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Effects of High-Intensity Resistance Training on Bone Mineral Density in Young Male Powerlifters

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Abstract. The effects of high-intensity resistance training on bone mineral density (BMD) and its relationship to strength were investigated. Lumbar spine (L2-L4), proximal femur, and whole body BMD were measured in 10 male powerlifters and 11 controls using dual-energy X-ray absorptiometry (DXA). There were significant differences in lumbar spine and whole body BMD between powerlifters and controls, but not in proximal femur BMD. A significant correlation was found between lumbar spine BMD and powerlifting performance. These results suggest that high-intensity resistance training is effective in increasing the lumbar spine and whole body BMD.

Key words: Bone mineral density — Dual-energy X-ray absorptiometry — Resistance training — Young male.

One of the most serious public health problems is osteoporosis, characterized by a reduction in the amount of bone mass. Elderly individuals who have had hip fractures show lower bone mineral density (BMD) than those of similar age who have not had fractures [1, 2]. Therefore, maximizing peak bone mass during youth and maintaining BMD throughout the aging process is considered to be important in preventing osteoporosis later in life [3, 4]. Some studies have found that higher peak forces of mechanical loading have a greater influence on bone formation than the number of cycles loaded [5–7]. The effects of weight-bearing exercises such as running, volleyball, gymnastic, and squash have also been reported for increasing peak bone mass and BMD [7–12].

Conroy et al. [13] reported higher lumbar spine and proximal femur BMD in junior male weightlifters (mean age, 17.7 years) than in age-matched controls. Moreover, lumbar spine and femoral neck BMD in the junior weightlifters were found to be significantly greater than in adult men aged 20–39 years, based on reference data. Significant relationships were also found between BMD at all sites and maximum lifting ability. Other studies have shown that powerlifters and weightlifters have higher BMD than athletes in other sports and in sedentary individuals [14–17].

Granhed et al. [16] found that bone mineral content of the lumbar vertebra in powerlifters was significantly higher than in controls and was correlated ($r = 0.815$) with the amount of weight lifted annually. They also estimated that the load on the third lumbar vertebra during a deadlift was 18.8–36.4 kN. These findings suggest that the strain magnitude, the site specificity, and the distribution of strain throughout the bone structure are important factors in the adaptive response of the bone [18].

There has not been much research conducted since Granhed's biomechanical analysis. Although most studies have shown greater bone mass in weightlifters, one study actually found a decrease in bone density with training [19]. The purpose of this study was to examine the effects of high-intensity resistance training on BMD in young male powerlifters and its relationship to strength.

Materials and Methods

Subjects

Ten collegiate, male powerlifters (mean age 20.7 ± 1.7 years) and 11 collegiate male controls (mean age 18.4 ± 0.7 years) participated in this study. Table 1 lists the descriptive characteristics of the subjects. The powerlifters had participated in a continuous exercise program for an average of 8 hours/week for at least 12 months prior to the study, and their average years of training experience was 2.5 ± 1.7. In the daily training program, the training loads were 80–90% of the one repetition maximum for five sets of four to eight repetitions. Because powerlifters aim at increasing muscular strength rather than muscle hypertrophy, they usually use larger weights with fewer repetitions than bodybuilders. The maximum weight lifted for each lifter is shown in Table 2. In contrast, the physical activity of the control group did not exceed 2 hours/week during the previous 12 months and they had not been engaged in any resistance training. After being informed of the purpose and the risks associated with the study, consent was given by all subjects. No subject in either group had a history of metabolic bone disease or was taking medication known to affect mineral metabolism. None of the subjects reported any past or current use of either anabolic steroids or growth hormones. In all subjects, circumferences of the chest, upper arm, forearm, thigh, and calf were measured using standard anthropometric measurement methods. Body mass index (BMI, kg/m^2) was calculated from the measured body height and weight. The percentage of body fat was determined from the sum of the measurements taken from two skinfolds in the triceps and the subscapular regions. Lean body mass was calculated from the body weight and the percentage of body fat.

Bone Mineral Measurements

The BMD of the lumbar spine (L2-L4), proximal femur (femoral neck, trochanter region, and Ward's triangle) and whole body were

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Table 1. Anthropometric data for powerlifters and controls (mean ± SD)

		Powerlifters (n = 10)	Controls (n = 11)	
Height	(cm)	167.5 ± 6.0	168.5 ± 4.8	—
Body weight	(kg)	70.6 ± 10.8	64.5 ± 9.4	—
Age	(y)	20.7 ± 1.3	18.4 ± 0.7[b]	—
BMI	(kg/m^2)	25.0 ± 2.5	22.6 ± 2.8	—
%Fat	(%)	17.7 ± 5.7	19.2 ± 5.9	—
LBM	(kg)	57.6 ± 6.2	51.7 ± 5.3[a]	—
Chest	(cm)	94.7 ± 7.7	85.8 ± 5.8[b]	—
Upper arm	(cm)	30.9 ± 2.7	27.8 ± 2.2[b]	—
Forearm	(cm)	27.5 ± 1.7	25.1 ± 1.5[b]	—
Thigh	(cm)	55.4 ± 6.9	51.7 ± 4.9	—
Calf	(cm)	39.8 ± 5.4	36.9 ± 2.6	—

BMI: body mass index, LBM: lean body mass
[a] $P < 0.05$; [b] $P < 0.01$

Table 2. The age, height, body weight, and the best record for each lifter

Powerlifter	Ht (cm)	BW (kg)	Age (y)	Sq (kg)	BP (kg)	DL (kg)	Total (kg)
1	158	51	20	115.0	72.5	145.0	332.5
2	173	78	20	150.0	75.0	165.0	390.0
3	159	57	20	135.0	75.0	180.0	390.0
4	168	80	24	150.0	100.0	150.0	400.0
5	167	67	20	150.0	95.0	180.0	425.0
6	176	83	21	175.0	90.0	195.0	460.0
7	169	80	21	165.0	120.0	175.0	460.0
8	175	76	21	185.0	110.0	205.0	500.0
9	165	65	21	210.0	110.0	200.0	520.0
10	166	69	19	185.0	117.5	235.0[a]	537.5

Ht: height, BW: body weight, Sq: squat, BP: bench press, DL: deadlift
[a] Japan junior record

measured by dual-energy X-ray absorptiometry (DXA, HITACHI BMD - 1X). Measurements for the BMD of the head, arms, legs, trunk, ribs, pelvis, and spine were obtained by a whole body scan. All scanning and analyses were done by the same operator to assure consistency. The day-to-day precision (coefficient of variation; CV) of the BMD measurement was 0.7%.

Statistical Analysis

All the statistical analyses were made with a Statview 4.5 (Abacus Concepts, Inc., Berkeley, CA, USA) on a Macintosh computer. Statistical significance of differences between the two groups was determined by using the Student's *t*-test. To assess the relationship between the powerlifting records of squat/bench press/deadlift and BMD, Pearson's correlation coefficients were used. All comparisons were considered statistically significant at $P < 0.05$.

Results

There were significant differences between the powerlifters and the controls in both age and lean body mass. The powerlifters also showed significantly larger circumferences in the upper body measurements than the controls, but no significant differences were observed in the lower extremities (Table 1). Analyzed by Student's *t*-test (Fig. 1), the BMD of the whole body, lumbar spine, arm, leg, and pelvis was significantly higher in the powerlifters than in the controls. However, no significant difference ($P < 0.05$) was found for the proximal femur BMD. Figure 2 shows the correlations between BMD and deadlift (DL) records in powerlifters. A high correlation ($r = 0.79$) between the lumbar spine BMD and the DL records was observed, but no significant correlation was observed between the femoral neck BMD and the DL records. Table 3 summarizes the correlation between BMD and powerlifting performance. The lumbar spine BMD was significantly correlated with squat (Sq), DL, Sq + DL, and total records in powerlifters.

Discussion

In this study, we investigated the effects of high-intensity resistance training on BMD in young male powerlifters. In powerlifting competition, the records for each lifter are calculated as the sum of Sq, bench press (BP), and DL records. Powerlifting routines also include both upper (BP) and lower body exercises (Sq, DL) that involve slow-speed/high-load muscle contractions. In the present study, because of their initial ability to lift greater amounts of weight, powerlifters were enrolled to evaluate the effects of high-intensity resistance training on bone. Many studies have been conducted to investigate the relationship between BMD and the intensity of strain in training exercise, site specificity involved in the exercise, and the strain distribution in the bone structure [18, 20, 21]. Though most cross-sectional studies comparing weightlifters to controls have shown greater BMD, intervention studies have shown inconsistent results. For example, Rockwell et al. [19] found contrary results in premenopausal women. Therefore, the most effective exercise program for significant bone formation is still not clear.

The results from the present study showed that the powerlifters' BMD in the lumbar spine was significantly higher than the controls'. There was a significant positive correlation between the BMD of the lumbar spine and the Sq, DL, Sq + DL, and total records in powerlifters. These results suggest that a larger strain may be generated in the lumbar region during Sq or DL. Although the position of the weights is different in these two exercises, the force from the barbell weight in both lifts is applied to the shoulder. To keep the inclination of the trunk segment constant, a force necessitating backward rotation of the trunk segment should be applied. This force must be supplied by muscle contraction of the erector spinal muscle group, and the contraction may cause a larger compressive stress in the lumbar region during Sq and DL.

In contrast to the Sq and DL, there was no significant positive correlation between the lumbar spine BMD and the BP records. Taking into account that the BP is an exercise for the upper body, not for the lumbar muscle area, results indicate that when bone is mechanically loaded, a response will occur in that specific bone. The combination of high magnitude compressive stress and site specificity play a vital role in increasing the BMD. With the exception of Rockwell et al.'s study [19], some authors reported an increase of BMD in both the lumbar spine and femoral neck [13, 22], and others indicated increases only in the lumbar spine [23–25]. Kerr et al. [12] examined the effect of exercise on bone mass in postmenopausal women and observed significant increases in BMD of the greater trochanter region where various muscle groups were attached but not in BMD of the femoral neck where no muscles were attached. They speculated the reason to be because muscle pull is

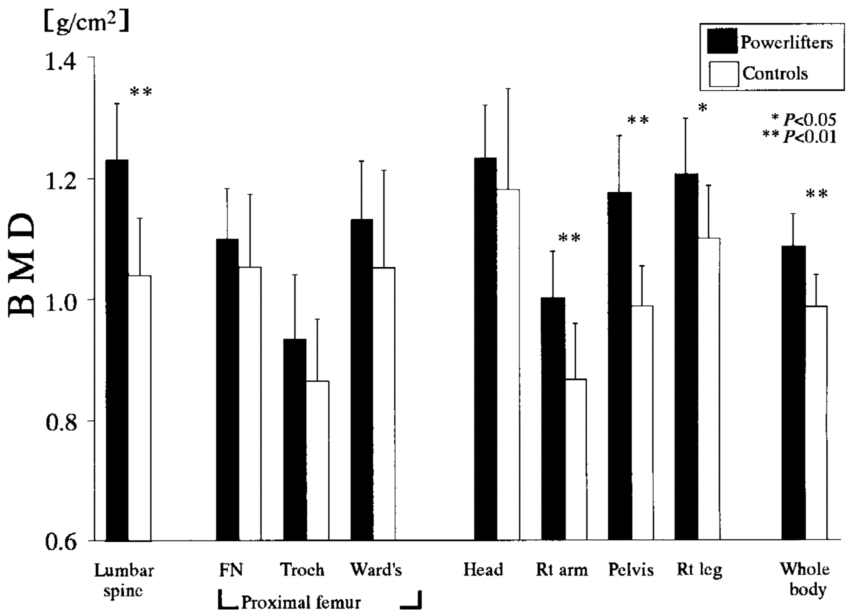

Fig. 1. Bone mineral density in powerlifters (n = 10) and controls (n = 11). FN, femoral neck; Troch, trochanter region; Ward's, Ward's triangle.

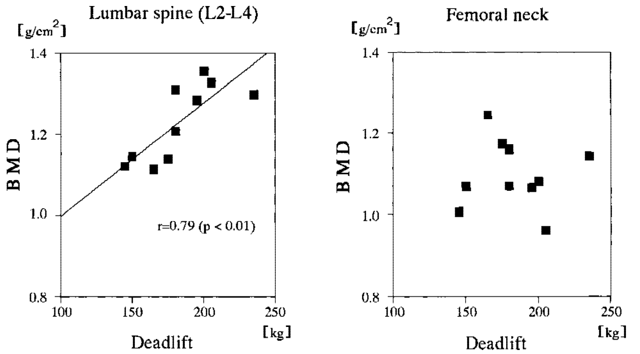

Fig. 2. Correlations between BMD and DL records.

Table 3. Correlations between BMD and powerlifting performance

	Lumbar spine	Femoral neck	Trochanter region	Ward's triangle
Squat	0.74[a]	−0.01	0.07	−0.37
Bench press	0.47	0.02	0.24	−0.07
Deadlift	0.79[b]	−0.01	0.02	−0.36
Total	0.77[b]	0.00	0.11	−0.33
Squat + Deadlift	0.81[b]	−0.01	0.05	−0.39

[a] $P < 0.05$; [b] $P < 0.01$

mediated through the force of the muscle contraction at the site of attachment of tendon to bone; thus, the bone may respond locally to reallocate the forces generated from the muscle at the site of loading [12]. Although, the Sq, and DL exercises require contraction of various muscle groups that are attached to the trochanter region, we found no significant relationship between the powerlifting performance and the proximal femur BMD in this study. Moreover, there was no significant difference in the proximal femur BMD between the powerlifters and the controls. Several explanations for why the BMD of proximal femur did not significantly differ between powerlifters and controls are possible. First, because of the angular shape of the proximal femur, the stress is not of a compressive type, but rather of a bending type stress, which may not be an effective stimuli for bone formation. Second, the proximal femur is always loaded in daily life by walking, standing, and other postures in which the threshold becomes significantly higher, and does not always give a noticeable response, as does the lumbar spine. And third, the lumbar spine is composed of as much as 80% trabecular bone, whereas the proximal femur is only 50%. The metabolic rate of trabecular bone is eight times higher than that of cortical bone. Therefore, different metabolic rates and bone compositions with site-specific differences in the skeleton may cause variable osteogenic thresholds for loading stimuli. Furthermore, the duration of the high-intensity resistance training of powerlifters in the present study (2.5 years) may not be enough to increase the BMD of the proximal femur.

In summary, in studies comparing several activities (running, gymnastics, volleyball, swimming weightlifting etc.) it was found that high-intensity loading is effective in increasing BMD [7, 9, 11]. Although this study supports this suggestion, our results were not derived from comparisons of other sports study results, but only from direct biomechanical analysis of a high-intensity resistance training. Granhed et al. [16] have shown a positive correlation between the L3 bone mineral content and the amount of weight lifted annually. They only analyzed and examined DL exercise, not Sq exercise. In our study the effects of the Sq exercise were also examined, and the results suggest the importance of compressive stress generated in Sq as well as DL for increasing lumbar BMD. In conclusion, exercise or training with high-intensity loads to generate compressive stress on bone may be effective in increasing site-specific BMD in the skeleton.

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