Effect of low-repetition jump training on bone mineral density in young women

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Effect of low-repetition jump training on bone mineral density in young women. J Appl Physiol 100: 839–843, 2006. First published November 3, 2005; doi:10.1152/japplphysiol.00666.2005.—The hypothesis of the present study was that low-repetition and high-impact training of 10 maximum vertical jumps/day, 3 times/wk would be effective for improving bone mineral density (BMD) in ordinary young women. Thirty-six female college students, with mean age, height, and weight of 20.7 ± 0.7 yr, 158.9 ± 4.6 cm, and 50.4 ± 5.5 kg, respectively, were randomly divided into two groups: jump training and a control group. After the 6 mo of maximum vertical jumping exercise intervention, BMD in the femoral neck region significantly increased in the jump group from the baseline (0.984 ± 0.081 vs. 1.010 ± 0.080 mg/cm²; P < 0.01), although there was no significant change in the control group (0.985 ± 0.0143 vs. 0.974 ± 0.134 mg/cm²). And also lumbar spine (L2–L4) BMD significantly increased in the jump training group from the baseline (0.991 ± 0.115 vs. 1.015 ± 0.113 mg/cm²; P < 0.01), whereas no significant change was observed in the control group (1.007 ± 0.113 vs. 1.013 ± 0.110 mg/cm²). No significant interactions were observed at other measurement sites, Ward’s triangle, greater trochanter, and total hip BMD. Calcium intakes and accelerometry-determined physical daily activity showed no significant difference between the two groups. From the results of the present study, low-repetition and high-impact jumps enhanced BMD at the specific bone sites in young women who had almost reached the age of peak bone mass.

jump exercise; peak bone mass; high-impact training

PHYSICAL ACTIVITY MAY PLAY an important role in maximizing bone mass during childhood and may have long-lasting benefits on bone health. Because peak bone mass is thought to be attained by the end of the third decade, the early adult years may be the final opportunity for its augmentation (13). Skeletal unloading, such as long bed rest, immobilization, and microgravity environment, lead to bone loss, whereas the positive effects of physical exercise on bone mass is generally acknowledged. It has been shown that dynamic loading is more effective for increasing bone mineral density (BMD) than static loading (15). Furthermore, the strain rate is more important than the number of loading trials (22).

Prepubescent children (7.5–8.2 yr) who have not yet reached their peak bone mass have shown significant develop in lumbar spine bone mass by 100 two-footed drop landings off of a 61-cm-high box 3 times/wk compared with a randomized control group (6). Bassey and Ramsdale (1) found a significant increase in femoral BMD after 6 mo of 50 jumps daily among premenopausal young women (29.8–32.0 yr). These exercise programs, however, required a relatively large number of jumps in the range of 300–350 jumps/wk. Johansen and coworkers (11) have found greater increases in total and leg bone mineral content (BMC) by relatively fewer jumps from a 45-cm-high box, 25 jumps/day, 5 times/wk, total of 125 jumps/wk in a randomized, controlled trial conducted with children (3–18 yr). Also, Snow et al. (24) reported, after 5 yr of resistance training with weighted vest and an average 51.7 jumps/day, 3 times/wk, for a total of 155 jumps/wk from a 20.3-cm-high step, improved femoral neck BMD compared with a control group in postmenopausal woman (64.1–69.9 yr).

Evidence from more invasive interventions in animals suggested that a quite brief exposure to strain is enough (9, 10, 15, 26–28). Rubin and Lanyon (23) presented results showing that a passive stimulus of 36 and 1,800 cycles/day was equally effective in turkeys. A smaller number of strains, as few as 5 jumps/day (26), imposed by active stimuli as jumps, improved the strength of regional bones in immature rats, although the training required only a short time. The hypothesis of the present study was that low-repetition high-impact jump training, 10 jumps/day and 3 times/wk, would be effective for improving BMD in ordinary young women reaching the age of peak bone mass.

MATERIALS AND METHODS

Subjects and groups. One hundred twenty-eight female college students with experience in weighted food records were asked to take part in this study, and 48 students volunteered to participate. The subjects completed the questionnaire containing information about menstrual cycle, pregnancy, past and current physical activity, smoking habit, as well as background information, including history of bone diseases, medication use, and bone fracture. The entry criteria for subjects were eumenorrheic, nonpregnant, no oral medication, nonsmoker, no regular high-impact training, with no medical or surgical problems likely to affect bone metabolism or providing contraindications to exercise. Six subjects were excluded because they had regularly engaged in high-impact sports such as volleyball, basketball, and tennis in the last 5 yr.

Forty-two subjects were randomly divided into two groups, jump training or a control group. In compliance with the university’s Institutional Review Board policy, the purpose and all experimental procedures were explained, and written, informed consent was then obtained from each subject. The study was approved by the local...
health research review board. The subjects were permitted to withdraw at any time for any reason. Bone measurements were conducted at initial baseline and final completion of the 6-mo exercise program. Because the training consisted of only 30 jumps/wk, the subjects in jump groups were carefully instructed to jump regularly and with the maximum voluntary effort, unless otherwise excluded from the jumping group. Three jumpers were then excluded from the exercise group because they had not done enough jump training (9, 19, and 22 days in 6 mo). In the control group, two subjects did not take the calcium supplements regularly (0 and 65 days in 6 mo), although their calcium intakes were well below the sufficient level, and one subject lost interest in this study. Thirty-six healthy female college students completed the study and were analyzed as subjects in this experiment. Their mean age, height, and weight were 20.7 ± 0.7 yr, 158.9 ± 4.6 cm and 50.4 ± 5.5 kg, respectively.

**BMD and deoxypyridinoline measurements.** Bone mineral density (g/cm²) was assessed, using dual-energy X-ray absorptiometry (ALOKA, DCS-3000), in the lumbar spine (L2–4, anterior-posterior view) and the right proximal femur. The femoral neck, Ward’s triangle, and greater trochanter of the proximal femur were selected for analysis according to the manufacturer’s software. The same radiographer made the initial and final dual-energy X-ray absorptiometry measurements, and the groups (jumping or control) were blinded. The coefficient of variation of the BMD measurement had an in-house precision error of 1.0% based on the adult scans. We did not estimate the coefficient of variation of the BMD measurement because of the increased X-ray exposure to the young subjects (20–23 yr). The dual-energy X-ray absorptiometry machine was calibrated daily by using a phantom calibration procedure, and there was no significant drift during the study.

**Deoxypyridinoline (DPD) is primarily located in bone collagen, and urinary DPD has been used as one of the standard bone resorption markers.** Urine samples were collected between 9:30 and 11:30 AM on both initial and final BMD measurement days and were frozen at −60° until assayed in a subsample of 20 volunteers (10 jumpers and 10 controls) who were able to attend the urine sample collection. The DPD was measured with ELISA (SRL), and the subject groups were blinded for the analysis. Urine DPD values were corrected for changes in urine concentration by expressing them per millimole of creatinine.

**Dietary calcium and supplementation.** Subjects completed 3-day weighted food records at baseline for providing a calcium supplement to adjust the dietary requirements, and also just before the completion of the exercise intervention period. These records were completed over 3 days: 2 weekdays and 1 weekend day. The diets were analyzed by software (Eiyokun Ver. 3.0, Kenpakusha) that is based on a standard food database. Calcium carbonate supplements were given to 34 subjects (17 jumpers and 17 controls) as 300-mg tablets and taken with meals to bring intakes over 650 mg/day of elemental calcium, which exceeds the requirements for the recommended calcium allowances in Japanese adult women of this age (13).

**Exercise program.** The jump exercise group performed two-legged maximum vertical jumps 10 times using an arm swing in counter-movement style on 3 alternated days/wk. The maximum jumps were performed barefoot at home on a relatively hard floor. The interval of each jump was ~8–12 s, so the exercise required less than 2 min. Home record cards were supplied and collected each month.

**Maximum vertical jump and ground reaction force.** Maximum vertical jump height was measured by a jump height measuring device (Takei Scientific Instruments, Jump-MD) in both the pre- and postexercise program. At both visits for measuring jump height, subjects jumped vertically at least twice with maximum voluntary effort, and the best performance was recorded. The subjects stood at the center of the circular thin rubber mat (38 cm in diameter). The jumper attached the height-measuring device to her waist. The jump height measuring device and the circular mat were attached by a rope so that the traveling distance from the standing position to the maximum height reached at waist level could be measured. When the jumpers could not land stably within the circular rubber mat, the jumpers had to perform another trial.

Peak ground reaction force (GRF) was measured by using the AMTI force platform (Advanced Mechanical Technology, OR6-6, 46.4 × 50.8 cm) in a randomly selected subsample of volunteers (n = 12) in a jump group at posttesting. They were asked to jump vertically with maximum effort, using countermovement style as they did regularly during the jump exercise intervention period, and jumping trials were conducted at least three times for each subject. The force platform was used to record GRF with a 1,080-Hz sampling rate. Values for the peak force on the vertical axis were then obtained from the recordings at takeoff and landing.

**Accelerometry-determined measures of physical activity.** The subjects were asked to attach the accelerometer motion sensor (Suzuken, Lifecorder EX) at waist height for a whole week except while sleeping or bathing. The physical activity measurements were done during September to October, about halfway through the whole intervention period. Movement count values, shown as steps, were stored every 2 min. The stored data on the accelerometer motion sensor were downloaded by personal computer using a USB cable for analysis.

**Statistics.** Two-way ANOVA [2 times (initial and final) × 2 groups (jump and control)] with repeated measures was used to determine differences between and within the jump and control groups for dependent variables. When ANOVA revealed significant interaction (time x group), paired t-tests were performed to determine differences between initial and final values in each group. Initial mean physiological characteristic values and daily activity shown as steps were compared using unpaired Student’s t-test. Statistical analysis was achieved through computer programs available in the Statistical Package for the Social Sciences, version 12.01 (SPSS). The statistically significant level was set at 0.05, and comparisons were two tailed.

**RESULTS**

Descriptive statistics indicated that the initial height, age, and movement count were not significantly different between the jump and control groups (Table 1). In the jump group, compliance (82%) at jump training was averaged 2.5 times/wk.

| Table 1. Physiological characteristics of the subjects, calcium intake, jump height, movement count, and DPD |
|---|---|---|---|
| **Jump (n = 18)** | **Control (n = 18)** |
| **Initial** | **Final** | **Initial** | **Final** |
| **Age, yr** | 20.5 ± 0.6 | 20.9 ± 0.8 | 15.8 ± 5.4 |
| **Height, cm** | 159.1 ± 3.8 | 158.8 ± 5.4 | 116.8 ± 5.8 |
| **Weight, kg** | 5.1 ± 5.2 | 50.2 ± 4.9 | 49.0 ± 6.2 |
| **Calcium, mg** | 760.6 ± 146.6 | 719.6 ± 209.6 | 654.6 ± 163.8 |
| **Vertical jump, cm** | 38.1 ± 5.5 | 41.5 ± 7.3 | 39.6 ± 6.2 |
| **Movement count, steps/day** | 1,546.6 ± 2,034.2 | 1,546.6 ± 2,034.2 | 1,546.6 ± 2,034.2 |
| **DPD, mmol/mmol creatinine** | 5.8 ± 1.5 | 5.4 ± 1.8 | 5.4 ± 1.8 |

Values are means ± SD. DPD, deoxypyridine. *Significant difference within groups (P < 0.05).
After the 6 mo of exercise intervention, body weight (BW) was significantly decreased within groups ($P < 0.05$) (Table 1). The maximum vertical jump height was significantly improved within groups ($P < 0.05$) (Table 1). The average vertical jump height with the same measuring method in the similar age group among Japanese women was 41.0–41.8 cm (17). Calcium intake and urinary DPD showed no significant differences between and within groups (Table 1).

A two-way ANOVA with repeated measures revealed significant interactions (time × group) in BMC at the femoral neck regions ($P < 0.05$) and at the lumbar spine ($P < 0.05$). From the results of paired t-test, the jump group showed significantly increased BMC at the femoral neck ($P < 0.01$) and lumbar spine ($P < 0.01$), whereas the control group BMC did not change significantly. No significant interactions or main effects were observed at other measurement sites in either jump or control groups: Ward’s triangle, greater trochanter, and total proximal femur BMC. Mean percentage changes over 6 mo in BMC at the femoral neck and lumbar spine significantly increased in the jump group ($P < 0.01$) (Fig. 1).

BMC in lumbar spine in the jump group was initially 40.88 ± 6.12 mg and finally 42.25 ± 6.33 mg, whereas in the control group BMC was initially 41.64 ± 8.83 mg and finally 41.97 ± 8.62 mg. Also, bone area (BA) in the jump group was initially 41.18 ± 2.67 cm² and finally 41.54 ± 2.95 cm², whereas in the control group BA was initially 41.00 ± 4.45 cm² and finally 41.14 ± 4.50 cm². A two-way ANOVA with repeated measures revealed significant interactions (time × group) in BMC at the lumbar spine ($P < 0.01$). BA in the lumbar spine was significantly increased within groups ($P < 0.05$), but there was no significant difference between groups. From the result of paired t-test, the jump group showed significantly increased BMC at the lumbar spine ($P < 0.01$), whereas the control group BMC did not change significantly.

Peak GRFs at takeoff and landing phases were 2.35 ± 0.25 and 4.76 ± 0.86 times BW, respectively.

**DISCUSSION**

The most important observation made in the present study was that jump training of 10 jumps/day, 30 jumps/wk significantly increased BMC at the femoral neck ($P < 0.05$), whereas BMC in the control group remained unchanged after 6 mo of exercise intervention. Other investigators have shown that loading with many repetitions at one time had a relatively small additional effect on bones compared with loading of only 10–40 repetitions (23, 26). After many repetitions of mechanical loading on bones, the mechanosensor might show decreased sensitivity (19, 20). Thus its effectiveness as a bone stimulus would appear similar even with fewer repetitions. The loading interval may be another important factor associated with mechanosensor sensitivity (20). A high strain rate may enhance the mechanosensor’s less sensitive period and require a longer recovery period (27). The interval of mechanical loading in jogging or running may not be long enough to recover its sensitivity, so the effectiveness of low-repetition, maximum vertical jumps may have the same levels as training with numerous loading repetitions.

High-impact jump training is reportedly effective for increasing bone mass and breaking force in animals (9, 10, 25–27) and also for increasing BMC in the human lumbar spine (2, 6, 7) and femoral neck regions (1, 2, 6, 7). In human jump training studies, 125–350 jumps/wk were reported to be required as an effective stimulus for bone formation (1, 2, 6, 11, 24). In the present study, only 10 jumps/day, 30 jumps/wk with maximum effort were demonstrated to be an effective bone stimulus. Our results are consistent with those of Beverly et al.’s (4) study. They reported that a relatively brief but strenuous physical stress exercise resulted in increased BMC in the stressed forearms. Squeezing a tennis ball with maximum voluntary effort three times consecutively, morning and evening, which took less than 30 s each day for 6 wk, produced a 3.4% increase in BMC in the stressed forearms. It should be noted that, in these studies, the levels of strain likely exceeded those generated during typical human physical activities.

In human high-impact jump exercise studies, a 3.0 (young adult) (2) to 8.8 (prepubertal) (6) times BW in GRF at landing
was reported to be a sufficient bone stimulus (2, 6, 7, 11). Johansson et al. (11) reported in a study of GRF of children jumping off from a 45-cm box that younger subjects tended to show a higher peak GRF during landing and that subjects in jump training seemed to attenuate the impact force more than not in jump training. It is suggested that the ability to attenuate the landing force may be linked with skill levels that are also age related. In the present study, young adult jumpers showed a peak GRF during takeoff of 2.35 ± 0.25 (2.02–2.67) times BW and a peak GRF during landing of 4.76 ± 0.86 (3.31–5.90) times BW. These GRF values are lower than prepubertal study (6) values but comparable with those of other studies (2, 7, 11). Thus maximum vertical jumps may provide a sufficient stimulus in specific bone sites.

Our findings are in agreement with those of Kohrt et al. (12), who observed a positive high-impact loading effect on femoral neck BMD in postmenopausal women. The training program involved exercises in which forces acting on the skeleton were generated by GRFs, such as walking and jogging, whereas another program included activities that introduced stress to the skeleton through joint-reaction forces, such as weight lifting and rowing. However, a significant increase in BMD of the femoral neck was only observed in response to the GRF exercise program. Heinonen et al. (7) reported that high-impact jump training from a height of 10–25 cm, at which the estimated GRF is 2.1–5.6 times BW, produced significant improvement in femoral neck and lumbar spine BMD in premenopausal women aged 35–45 yr. In the present study high-impact exercise had a systematic, positive effect on the loaded axial and appendicular bones, indicating that high-impact GRF exercise programs, such as jumping, are specifically effective as site stimuli, especially for the femoral neck region.

Because an adaptive response occurs only when a loading stimulus exceeds the usual loading conditions, continued adaptation requires a progressively increasing overload. The present study required maximum voluntary effort for vertical jumps throughout the intervention period. As a result, subjects in the present study. Heinonen et al. (7) reported that high-impact jump training from a height of 10–25 cm, at which the estimated GRF is 2.1–5.6 times BW, produced significant improvement in femoral neck and lumbar spine BMD in premenopausal women aged 35–45 yr. In the present study high-impact exercise had a systematic, positive effect on the loaded axial and appendicular bones, indicating that high-impact GRF exercise programs, such as jumping, are specifically effective as site stimuli, especially for the femoral neck region.

Because an adaptive response occurs only when a loading stimulus exceeds the usual loading conditions, continued adaptation requires a progressively increasing overload. The present study required maximum voluntary effort for vertical jumps throughout the intervention period. As a result, subjects continued to progressively increase the overload on the specific bone sites. This may also suggest that not only external passive movements, are imposed on the specific bone sites.

Henry et al. (8) reported that the peak volumetric BMD in lumbar spine was achieved at 29 yr of age in women, whereas the peak volumetric BMD in femoral neck was already reached at 12 yr of age. In the present study, the mean age of our subjects was 20.7 ± 0.7 (20–23) yr. Thus the growth and maturation may affect the lumbar spine, implying that BMC and BA would be useful information. Estimated lumbar spine bone volume (area × π × width/4) showed the peak was reached at 39 yr of age in women. Although BA in the lumbar spine is different from the estimated lumbar spine bone volume, the results of our study evidence the same tendency. Around young adulthood, increasing BMC has an important role for later life, particularly for the lumbar spine.

Increasing BMD or BMC by high-impact exercises has reported with modest and small gains in premenopausal (1, 2, 5, 7, 12) and postmenopausal women (4, 23). However, the small changes of BMD or BMC by mechanical loading allow vary large increases in ultimate force (64–87%) and energy failure (64–165%) in rats (21). Bone strength can be enhanced substantially from small changes in BMD or BMC if the bone is added to the mechanically appropriate sites. New bone formation caused by mechanical loading was reported to be strategically localized to the biomechanically relevant sites (21). In humans, young adult jumpers (long-jump, high-jump, triple-jump, and pole-vault athletes) showed a greater tibial moment of inertia and strength strain index determined by peripheral quantitative computed tomography than swimmers and controls (16). In the present study, although the improvement of BMD was modest, low-repetition but high-impact maximum vertical jumps would lead the effective bone formation to optimize the relevant bone sites.

There are, however, some limitations of the present study. First, although an important issue, our study did not measure strain in the proximal femur during the maximum vertical jump. Bassey et al. (3) measured the compressive axial forces in an instrumented massive femoral implant and observed that the implant force at the hip was 2.60–2.90 times the GRF during takeoff and 1.37–1.47 times the GRF during landing in relatively slow-tempo jumps. Theoretically, this result indicates that the compressive forces at the hip during takeoff and landing in the maximum vertical jumps were comparable in the present study.

Second, to clarify bone metabolism, DPD was measured as the bone resorption marker in urinalysis, although we could not measure bone formation markers such as osteocalcin, which can only be analyzed through blood samples. However, the increased BMD was not associated with increased remodeling, because none of the DPD levels were changed in both jump and control groups in the pre- and postexercise intervention period. Raab-Cullen et al. (18) showed that external load works by stimulation formation independent of resorption. They reported that the loading created a greater formation surface of externally loaded legs than in nonloaded legs in rats.

In conclusion, the results of the present study indicate that 10 maximum vertical jumps/day, 3 days/wk enhanced BMD at the femoral neck in young women who had almost reached the age of peak bone mass. For practical applications, low-repetition high-impact jumps are suggested to be one of the ideal training methods for enhancing and maintaining peak bone mass in young adult women.

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