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Original Article

Effect of the "Building Osteo Neatly Exercise" program on quantitative ultrasound parameters and plantar pressure distribution for college-aged females

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Abstract. [Purpose] We investigated the effects of a specifically designed exercise program that focused on the arches of the foot and the forefoot (the "Building Osteo Neatly Exercise" program) in college-aged females. [Participants and Methods] Forty college-aged females were divided randomly into experimental and control groups. The experimental group underwent the Building Osteo Neatly Exercise program for 60 min once a week for 4 months. In both groups, the plantar pressure distribution and quantitative ultrasound parameters of the calcaneus (speed of sound and bone area ratio) were evaluated at the beginning and end of the study. The plantar pressure distribution during walking was measured using a pressure plate to evaluate the deviation from the ideal values for the following: contact time, contact duration, peak pressure time, and foot pressure, all measured in the rear foot (the external and internal sides), medial forefoot including (the hallux and second and third toes), and lateral forefoot (the fourth and fifth toes). [Results] After completing the program, the speed of sound and bone area ratio had increased significantly in the experimental group and were significantly higher than those in the control group. The experimental group showed significant improvements in the deviations from the ideal values in contact time and contact duration in the medial forefoot, all four parameters in the lateral forefoot, and pressure in the rear foot. [Conclusion] College-aged females who participated in the Building Osteo Neatly Exercise program once weekly for 4 months exhibited significant improvements in bone strength in the calcaneus and in foot function, as shown by the plantar pressure distribution. Further studies are needed to examine the outcomes of the Building Osteo Neatly Exercise program in an elderly population.

Key words: Exercise therapy for bone, Quantitative ultrasound, Plantar pressure distribution

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INTRODUCTION

Locomotive syndrome is a condition in which locomotive function declines because of weakening of the locomotive organs, such as bone and muscle, making walking and moving difficult. It is seen mainly in middle-aged and elderly people. Walking function is correlated with bone strength[1, 2)]; however, 200 million worldwide have osteoporosis[3)]. Declining locomotive function and the deterioration of locomotive organs are serious problems that require urgent attention.

As well as measuring step and walking speed, locomotive function is evaluated by assessing an individual's plantar

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pressure distribution, the main method used in medical and sports science studies4). The ideal plantar pressure distribution for young people is normally described as a bimodal process in which a peak load is applied to the heel from the beginning to the middle of a step and then on the forefoot from the middle to the end5). However, many young people walk with the load constantly on the heel and only a light load on the forefoot, resulting in a plantar pressure distribution described by only a single peak6). Patients with locomotive syndrome tend to have single-peak plantar pressure distributions, and young female have a marked tendency toward a similar plantar pressure distribution because of weakness in their feet4). Weakness of the toes, and especially the forefoot, leads to a condition known as "floating toe," in which the individual is unable to apply load to the forefoot, and "flat footedness," in which the arches of the feet disappear. Over the last 10 years, the number of people with floating toe and/or flat footedness has increased seven-fold7). Locomotive function and bone strength peak at an early age and then decline slowly, and the level acquired when young has a considerable influence on the rate of decline8). It is therefore possible for poor plantar pressure distribution in young adults to result in increased deterioration of locomotive function when they become elderly.

Bone strength depends both on bone tissue and on bone mineral density (BMD), which is generally evaluated by dual-energy X-ray absorption. However, it has been reported that the decreasing rate of BMD does not match the incidence rate of bone fracture, and the incidence rate of bone fracture is involved in bone tissue9, 10). Bone tissue is a determinant of bone structure and elasticity, which is evaluated by quantitative ultrasound (QUS)9, 11). QUS results have been shown to correlate with those from dual-energy X-ray absorption12, 13). An association has been reported between bone tissue parameters and the risk of fatigue fracture, and it has been demonstrated that QUS of the calcaneus provides a reliable basis from which to estimate the risk of bone fracture14). Furthermore, QUS measurements of the calcaneus highly reflect the amount of physical activity undertaken by an individual15–17), with speed of sound (SOS) and bone area ratio (BAR) measured by QUS of the calcaneus showing positive correlations with an individual's level of physical activity18–20).

Loading and vibration of the bone increase bone strength21). To help prevent osteoporosis, it is necessary to develop as high a peak bone mass as possible at a young age22). Experimental studies in rats of different ages showed that the same amount of physical activity resulted in a significantly greater increase in BMD in young animals23, 24). In adult tennis players, BMD has been found to be significantly higher in the dominant arm than in the non-dominant arm, with the difference 2–4 times higher in those who trained from childhood than in those who started tennis after middle age25). In a study of postmenopausal women in their 50s, it was found that physical activity when they were aged 14–21 years had a stronger influence on their BMD than physical activity at any other age26). The incidence of bone fractures in young people has increased by 2.5 times compared with 10 years ago7). To increase peak bone mass and prevent weakening bones at a young age, young people can undertake jump exercises, resistance training, and aerobic exercises10, 27–31). However, a potential risk of this training is of bone fractures during the exercise programs due to high strength and applying a load to a limited part. In one study of young people, half the participants were unable to finish the program because of injuries or bone fractures32). Unlike improvement of the circulatory system, strengthening bone does not need physical stimulation of high frequency and strength33), but can be performed safely and effectively by low strength training. It has been reported that even low-impact training, such as Tai Chi exercise, can increase bone strength significantly in case of applying effective load and vibration to bone34). However, no training program for strengthening bone has been described.

Of the 29 lower limb bones, 27 are at or below the ankle. These bones support the entire weight of the body over the small area of the foot, as well as having other roles, such as forming the arch structure and supporting the lever function of the forefoot and calcaneus6). These functions of the foot can be evaluated from the plantar pressure distribution, and it is possible to improve locomotive function as well as bone strength.

In this study, it was investigated the effects of a specifically designed exercise program, the "Building Osteo Neatly Exercise (BONE) program", which focuses on strengthening bones and improving locomotive function. The BONE program was devised to apply physical loads and vibration21) to individual bones in the foot, because these stimuli have been shown to improve bone strength. This was assessed in college-aged women by measuring QUS parameters of the calcaneus and plantar pressure distribution.

PARTICIPANTS AND METHODS

The participants were 40 college-aged women who did not have a regular exercise habit. They were divided randomly into two groups: 20 in the experimental group, and 20 in the control group. The ages and baseline anthropometric characteristics of the participants are summarized in Table 1; there were no significant differences between the two groups. The experimental group underwent the BONE program for 60 min once a week over 4 months. QUS parameters (SOS and BAR) and plantar pressure distribution were evaluated at the beginning of the study (Pre) and at the time the experimental group finished the program after 4 months (Post). We explained the intents and methods of the study to the participants before the measurements were taken. Informed consent was obtained before proceeding. This research was approved by the research ethics committee of the Graduate School of Education, Hiroshima University on June 30, 2018. We were not granted an IRB/reference number. Informed consent implied voluntary participation.

The program also focused on developing the foot structure appropriately, given that bone changes according to the direction in which a load is applied35).

Table 1. Baseline characteristics of the experimental and control groups

	Experimental (n=20)	Control (n=20)	p
Age (years)	20.6 (4.1)	19.8 (2.2)	0.18
Height (cm)	159.0 (5.8)	158.7 (6.5)	0.97
Mass (kg)	51.4 (8.7)	53.5 (6.6)	0.51
Fat mass (kg)	14.6 (5.1)	15.2 (4.2)	0.32
Muscle mass (kg)	34.7 (3.8)	35.7 (2.9)	0.39
BMI (kg/m^2)	20.2 (2.6)	21.3 (2.0)	0.35

Data are means (SD). p-values are for independent t-test (2-tailed) comparison of the experimental group and the control group’s means.


1. Bent by hand 30 sec
2. Warp by hand 30 sec
3. Warp by foot 30 sec
4. Arch Strengthen 30 times
5. Twist 30 sec
6. Shake the foot 30 times
7. Shake the finger 30 times
8. Hit the sole 30 times
9, 10. Strengthen the arch 30 sec 30 sec
11,12. Strengthen the forefoot by wood ball 30 times 30 times

Fig. 1. The Building Osteo Neatly Exercise (BONE) program.
1, a load is applied in a state of bent with arches by hand; 2, same as 1 in a state of warp; 3, the heel is lifted using the little toe as a fulcrum; 4, using the heel as a fulcrum, the foot is laid down on the hallux and little toe sides alternatively to apply a load to the medial and lateral longitudinal arches; 5, holding the heel and toe, the heel is twisted to the internal side and the toe to the external side; 6, holding the heel the whole foot is shaken; 7, holding and shaking the finger, performed for each of the five fingers; 8, the sole is hit by hand with air included; 9, a load is applied in a state of bent with arches by leg; 10, same as 9 in a state of warp; 11, a 5-cm wooden ball is placed under the joints of index finger, and the heel is moved up and down; 12, same as 11, the heel is moved right and left. For all items, load intensity should be within pain-free range and individually adjusted.

The BONE program is summarized in Fig. 1. It comprised 12 steps, each performed for four sets (right foot, two setsand left foot, two sets), and it focused on bone strengthof two important functional points of the foot: the arches and forefoot. The foot has three arches: the lateral, inside longitudinal, and outside longitudinal arch[7]. These support the strength of the foot[6]. The lever function comprising the forefoot and heel acts so that the heel appropriately leaves the ground[36]. If the forefoot is weak, the lever cannot function normally and the heel is unable to leave the ground. Therefore, this program focused on providing loads and vibrations to the arch and forefoot bone. Steps 1–4 of the program were performed on the floor and step 5–12 on the chair, and load intensity was perfomed within pain-free range and individually adjusted.

Bone strength was evaluated using a QUS system (Benus Evo, Shibuya Corp., Tokyo, Japan) to measure the SOS and BAR of the calcaneus[17]. The calcaneus transmits an ultrasonic pulse.

To measure the plantar pressure distribution, the participant was asked to walk on a Metascan pressure mat (Footmaxx Co., Roanoke, VA, USA), using five trials of six steps each (three right and three left). Plantar pressure was measured at the rear foot (RF), including both the external and internal sides, the medial forefoot (MF), including the hallux and the second and third toes, and the lateral forefoot (LF), including the fourth and fifth toes (Fig. 2). With the time from the first contact of the foot to the end of the propulsive phase taken as 0% to 100%, respectively, the following were measured for each of the three regions of the foot: contact time (CT), the time that the foot grounded; contact duration (CD), the time the foot spent on the ground; peak pressure time (PT), the time at which the highest pressure was recorded; and pressure (P), the level of foot pressure. These were presented as deviations from the ideal values (devCT, devCD, devPT, and devP, respectively)[37].

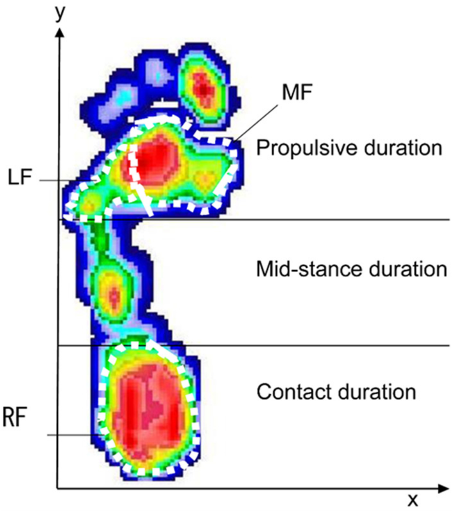

Fig. 2. Plantar pressure distribution.
LF: lateral forefoot; MF: medial forefoot; RF: rear foot.

The QUS parameters and plantar pressure distribution were statistically analyzed by a paired two-way factorial analysis of variance using SPSS v25.0 J. The relationships between the percentage increases in SOS and BAR (calculated as (Post − Pre) / Pre × 100%) and the plantar pressure distribution parameters (devCT, devCD, devPT, and devP) were evaluated by Pearson's correlation analysis. The significance level was defined as 5%.

RESULTS

The results of the SOS and BAR measurements are shown in Table 2. After the BONE program, SOS and BAR significantly increased in the experimental group, and SOS was significantly higher than in the control group.

The deviations from the ideal values of plantar pressure distribution measured in the MF, LF, and RF at baseline (Pre) and after 4 months (Post) are shown in Table 3. The values represent deviations from the ideal values, so lower numbers indicate improvements. Following the BONE program, the experimental group showed significant improvements in devCT and devCD in the MF, all four parameters in the LF, and devP in the RF. There were no significant differences between the experimental and control groups at baseline, but at 4 months, the experimental group showed significantly lower values for all four parameters in the MF and for devP in the LF. This suggests that the use of MF–LF, i.e., the forefoot, improved in the experimental group.

The correlations between SOS and BAR and the deviations of the plantar pressure distribution values from ideal values are summarized in Table 4. There were significant correlations for devP in the RF with SOS ($r=-0.52$, $p<0.01$) and BAR ($r=-0.51$, $p<0.01$).

DISCUSSION

This study investigated the effects of the 4-month BONE program on bone strength, assessed by SOS and BAR measured in the calcaneus, and plantar pressure distribution. In the experimental group, SOS increased by about 2% and BAR by

Table 2. Speed of sound (SOS) and bone area ration (BAR) measured with quantitative ultrasound in the calcaneus at baseline (Pre) and after 4 months (Post)

	Experimental (n=20)			Control (n=20)			Two-way ANOVA
	Pre	Post	%I	Pre	Post	%I	
SOS (m/s)	1,628.0 (43.0)	1,660.0 (34.0)	1.9	1,635.0 (31.0)	1,627.0 (33.0)	−0.5	a***, b*
BAR (%)	33.2 (6.1)	36.5 (5.2)	9.9	33.4 (4.4)	33.5 (4.4)	0.4	a**

Data are presented as means (SD). %I, percentage increase, calculated as (Post − Pre) / Pre ×100%. Significant differences between groups were assessed by two-way ANOVA, as follows: a, Pre and Post in the experimental group; b, Post values for the two groups. *$p<0.05$, **$p<0.01$, ***$p<0.001$.

Table 3. The deviations from the ideal values of plantar pressure distribution measured in the medial forefoot (MF), lateral forefoot (LF), and rear foot (RF) at baseline (Pre) and after 4 months (Post)

	Experimental (n=20)		Control (n=20)		Two-way ANOVA
	Pre	Post	Pre	Post	
MF: devCT (%)	10.5 (5.5)	7.8 (3.5)	11.8 (5.1)	12.0 (4.0)	a**, b*
MF: devCD (%)	12.0 (5.2)	8.6 (3.6)	12.7 (5.4)	12.6 (4.0)	a***, b*
MF: devPT (%)	11.8 (5.2)	10.2 (4.5)	10.4 (5.1)	10.6 (4.8)	b**
MF: devP (%)	4.4 (2.4)	2.6 (1.3)	2.5 (1.5)	2.8 (1.5)	b***
LF: devCT (%)	8.4 (4.5)	5.6 (3.0)	8.1 (4.7)	7.8 (3.5)	a***
LF: devCD (%)	11.6 (4.8)	7.7 (4.2)	10.5 (5.8)	10.3 (4.5)	a***
LF: devPT (%)	12.1 (10.2)	7.2 (6.4)	9.5 (7.7)	9.3 (6.5)	a**
LF: devP (%)	5.4 (2.2)	3.1 (1.6)	6.4 (2.6)	6.0 (2.0)	a***, b***
RF: devCT (%)	0.8 (0.9)	0.8 (0.2)	0.9 (1.2)	0.9 (1.0)	
RF: devCD (%)	6.2 (4.9)	5.7 (3.3)	5.4 (3.8)	5.8 (3.5)	
RF: devPT (%)	6.0 (4.5)	7.3 (3.8)	7.6 (4.5)	8.1 (3.9)	
RF: devP (%)	39.5 (2.5)	34.7 (3.7)	34.0 (4.0)	35.0 (3.8)	a***

Data are presented as means (SD) for the deviations (dev) of the following parameters from their ideal values: CT: contact time; CD: contact duration; PT: peak pressure time; P: foot pressure. Significant differences between groups were assessed by two-way ANOVA, as follows: a, Pre and Post in the experimental group; b, Post values for the two groups. *p<0.05, **p<0.01, ***p<0.001.

Table 4. Correlations between the percentage increases in speed of sound (SOS) and bone area ratio (BAR) in the calcaneus and the plantar pressure distribution parameters in experimental groups

Plantar pressure distribution parameters	Ultrasound parameters (n=40)	
	SOS	BAR
MF: devCT	−0.05	0.03
MF: devCD	−0.16	−0.07
MF: devPT	0.19	0.32
MF: devP	0.13	0.19
LF: devCT	0.06	0.02
LF: devCD	−0.04	−0.03
LF: devPT	−0.17	−0.17
LF: devP	−0.05	−0.11
RF: devCT	0.01	−0.01
RF: devCD	−0.09	−0.03
RF: devPT	−0.12	−0.02
RF: devP	−0.52**	−0.51**

The data are Pearson correlation coefficients. The plantar pressure distribution parameters were measured in the medial forefoot (MF), lateral forefoot (LF), and rear foot (RF) and represent the deviations (dev) of the following parameters from their ideal values: CT: contact time; CD: contact duration; PT: peak pressure time; P: foot pressure. **p<0.01.

nearly 10%. Various previous studies have measured QUS parameters to examine the effect of training. A study on resistance training of the upper body performed three times a week for 4 months by males aged 18–25 years reported that SOS increased by 2% in the humerus10). In a study of walking and running undertaken by 246 males aged 18–20 years, SOS increased by 1.3%; the study also reported a significant correlation between SOS and BMD28). A study of 67 soccer players aged in their 20s who undertook high-strength soccer training, including high-impact training, over 5 years showed that SOS was higher for the soccer players that for people who did not exercise regularly29). A study of young women who undertook high-impact training for 1 year found that SOS did not change significantly30), whereas a study of the calcaneus in 20-year-old women reported that SOS was about 3% higher after volleyball training six times a week for 10 years, when compared with a non-exercise group31). It has reported that, in young adults who exercised two times a week over 6 years, BAR was consistently 9% higher than in those who did not19). In a study of strength training performed two times a week for 9 weeks by 11 college-aged women, BAR significantly increased by 8%20). The 10% increase in BAR in the present study's experimental group was similar to the increases reported in these previous studies. By the same token, the 1.9% increase in SOS of the experimental group in the present study was similar to the increases in previous studies, and the significant increase of 1.1

in the experimental group was particularly large. It is well documented that the calcaneus shows a similar rate of age-related bone loss as the spine and hip[38]. In addition, it has been reported that an increase of QUS parameters in the calcaneus affects a minute injury in physical activities, bone mass, and bone tissue such as the elasticity and structure of trabeculae[11, 27, 39].

This study also investigated the plantar pressure distribution in the MF, LF, and RF to assess improvements in foot function. The CT, CD, and time and level of the peak pressure were measured in each region of the foot, and the improvements were noted in all the parameters in the forefoot (MF and LF), although only the pressure level was improved in the RF. It is likely that these improvements resulted from increases in the strength of the arches and the lever function of the foot.

The arches play a role in enhancing the strength of the three-dimensional structure of the foot. It has reported that the disappearance of the arches brings about a gait pattern described as “flat footedness,” which results from the heel and the forefoot landing at the same time[36]. In this study, the mean CT of the forefoot at baseline was faster than the ideal value, indicating a tendency of the participants to walk with a flat foot. After 4 months, the CT of the forefoot occurred later, indicating that the participants now walked by using the heel at the beginning of the foot placement and the forefoot at the end, which is the proper bimodal plantar pressure distribution. This suggested that the index of plantar pressure on the MF and LF improved because the arches of the foot were strengthened.

The lever function of the foot comprises the heel and the forefoot. The heel consists of the calcaneus and the talus, heavy bones that together account for 50% of the weight of the foot. Patients with locomotive syndrome, including osteoporosis, find it difficult to raise the heel while walking. This contributes to them stumbling and falling and often requires them to use a cane or to walk only in areas free from obstacles[36]. With this gait, there is too much pressure on the heel in the plantar pressure distribution[6]. In the present study, the participants showed excessive pressure on the RF at baseline. However, after 4 months of the BONE program, the pressure on the RF decreased and became closer to the ideal pressure. This suggested that the index of pressure on the RF improved because the lever function of the foot was strengthened.

In this study, the pressure on the RF was negatively correlated with both SOS and BAR. There was considerable validity in the fact that patients with osteoporosis ran into gait with the burden on the heel. The participants in this study were young adults with no serious decline in BMD, such as is seen in osteoporosis. However, people whose BMD has a tendency to decrease from young age exhibit increased pressure in the RF with a greater difference from the ideal value. This suggested that it is important to undertake a program such as the BONE program from a young age because this strengthens bones, focusing on the arches and the lever function of the foot.

This study had some limitations. It is unclear whether the improvements from stimulating the calcaneus directly, such as with the BONE program exercises, would be maintained over the long term. Furthermore, although the study showed the plantar pressure distribution improved, the inferred changes in foot structure, such as in the arches and forefoot, were based on supposition rather than experiment. Therefore, there is one further topic of discussion because it was unclear whether BONE program had a direct effect on foot structure. None of the participants had osteoporosis or a problem with walking; nevertheless, the QUS parameters increased and their parameters of walking function improved, suggesting the efficacy of the BONE program. However, it is unclear whether similar outcomes would be observed in elderly patients with osteoporosis and walking dysfunction. A further study is needed to examine the outcomes of the BONE program in this patient population.

In this study, it was investigated the effects of the BONE program on QUS parameters of the calcaneus and plantar pressure distribution in college-aged women. Of note, the BONE program significantly improved SOS and BAR in the calcaneus. In addition, the program resulted in significant improvements to all points of the plantar pressure distribution in the forefoot, including CT, CD, PT, and P. Furthermore, the pressure on the heel showed a negative correlation with the increase of QUS parameters. It was concluded that the BONE program brings positive effects in terms of increased bone strength and improvement of the plantar pressure distribution in the forefoot.

Funding and Conflict of interest

There are no conflicts of interest to declare.

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