	0.60 (0.00)(FN+)	0.57 (0.00)(FN+)
FN	0.29 (0.04)(FN*)	0.18 (0.28)	0.29 (0.05)(FN*)	0.30 (0.03)(FN*)
WT	0.07 (0.61)	0.05 (0.78)	0.22 (0.13)	0.16 (0.26)
APS	0.38 (0.01)(FN+)	0.33 (0.05)(FN*)	0.43 (0.00)(FN+)	0.41 (0.00)(FN+)
LS	0.60 (0.00)(FN+)	0.44 (0.01)(FN+)	0.61 (0.00)(FN+)	0.63 (0.00)(FN+)

LP, leg press 1-RM; OP, overhead press 1-RM; LMB, total lumbar extension strength; TS, total strength; TB, total body; FN, femoral neck; WT, Ward's triangle; APS, anteroposterior spine; LT, lateral spine.

FOOTNOTE

* Correlation significant at P < 0.05.

+ correlation significant at P < 0.01.

TABLE 5. Comparison of changes in markers of bone metabolism for the CON. LEX. and HEX groups following 6 months of resistance training.

	CON (N = 16)		LEX (N = 24)	
Marker	Before	After	Before	After
OC (ng•mL[sup-1])	12.32 +/- 5.4	13.23 +/- 5.2	10.74 +/- 4.0	13.58 +/- 7.2
% Delta		6.6 +/- 31.7		25.1 +/-
BAP (U•L[sup-1])	21.14 +/- 10.4	18.88 +/- 4.6	16.62 +/- 5.6	17.54 +/- 5.7
% Delta		-4.0 +/- 18.9		8.0 +/-
PYD (nmol•L[sup-1])	1.82 +/- 0.8	1.72 +/- 0.6	1.50 +/- 0.7	1.51 +/- 0.6
% Delta		-1.3 +/- 34.5		11.3 +/-

	HEX (N = 22)	
Marker	Before	After
OC (ng•mL[sup-1])	11.94 +/- 5.0	15.57 +/- 7.4(FN*)
% Delta		39.0 +/- 44.6
BAP (U•L[sup-1])	17.86 +/- 6.6	19.15 +/- 7.5(FN*)
% Delta		8.0 +/- 12.7
PYD (nmol•L[sup-1])	1.53 +/- 0.7	1.45 +/- 0.6
% Delta		9.9 +/- 66.4

CON. control group: LEX. low-intensity group; HEX. high-intensity group; OC. serum osteocalcin; BAP, bone-specific alkaline phosphatase; PYD, serum pyridinoline cross-links. Values are mean +/- SD.

FOOTNOTE

* P < 0.05 vs before.

FIGURE 1--Percent change in femoral neck (FN) BMD for the control (CON), low-intensity (LEX) and high-intensity (HEX) groups measured before and after the 6-month study period. Values are mean +/- SE. *P < 0.05 from before to after study.

FIGURE 2--Ratio of osteocalcin (OC) to pyridinoline cross-links (PYD) for the control (CON), low-intensity (LEX), and high-intensity (HEX) groups measured before (PRE) and after (POST) the 6-month study period. Values are mean +/- SE. * $P < 0.05$ vs CON; $P < 0.05$ vs LEX.

FIGURE 3--Ratio of bone-specific alkaline phosphatase (BAP) to pyridinoline cross-links (PYD) for the control (CON), low-intensity (LEX) and high-intensity (HEX) groups measured before (PRE) and after (POST) the 6-month study period. Values are mean +/- SE. * $P < 0.05$ vs CON; $P < 0.05$ vs LEX.

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