ORIGINAL RESEARCH

Effect of short-term upper-body resistance training on muscular strength, bone metabolic markers, and BMD in premenopausal women

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Abstract: To examine the effect of a 10-week upper-body resistance training program on bone turnover markers and site-specific bone mineral density (BMD) in the wrist and distal half of the ulna and radius in untrained and healthy young premenopausal women.

Methods: Twenty-two subjects (aged 22.1 ± 1.8 years) were randomly assigned to a resistance training (n = 12) or no training control (n = 10) group. The following outcome variables were measured before and after 10 weeks of resistance training: (1) bone formation biomarker osteocalcin, and bone resorption biomarker tartrate-resistant acid phosphatase isoform 5b; (2) BMD in the wrist and distal half of the ulna and radius; (3) isokinetic strength of the elbow and knee extensors and flexors; (4) dynamic strength of the arm extensors and flexors; and (5) maximum number of push-ups.

Results: The 10-week upper body resistance training intervention resulted in improved strength performance in push-ups (resistance training versus control: $P < 0.05$), chest presses ($P < 0.05$), and pulldowns ($P < 0.05$). However, there was no improvement in the BMD of the wrist ($P > 0.05$), BMD of the distal half of the ulna and radius ($P > 0.05$), and metabolic biomarkers osteocalcin ($P > 0.05$) and tartrate-resistant acid phosphatase isoform 5b ($P > 0.05$), except for the osteocalcin/tartrate-resistant acid phosphatase isoform 5b ratio. Also, no improvement in the resistance training group was observed for isokinetic strength of the knee and elbow flexion/extension.

Conclusion: Upper-body muscular strength performance, but not bone metabolic markers and BMD of the wrist, can be improved with a 10-week upper body resistance training program of the nonweight-bearing limbs in untrained young premenopausal women.

Keywords: osteocalcin, TRACP5b, wrist and heel mineral density, isokinetic strength, dynamic strength training

Introduction

Osteoporosis is a silent skeletal disease characterized by increased bone resorption without an adequate compensating formation of new bone. In humans, after bone mass reaches its peak, it remains relatively stable until the onset of menopause in women or around the age of 70 years in men. The suggested age-related decline of bone mineral density (BMD) in postmenopausal women is approximately 1% per year.[1] It is expected that exercise-trained or physically active persons acquire higher peak bone mass (PBM) during young adulthood than untrained or inactive persons. Walsh et al found that bone size and density increase and bone turnover markers decrease until age 25 years, and suggest that PBM may influence bone accrual into the third decade.[2] Although the causes of osteoporosis are not fully understood, increasing one's

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PBM may assist in optimizing bone health and preventing osteoporosis. Resistance training or impact-loaded exercise and adequate calcium intake are thought to be particularly important in achieving PBM.[3] Studies suggest that physiologic and pathologic aspects of bone formation and resorption are "coupled," ie, these bone markers change in parallel.[4,5] Studies also suggest that a single bout of strength exercise or short duration (ie, 4–20 weeks) resistance training may increase bone formation markers.[4–10] However, some inconsistencies exist among studies as to the duration of resistance training that can effectively induce osteogenic responses in premenopausal women. Most studies have investigated bone metabolic markers and fracture risk focusing on older adult women, but not in premenopausal women using short-term (ie, <12 weeks) resistance training of the upper body.

To understand the relationship between resistance training and the osteogenic effect on bone, one could focus effort on the specificity of musculoskeletal loading in the nonweight-bearing skeleton, such as the upper extremities.[7,11,12] The optimal duration of resistance training that might enhance PBM and BMD needs to be identified. Although the benefits of exercise training on BMD and fracture risk in the lower extremities have been well studied, there is a need to determine if short-term upper-body resistance training can induce osteogenic responses in untrained premenopausal women in terms of bone metabolic biomarkers and upper-body BMD. Therefore, the purpose of this study was to assess the effect of a 10-week upper-body resistance training program with calcium and vitamin D_3 supplementations on changes in biochemical markers and site-specific ulna and radius BMD in healthy, untrained premenopausal women.

Material and methods
Subjects
Twenty-eight healthy, untrained premenopausal females, 19–30 years old, were recruited for the study. The eligibility criteria for serving as study subjects included: (1) willingness to sign an informed consent approved by the Institutional Review Board of California State Polytechnic University, Pomona and (2) commitment to a two-session/week resistance training regimen in the weight room and one session/week elastic band exercises at a convenient location of their choice. All participants were screened using a Physical Activity Readiness Questionnaire and Health/Exercise History Questionnaire to exclude the presence of the following health conditions or diseases: insulin-dependent diabetes, amenorrhea (zero to three cycles per year), pregnancy, cardiovascular and pulmonary disease, orthopedic disorders,

thyroid dysfunction, gastrointestinal disease resulting in malabsorption, eating disorders, kidney disorder, liver disease or cancer, chronic corticosteroid, drug, or alcohol use, participation in strength training in the past 6 months, maximal oxygen uptake (VO_{2max}) ≥31.0 mL/kg/minute, or body mass index (BMI) ≤18.0 or ≥25 kg/m^2. Participants were randomly assigned to either: (1) a 10-week upper-body resistance training group (RT, n = 14) or (2) a 10-week untrained control group (CON, n = 14). The screening revealed that two participants were not eligible for study: one had a BMI < 18 kg/m^2 (CON group) and the other had a BMI > 25 kg/m^2 (RT group). As a result, 26 subjects were eligible to serve as study participants. At the conclusion of the training, four participants withdrew from the study: one from the RT group was dropped due to noncompliance with the training protocol and three from the CON group were dropped due to loss of interest in the study. Thus, a total of 22 subjects completed the baseline and follow-up measurements (RT, n = 12; CON, n = 10). This dropout rate of 15% is considered highly acceptable for this type of resistance training study involving a young, healthy female population.[13]

Study design
Subjects in the RT group trained three times a week for 10 weeks, while the CON group did not participate in any exercise training. Both groups were required to provide weekly physical activity logs at the end of the 10-week study. To promote better compliance, the RT group did supervised and self-directed training: subjects trained two sessions per week under supervision and one session per week without supervision using an elastic band protocol.

Resistance training and self-directed elastic band training protocol
The resistance training program was designed to load the upper-body musculoskeletal system and to improve upper-body muscle strength with the aim of testing whether strength gain can enhance site-specific BMD in the upper extremities in 10 weeks. The supervised resistance exercises and the elastic band strength training protocol are presented in Table 1.

The supervised resistance training intensity was set at 50%–60% of one repetition maximum (1RM) and the duration of training was 45–55 minutes per session, two times a week. The self-directed elastic band strength training intensity was approximated by the resistance level (color coded) of the elastic band (Thera-Band®; The Hygenic Corporation, Akron, OH) to match each exercise used in the supervised

Table 1 Upper-body resistance training protocol

Type of exercise	Number of reps	Number of sets	Weight type used
Supervised resistance training exercises			
Chest press	10–12	2–3	Machine weight
Lateral pulldown	10–12	2–3	Machine weight
Shoulder press	10–12	2–3	Machine weight
Bicep curl	10–12	2–3	Machine weight
Triceps extension	10–12	2–3	Machine weight
Modified push-up	Max reps	1	Self-body
Right wrist flexion	Max reps	1	Free weight
Left wrist flexion	Max reps	1	Free weight
Right wrist extension	Max reps	1	Free weight
Left wrist extension	Max reps	1	Free weight
Type of exercise	**Number of reps**	**Number of sets**	**Thera-band tension used**
Self-directed elastic band exercises			
Chest press	10–12	2–3	Red, green, or black
Lateral pulldown	10–12	2–3	Red, green, or black
Shoulder press	10–12	2–3	Red, green, or black
Bicep curl	10–12	2–3	Red, green, or black
Triceps extension	10–12	2–3	Red, green, or black
Modified push-up	Max reps	1	Self-body
Right wrist flexion	Max reps	1	Red, green, or black
Left wrist flexion	Max reps	1	Red, green, or black
Right wrist extension	Max reps	1	Red, green, or black
Left wrist extension	Max reps	1	Red, green, or black

Abbreviations: black, high tension; green, medium tension; max, maximum; reps, repetitions.

1RM strength. Participants were provided with two different levels (ie, light resistance and moderate resistance) of elastic bands at the beginning of the program and two different levels (ie, moderate resistance and high resistance) of elastic bands during the fifth week of training. Using the elastic band, the subjects trained 45–55 minutes per session, once a week at a location of their choice, ie, home or dormitory. All training sessions included a 5-minute warm-up with callisthenic stretching exercises and a 5–10-minute cooldown with light stretching exercises. Participants were instructed not to undertake any additional aerobic or strength exercise during the study period. Participants' attendance was recorded and the compliance with the training protocol was excellent (100%).

Calcium supplement
Subjects were instructed on recommended hydration and dietary guidelines prior to the initial training session to ensure that daily caloric intake adequately matched their energy expenditure. Each subject was given a daily dose of 500 mg of calcium carbonate supplement fortified with 500 IU of vitamin D_3 (Viactiv®; McNeil Nutritionals LLC, Fort Washington, PA). Throughout the entire study, supplements were provided directly to the subjects and were monitored daily in person and via email or telephone. Participants reported 100% compliance in taking the supplements.

Outcome measurements
The following primary outcome measurements were performed at baseline and at the conclusion of the 10-week study period: (1) bone turnover biomarkers; (2) areal BMD; (3) peak muscular strength and power; (4) anthropomorphic measurements; (5) 1RM measurement; and (6) aerobic capacity measurement.

Bone turnover biomarkers
Two biochemical markers in bone were measured: (1) bone formation biomarker osteocalcin (OC) and (2) bone resorption biomarker tartrate-resistant acid phosphatase isoform 5b (TRACP5b). The osteoclast-specific isoform TRACP5b is a lysosomal enzyme secreted by activated osteoclasts and has small within-subject variability (6.6%) with a modest decrease in response to feeding (2.4%).[14] Also, TRACP5b appears to have low biological variability. OC, synthesized by mature osteoblasts, is considered a specific biomarker of osteoblast function. OC has been used by researchers as a bone formation marker for over a decade.[4] Because OC has a high biological and circadian variability, blood samples for an OC assay must be processed rapidly and stored at −70°C.[5]

Prior to the blood samples, subjects were instructed to maintain adequate hydration and observe a 10-hour overnight fast. Fasting blood was obtained from an antecubital vein and the samples were left to clot at room temperature for 30 minutes and then immediately centrifuged and aliquoted. All samples from both visits were stored at −70°C and analyzed in duplicate for each subject on the same day at the conclusion of the study. OC was measured using the MicroVue™ OC Enzyme Immunoassay kit (Quidel Corporation, San Diego, CA) and TRACP5b was measured using the MicroVue™ TRACP5b Immunocapture Enzyme Assay kit (Quidel). Samples were determined using a SpectraMax® 340PC microplate spectrophotometer (Molecular Devices LLC, Sunnyvale, CA). For OC, the mean intra-assay and interassay coefficient of variation was 7.8% and 7.4%, respectively. For TRACP5b, the mean intra-assay and interassay coefficient of variation was 2.1% and 2.5%, respectively.

Areal BMD
Site-specific BMD of the left wrist, distal half of the ulna and radius, and calcaneus (heel) were scanned using a peripheral instantaneous X-ray imager dual energy X-ray absorptiometry (Lunar Model 30200; GE Healthcare, Little Chalfont, United Kingdom). Based on previous bone density data collected for

untrained healthy premenopausal females, it was observed that wrist and heel BMD were significantly higher in the right arm ($P < 0.01$) and heel ($P < 0.05$) than in the left arm and heel. The assumption is that when examining bone mineral response to musculoskeletal loading it would be appropriate to use the nondominant side of the skeleton with lower baseline BMD values. Thus, all wrist and heel BMD were assessed using the nondominant side of the skeleton. All subjects were right-handed based on the self-reported Health/Exercise History Questionnaire. During the wrist BMD study, the subjects were asked to remove all metal objects (rings and bracelets) from the left arm or fingers. The subjects then sat in the chair and rested their left wrist, fist closed, on the platform in the center of the scanner with the ulnar styloid in line with the distal edge of the platform. During the heel BMD study, the subjects were asked to remove their left shoe and sock. From a sitting position, the subjects then placed their left heel into a V-shape slot provided by the manufacturer with the heel closely touching the bottom of the V support and the sole extended to touch the front of the V support. During the scanning, the subjects' left arm or left foot was held motionless for 10–15 seconds when the scanner was turned on. All acquired BMD images were visually examined by the investigator to ensure that the image was free of motion artifacts. The coefficient of variation of the BMD using the manufacturer's standard phantoms for the wrist was 3.45%, and 0.44% for the heel. The coefficients of variation on repeated measures of the same individual were: 1.2%, 1.9%, and 0.54% for the wrist, distal half of the ulna and radius, and heel, respectively.

Peak muscular strength and power

Peak muscular power of the right leg and arm was assessed using a multijoint isokinetic dynamometer (Biodex™ System 3 Pro; Biodex Medical Systems Inc, Shirley, NY) to measure peak torque of the knee and elbow extensor and flexor strength according to the standardized procedures recommended by the manufacturer. During the test, subjects were instructed to extend the knee (or elbow) maximally and then flex the knee (or elbow) through full range of motion five times in succession to complete one set. Two sets of five trials, with a 3-minute rest between each set, were performed by the subjects at the contraction speeds of 60 degrees/second and 120 degrees/second, respectively.

Anthropomorphic measurements

Weight (kg) and height (cm) were measured without shoes in light indoor clothing using a calibrated clinical weight/height scale (Detecto Scale; Cardinal Scale Manufacturing Company, Webb City, MO). BMI was calculated using weight divided by height squared (kg/m^2).

1RM measurement

Maximum muscular strength was determined on weight machines (LifeFitness, Forest Park, IL) using the 1RM test on each of five exercises including (1) chest press, (2) lateral pulldowns, (3) shoulder press, (4) bicep curls, and (5) triceps extension. The 1RM testing consisted of one warm-up set using three to five repetitions at 40% and 60% of estimated 1RM lift load, followed by three to five repetitions of subsequent attempts with increasing weights until the subject was unable to lift the weight through a full range of motion. The heaviest weight that could be lifted through a full range of motion with proper form was used as the 1RM test value. The 1RM lift load was reevaluated at week five to adjust the weight used for the next 5 weeks of training at 50%–60% of the 1RM.

Aerobic capacity measurement

Subjects VO_{2max} was measured using an open circuit automated metabolic cart system (TrueOne 2400 Metabolic Measurement System; ParvoMedics, Sandy, UT) and a treadmill (Trackmaster® TMX55; Full Vision Inc, Newton, KS). During the treadmill test, subjects walked at a constant speed of 88 m/minute (3.3 mph) at 0% incline for 2 minutes, thereafter the incline increased 2% every 2 minutes until the subject reached a point of exhaustion. At this point the VO_2 value was considered VO_{2max}.

Statistical analysis

Group differences in baseline anthropometric and VO_{2max} measures were compared using analysis of variance. The primary outcome variables (bone turnover markers, BMD of the heel and wrist, peak isokinetic power, and 1RM strength) were analyzed in separate two-way analysis of variance (group × time point), with repeated measures on time point. When a significant interaction was detected, Tukey's honestly significant difference post hoc test was conducted to locate the inequities among the means. All statistical analyses were carried out using SPSS® version 17.0 (IBM Corporation, Armonk, NY). The significance level was set at $P < 0.05$.

Results

There were no significant differences between the RT and CON groups in participants' physical characteristics before or after the 10-week intervention, nor were there any significant changes from pre- to postintervention in either group (Table 2). Also, the pre-versus postintervention VO_{2max} values

Table 2 Mean (±standard deviation) participant characteristics before and after the intervention for the upper-body resistance training and control (no training) group

Variable	Test	RT (n = 12)	Control (n = 10)
Age (years)	Pre	22.0 ± 1.8	21.9 ± 1.6
	Post	22.0 ± 1.6	21.9 ± 1.6
Height (cm)	Pre	163.2 ± 6.3	161.8 ± 6.6
	Post	163.2 ± 6.3	161.8 ± 6.6
Weight (kg)	Pre	62.7 ± 11.6	58.5 ± 6.6
	Post	62.7 ± 11.7	58.4 ± 6.4
BMI (kg/m^2)	Pre	23.4 ± 4.0	22.6 ± 2.2
	Post	23.5 ± 4.0	22.3 ± 1.6
VO$_{2max}$ (mL/kg/minute)	Pre	23.5 ± 4.0	22.3 ± 1.6
	Post	30.2 ± 4.7	30.9 ± 4.2

Notes: Group and pre–post differences were not significant, $P > 0.05$.
Abbreviations: BMI, body mass index; RT, upper-body resistance training; VO$_{2max}$, maximal oxygen uptake.

showed no difference ($P > 0.05$) between the two groups at baseline (mean ± standard deviation: 23.5 ± 4.0 versus 22.3 ± 1.6 mL/kg/minute) and at the end of the 10-week study (30.2 ± 4.7 versus 30.9 ± 4.2 mL/kg/minute).

The findings show that 10 weeks of upper-body resistance training produced significant improvement in strength performance in the number of push-ups (111%; $P < 0.05$), chest presses (23.5%; $P < 0.05$), and pulldowns (15.6%; $P < 0.05$), but not in BMD of the wrist ($P > 0.05$), distal

half of the ulna and radius ($P > 0.05$), and heel ($P > 0.05$) (Table 3). In addition, there were no improvements in either group in peak isokinetic muscular power (peak torque) of the knee and elbow extension and flexion performed at the muscular contraction speeds of 60 and 120 degrees/second, nor any changes in OC and TRACP5b response ($P > 0.05$); however, the OC/TRACP5b ratio was significantly higher after training than before in the RT group (Table 4). The improved chest press, lateral pulldown, and push-up strength performance after training in the RT group was not accompanied by a significant improvement in any of the BMD.

Discussion

In untrained premenopausal women, relatively few studies have examined the effect of short-term resistance training of the upper-body skeleton with calcium plus vitamin D$_3$ supplementation on changes in bone turnover markers and site-specific BMD of the upper extremities. This study is novel in regard to the study population and the musculoskeletal loading of the nonweight-bearing upper-body skeleton that can be generalized to adult premenopausal women. Ten weeks of site-specific resistance training can significantly increase upper-body strength performance and maintain site-specific BMD in the wrist and distal half of

Table 3 Mean (±standard error) one repetition maximum strength and peak isokinetic muscular power before and after the intervention for the upper-body resistance training and control (no training) groups

Variable	Test	RT (n = 12)	95% CI	Control (n = 10)	95% CI
1RM chest press (kg)	Pre	32.8 ± 2.3	7.76 ± 2.57	32.2 ± 2.2	2.41 ± 4.08
	Post	40.5 ± 2.5*		34.7 ± 1.3	
1RM lateral pulldowns (kg)	Pre	37.9 ± 1.9	5.97 ± 2.67	38.9 ± 1.9	0.00 ± 3.05
	Post	43.8 ± 2.1*		38.9 ± 2.0	
Push-ups (number)	Pre	14.4 ± 2.6	16 ± 5.05	17.3 ± 3.3	1.5 ± 4.19
	Post	30.4 ± 3.7*		18.8 ± 3.2	
KEx 120°/second (NM)	Pre	93.9 ± 8.9	0.47 ± 10.11	96.3 ± 4.7	4.48 ± 11.83
	Post	94.4 ± 5.6		100.7 ± 8.0	
KFl 120°/second (NM)	Pre	45.2 ± 4.8	3.05 ± 3.38	48.3 ± 2.8	−0.25 ± 6.41
	Post	48.3 ± 3.8		48.1 ± 3.2	
KEx 60°/second (NM)	Pre	126.7 ± 6.4	−2.38 ± 8.39	114.9 ± 7.5	−2.98 ± 14.24
	Post	124.3 ± 6.9		111.9 ± 6.8	
KFl 60°/second (NM)	Pre	61.8 ± 3.9	4.7 ± 10.32	62.0 ± 3.6	−6.55 ± 8.28
	Post	66.5 ± 7.1		55.4 ± 3.2	
EEx 120°/second (NM)	Pre	28.0 ± 2.0	1.89 ± 2.75	25.3 ± 1.7	1.06 ± 4.14
	Post	29.9 ± 1.6		26.4 ± 2.3	
EFl 120°/second (NM)	Pre	17.9 ± 1.8	3.26 ± 3.35	18.9 ± 1.3	1.36 ± 3.52
	Post	21.1 ± 1.7		20.2 ± 2.0	
EEx 60°/second (NM)	Pre	34.1 ± 2.1	0.625 ± 3.00	31.5 ± 1.7	−1.48 ± 2.52
	Post	34.7 ± 1.8		30.0 ± 4.8	
EFl 60°/second (NM)	Pre	23.4 ± 1.5	1.86 ± 2.73	22.7 ± 1.3	−0.20 ± 2.22
	Post	25.3 ± 1.6		22.5 ± 2.6	

Notes: *Significant pre–post difference, $P < 0.05$.
Abbreviations: 1RM, one repetition maximum; CI, confidence interval; EEx, elbow extension; EFl, elbow flexion; KEx, knee extension; KFl, knee flexion; NM, Newton meter; RT, upper-body resistance training.

Table 4 Mean (±standard error) bone metabolic markers and bone mineral density in the arm and heel and before and after the intervention for the upper-body resistance training and control (no training) groups

Variable	Test	RT (n = 12)	95% CI	Control (n = 10)	95% CI
OC (ng/mL)	Pre	14.27 ± 0.1	0.001 ± 0.005	13.70 ± 1.2	0.005 ± 0.011
	Post	14.54 ± 0.8		14.71 ± 0.4	
TRACP5b (U/L)	Pre	2.97 ± 0.29	−0.258 ± 0.35	2.83 ± 0.38	−0.266 ± 0.54
	Post	2.69 ± 0.36		2.60 ± 0.37	
Ratio OC/TRACP5b	Pre	5.144 ± 0.35	1.097 ± 0.959	5.462 ± 0.86	0.792 ± 1.50
	Post	6.242 ± 0.69*		6.254 ± 0.62	
Wrist BMD (g/cm^2)	Pre	0.482 ± 0.01	0.005 ± 0.014	0.444 ± 0.2	−0.002 ± 0.017
	Post	0.487 ± 0.01		0.445 ± 0.2	
½ UR BMD (g/cm^2)	Pre	0.640 ± 0.02	0.017 ± 0.023	0.613 ± 0.02	−0.007 ± 0.019
	Post	0.657 ± 0.02		0.606 ± 0.02	
Heel BMD (g/cm^2)	Pre	0.564 ± 0.02	0.0025 ± 0.004	0.529 ± 0.02	−0.009 ± 0.02
	Post	0.566 ± 0.02		0.520 ± 0.03	

Notes: *Significant pre–post differences, $P < 0.05$.
Abbreviations: ½ UR, distal half of the ulna and radius; BMD, bone mineral density; CI, confidence interval; OC, osteocalcin; RT, upper-body resistance training; TRACP5b, tartrate-resistant acid phosphatase isoform-5b.

the ulna and radius. The results might contribute to a better understanding of the duration of resistance training with a daily calcium supplement that leads to increased muscle strength without inducing a significant osteogenic adaptation in untrained and lean premenopausal women.

Previous studies reported equivocal findings with resistance training on bone turnover markers and BMD in untrained premenopausal or postmenopausal women using weight training exercises with a duration of 4 weeks, 12 weeks, or 20–26 weeks.[6–8,13,15–17] In light of the bone metabolic markers, the current results agree with those of Vincent and Braith who observed a significant increase in the ratio of OC to pyridinoline crosslinks after 24 weeks of high-intensity whole-body resistance training in elderly women and men.[8] Mullins and Sinning, who studied untrained healthy premenopausal women with a 12-week resistance training program, found no significant change in bone formation biomarker OC but an increase in the bone resorption biomarker crosslink deoxypyridinoline.[15] The current results also agree with those of Liang et al, who reported no change in urinary deoxypyridinoline after 26 weeks of lower-body resistance training in young premenopausal women,[13] and Hla et al, who reported no change in OC and the bone resorption biomarker amino-terminal telopeptide in healthy postmenopausal women with aerobic exercise.[18] On the other hand, the current results did not support those of Adami et al who observed an increase in bone formation (OC) but not in bone resorption biomarkers after 4 weeks of endurance training in young, untrained women.[6] Using a single bout of whole-body strength training in untrained young men, Whipple et al observed a significant increase in the ratio of biochemical markers of bone formation to bone resorption

after exercise.[19] Also, Ashizawa et al reported a significant decrease in the bone resorption marker urinary deoxypyridinoline 3 days after an acute bout of whole-body strength exercise.[9] It appears that strength exercise involving the whole-body skeleton may increase bone formation and lower bone resorption biomarkers before changes in BMD can be detected. Also, gender differences and the length of training program may contribute to the differences in results on metabolic biomarkers.[6,8,9,19] Note that bone turnover markers reflect whole-body skeletal activity,[6,9,20] while BMD turnover is site specific and generally very slow, ie, changes occur after 20 weeks of strength training.[6,8] However, there is general agreement that there is a quantitative relationship between changes in bone turnover markers and changes in site-specific BMDs.[5,20,21] The current data show that the 10-week upper-body resistance training program appears to be insufficient for inducing osteogenic response in the nonweight-bearing skeleton. Other researchers have suggested that the optimal duration of upper-body resistance training program for inducing osteogenesis is 20–24 weeks.[7,8,16,17]

In premenopausal women, site-specific BMD response with different modes of resistance training has been reported. For example, Miller et al examined untrained and healthy premenopausal women (aged 18–26 years and BMI 18–25 kg/m^2) using an upper-body isokinetic strength training program, three times a week for 20 weeks, and observed an average increase of 2.2% in ulnar BMD and a 17% increase in elbow isokinetic strength.[7] Simkin et al reported a 3.8% increase in radial bone mass with a 20-week upper-body exercise intervention in postmenopausal women.[16] Adami et al also observed a 2.2% increase in cortical BMD and a 2.6% increase in trabecular BMD in the ultradistal radius after

26 weeks of upper-body exercise training in postmenopausal women.[17] Using a high-intensity whole-body resistance training regimen, Vincent and Braith observed a significant 1.96% increase in femoral neck BMD after 24 weeks in elderly women and men.[8] Kerr et al also observed a significant increase in BMD at the ultradistal radial site in postmenopausal women who completed a 52-week resistance training program.[22] Liang et al, using a lower-body resistance training program for 52 weeks, observed an insignificant change in BMD of the hip and lower leg in young premenopausal women.[13] It appears that differences in the age and gender of the participants as well as the training modality may have contributed to the differences in the results on BMD observed in the current study.[7,8,13,16,17,22] Note that the resistance training modality in the current study also involved elastic band exercises, which employ multiple directions and progressive overloading of the muscle groups. However, the resistance band exercise training may not induce an optimal training stimulus due to variation in stiffness of the elastic band and some skills or experience of the participants in using the elastic band. Therefore, effective training intensity may not have been achieved during the self-monitored training sessions. For these reasons, the current results on BMD response did not agree with that of Miller et al,[7] Vincent and Braith,[8] and Kerr et al,[22] but agreed with that of Adami et al[17] in that 4 weeks of site-specific resistance training had no effect on BMD in the ultradistal and proximal radius in postmenopausal women.

Compared to the baseline values, the current results show that the 1RM chest press and lateral pulldown strength performance increased by 23.5% and 15.6%, respectively ($P < 0.05$), and maximum number of push-ups increased by 111% ($P < 0.05$) (Table 3). Liang et al observed that a 26% gain in 1RM leg press strength with lower-body resistance training for 26 weeks was not accompanied by a significant improvement in the BMD of the heel and lower leg or bone biomarker deoxypyridinoline.[13] It appears that muscle strength adaptation can be induced with a 10-week progressive musculoskeletal loading regimen, but not in BMD and bone metabolic markers. The lack of significant findings in BMD and bone biomarkers observed in this study may be attributed to the following factors: (1) the resistance exercise program was too short in duration and lacked sufficient intensity or both to induce positive osteogenic responses in the loaded skeleton and metabolic biomarkers, and (2) low statistical power due to the low number of participants in both groups. These may be considered the limitations of the study.

Conclusion

Ten weeks of moderate-intensity upper-body resistance training, three times a week, in untrained, healthy, and lean premenopausal women significantly improved muscle strength performance of the upper limbs (ie, chest press, lateral pulldowns, and push-ups). However, there was no change in bone biomarkers (ie, OC and TRACP5b) or site-specific BMD (ie, the wrist and distal half of the ulna and radius). Further studies are warranted using a longer training duration (ie, ≥ 20 weeks) and high-intensity upper-body resistance training (ie, $\geq 70\%$ 1RM lift load) to examine its osteogenic effect on bone turnover biomarkers and site-specific BMD in premenopausal women. Unraveling the mechanisms that lead to optimal osteogenic response to musculoskeletal loading (ie, resistance training) might provide new insights for maximizing PBM in young premenopausal women.

Acknowledgments

Disclosure

The authors report no conflicts of interest in this work.

References

1. Wolff I, van Croonenberg J, Kemper HC, Kostense PJ, Twisk JW. The effect of exercise training programs on bone mass: a meta-analysis of published controlled trials in pre- and postmenopausal women. *Ospeoporos Int*. 1999;9(1):1–12.
2. Walsh JS, Henry YM, Fatayerji D, Eastell R. Lumbar spine peak bone mass and bone turnover in men and women: a longitudinal study. *Osteoporos Int*. 2009;20(3):355–362.
3. Kohrt WM, Bloomfield SA, Little KD, Nelson ME, Yingling VR. American College of Sports Medicine Position Stand: physical activity and bone health. *Med Sci Sports Exerc*. 2004;36(11):1985–1996.
4. Szulc P, Delmas PD. Biochemical markers of bone turnover: potential use in the investigation and management of postmenopausal osteoporosis. *Osteoporos Int*. 2008;19(12):1683–1704.
5. Civitelli R, Armamento-Villareal R, Napoli N. Bone turnover markers: understanding their value in clinical trials and clinical practice. *Osteoporos Int*. 2009;20(6):843–851.
6. Adami S, Gatti D, Viapiana O, et al. Physical activity and bone turnover markers: a cross-sectional and a longitudinal study. *Calcif Tissue Int*. 2008;83(6):388–392.
7. Miller LE, Wootten DF, Nickols-Richardson SM, et al. Isokinetic training increases ulnar bending stiffness and bone mineral in young women. *Bone*. 2007;41(4):685–689.
8. Vincent KR, Braith RW. Resistance exercise and bone turnover in elderly men and women. *Med Sci Sports Exerc*. 2002;34(1):17–23.

9. Ashizawa N, Ouchi G, Fujimura R, Yoshida Y, Tokuyama K, Suzuki M. Effects of a single bout of resistance exercise on calcium on bone metabolism in untrained young males. *Calcif Tissue Int*. 1998;62(2): 104–108.

10. Fujimura R, Ashizawa N, Watanabe M, et al. Effect of resistance training on bone formation and resorption in young male subjects assessed by biomarkers of bone metabolism. *J Bone Miner Res*. 1997;12(4): 656–662.

11. Vuori I, Heinonen A, Sievanen H, Kannus P, Pasanen M, Oja P. Effects of unilateral strength training and detraining on bone mineral density and content in young women: a study of mechanical loading and deloading on human bones. *Calcif Tissue Int*. 1994;55(1):59–67.

12. Proctor KL, Adams WC, Shaffrath JD, Van Loan MD. Upper-limb bone mineral density of female collegiate gymnasts versus controls. *Med Sci Sports Exerc*. 2002;34(11):1830–1835.

13. Liang MT, Braun W, Bassin SL, et al. Effect of high-impact aerobics and strength training on BMD in young women aged 20–35 years. *Int J Sports Med*. 2011;32(2):100–108.

14. Hannon RA, Clowes JA, Eagleton AC, Al Hadari A, Eastell R, Blumsohn A. Clinical performance of immunoreactive tartrate-resistant acid phosphatase isoform 5b as a marker of bone resorption. *Bone*. 2004;34(1):187–194.

15. Mullins NM, Sinning WE. Effects of resistance training and protein supplementation on bone turnover in young adult women. *Nutr Metab (Lond)*. 2005;2:19.

16. Simkin A, Ayalon J, Leichter I. Increased trabecular bone density due to bone-loading exercises in postmenopausal osteoporotic women. *Calcif Tissue Int*. 1987;40(2):59–63.

17. Adami S, Gatti D, Braga V, Bianchini D, Rossini M. Site-specific effects of strength training on bone structure and geometry of ultradistal radius in postmenopausal women. *J Bone Miner Res*. 1999;14(1):120–124.

18. Hla MM, Davis JW, Ross PD, Yates AJ, Wasnich RD. The relation between lifestyle factors and biochemical markers of bone turnover among early postmenopausal women. *Calcif Tissue Int*. 2001;68(5): 291–296.

19. Whipple TJ, Le BH, Demers LM, et al. Acute effects of moderately intensity resistance exercise on bone cell activity. *Int J Sports Med*. 2004;25(7):496–501.

20. Eastell R, Hannon RA. Biomarkers of bone health and osteoporosis risk. *Proc Nutr Society*. 2008;67(2):157–162.

21. Ryan AS, Treuth MS, Rubin MA, et al. Effects of strength training on bone mineral density: hormonal and bone turnover relationships. *J Appl Physiol*. 1994;77(4):1678–1684.

22. Kerr D, Morton A, Dick I, Prince R. Exercise effects on bone mass in postmenopausal women are site-specific and load-dependent. *J Bone Miner Res*. 1996;11(2):218–225.