Impact of Exercise and Nutrition on Bone Mass

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Abstract: The present study aimed to examine various factors affecting the bone mass of female university students. An ultrasound bone assessment device was used to measure the bone mass of the right calcaneal (heel) bone of 285 female university students. The subjects were asked to complete a questionnaire on the type and amount of time they spent practicing sports while attending elementary, junior, and senior high school and university as well as on milk and natto (fermented soybean) consumption and age at menarche to determine their associations with bone mass. Furthermore, the relationship between sports experience, intensity, and history of the subjects to bone mass was examined. We classified sports into high- and low-impact groups according to the type of sport played to examine the effects of impact on bone mass. We found the strongest correlation between bone mass and the amount of time spent practicing sports while attending senior high school. No correlation was found between bone mass and age at menarche and milk or natto consumption. From the relationship between sports experience and bone mass, we found that bone mass was significantly higher in the group with sports experience while attending junior and senior high school and university. In the assessment of sports intensity and bone mass, we found a significantly higher bone mass in those who played high-impact sports than in those who played low-impact sports. We also examined the effects of continued practice of sports on bone mass and found that more sports experience had a greater effect of increasing bone mass. Exercising while attending junior and senior high school had the highest influence on bone mass, which suggests that the long-term, continued practice of high-impact sports during this period allows a high bone mass to be obtained.

Key words: Bone mass, OSI, Physical activity, High impact sports, University student

Introduction

Osteoporosis is characterized by reduction in bone strength and is defined as a bone disease that increases the likelihood of the risk of fractures1-7. Osteoporotic fractures are a cause of being bedridden and dramatically lower the quality of life. Currently, there is an estimated 12.8 million patients with osteoporosis in Japan, 80% of who are women8-10. The prevention of osteoporosis is an urgent task in the aging society in Japan.

Bone mass markedly increases with morphological transformation that occurs between elementary school age and puberty, and most people reach their peak bone mass: PBM around the age of 20 years5-9). PBM is defined as the highest bone mineral density (BMD) during one’s life10. Bone mass remains stable until around the age of 50 years, when it begins to decrease11,12. This is particularly true among women as bone mass reduction accelerates after menopause, around the age of 50 years11,12.

Some studies have noted the importance of obtaining a high PBM around the age of 20 years to prevent osteoporosis13-16, and one study has estimated that increasing Peak Bone Mass: PBM by 10% delays the onset of future osteoporosis by 13 years and reduces the risk of post-menopausal fractures by 50%17.

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Sex, age, genetics, exercise, and nutrition have been shown to impact bone mass13,14,15. Among the various minerals studied, the amount of calcium intake has been reported to have a particularly strong impact on bone mass14,15. However, there are contradicting reports that did not find a relationship between the amount of calcium intake and bone mass16, hence, conclusions have been inconsistent. However, there are many reports stating that there is a strong relationship between exercise and bone mass17,18, however, none of these previous reports have described which types of sports or the life stage when exercise was practiced had the highest impact on bone mass.

This study aimed to elucidate part of the mechanism of bone metabolism. Determining this mechanism has been a key target in the field of dental medicine. This study will contribute to the field of dental medicine as well as the entire field of life sciences.

The present study aimed to determine factors predicted to have an impact on the bone mass of female university students. These factors are sports experience, intensity of the sport played, history of exercising, intake of nutrients, and age at menarche.

Materials and Methods

Subjects

Subjects were 285 female university students between the ages of 19 and 22 years and living in the Kanto region. We used measurements and questionnaires to assess the subjects. We explained the nature of the study to the subjects verbally and in writing and obtained their
Table 1. Strength of the exercise

<table>
<thead>
<tr>
<th>high impact</th>
<th>low impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>karate</td>
<td>aikido</td>
</tr>
<tr>
<td>soccer</td>
<td>monocyte</td>
</tr>
<tr>
<td>jogging</td>
<td>walking</td>
</tr>
<tr>
<td>tennis</td>
<td>aerobic</td>
</tr>
<tr>
<td>skipping</td>
<td>kick base</td>
</tr>
<tr>
<td>basketball</td>
<td>kyudo</td>
</tr>
<tr>
<td>ballet</td>
<td>muscle</td>
</tr>
<tr>
<td>volleyball</td>
<td>cross-country</td>
</tr>
<tr>
<td>handball</td>
<td>kendo</td>
</tr>
<tr>
<td>beach volleyball</td>
<td>golf</td>
</tr>
<tr>
<td>marathon</td>
<td>bicycle</td>
</tr>
<tr>
<td>la crosse</td>
<td>judo</td>
</tr>
<tr>
<td>running</td>
<td>baseball</td>
</tr>
<tr>
<td>track and field</td>
<td>horse riding</td>
</tr>
</tbody>
</table>

Table 2. Subjects

<table>
<thead>
<tr>
<th>factor</th>
<th>(n)</th>
<th>mean ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>age (years)</td>
<td>285</td>
<td>20.1 ± 1.0</td>
</tr>
<tr>
<td>height (cm)</td>
<td>285</td>
<td>158.4 ± 6.0</td>
</tr>
<tr>
<td>weight (kg)</td>
<td>285</td>
<td>51.3 ± 6.5</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>285</td>
<td>20.4 ± 2.2</td>
</tr>
<tr>
<td>menarche age (year)</td>
<td>220</td>
<td>12.5 ± 1.4</td>
</tr>
<tr>
<td>bone mass (OSI*)</td>
<td>285</td>
<td>2.8 ± 0.3</td>
</tr>
<tr>
<td>bone mass (%YAM*¥)</td>
<td>285</td>
<td>103.9 ± 11.5</td>
</tr>
</tbody>
</table>

※OSI: Osteo sono assessment index
※¥:YAM: Young Adult Mean

Table 3. Relation between factors and OSI

<table>
<thead>
<tr>
<th>factor</th>
<th>(r)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>weight (kg)</td>
<td>0.372</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>0.248</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>menarche age (year)</td>
<td>0.055</td>
<td></td>
</tr>
<tr>
<td>exercise hours per week</td>
<td>0.083</td>
<td>0.186</td>
</tr>
<tr>
<td>intake of the milk</td>
<td>0.024</td>
<td>0.716</td>
</tr>
<tr>
<td>intake of the fermented</td>
<td>0.022</td>
<td>0.74</td>
</tr>
<tr>
<td>intake of soybeans</td>
<td>0.021</td>
<td>0.755</td>
</tr>
</tbody>
</table>

Table 4. Intake of the nutrient (19-22 years n = 285)

<table>
<thead>
<tr>
<th>nutrient</th>
<th>mean ± SD</th>
<th>Dietary reference intake for Japanese (2015) 18-29 years female</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium (mg)</td>
<td>472 ± 172</td>
<td>650 (recommended dietary allowance)</td>
</tr>
<tr>
<td>Magnesium (mg)</td>
<td>193 ± 57</td>
<td>270 (recommended dietary allowance)</td>
</tr>
<tr>
<td>Phosphorus (mg)</td>
<td>873 ± 244</td>
<td>800 (adequate intake)</td>
</tr>
<tr>
<td>Vitamin D (μg)</td>
<td>4.4 ± 2.4</td>
<td>5.5 (adequate intake)</td>
</tr>
<tr>
<td>Vitamin K (μg)</td>
<td>158 ± 64</td>
<td>150 (adequate intake)</td>
</tr>
</tbody>
</table>

Table 5. Relations of the nutrient and OSI

<table>
<thead>
<tr>
<th>nutrient</th>
<th>correlation coefficient (r)</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td>0.04</td>
<td>0.95</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.031</td>
<td>0.61</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>0.032</td>
<td>0.6</td>
</tr>
<tr>
<td>Vitamin D</td>
<td>0.002</td>
<td>0.98</td>
</tr>
<tr>
<td>Vitamin K</td>
<td>0.054</td>
<td>0.36</td>
</tr>
</tbody>
</table>

Bone mass measurement

We measured the bone mass of the right heel bone using density quantitative ultrasound (QUS) (AOS-100S; Hitachi Aloka Medical, Ltd., Tokyo, Japan). First, we measured the speed of sound (SOS) and transmission index (TI). Then, we calculated the osteo sono assessment index (OSI) using the following equation: TI × SOS².

The OSI is an index of bone strength including tensile strength related to bone resilience. We used this as the index of bone mass in the present study. OSIs are expressed as original indices divided by 10².

Questionnaire Survey

We asked the subjects several questions related to exercise, including which sports they participated while attending elementary, junior and senior high school and university. If the subjects had played multiple sports, we asked them to write all sports they practiced, as well as how many hours they exercised per week.

We also asked the subjects to answer how much milk they drank per day and how much natto they ate per week while attending elementary, junior and senior high school and university and their age at menarche.

Current Nutritional Intake with the Food Frequency Questionnaire

We used Food Frequency Questionnaire Based on Food Groups (FFQG) Ver.3.0 using the Microsoft Excel add-in software Excel Eiyokun (Kenpakusha, Tokyo, Japan) to survey the nutritional intake while attending university. We calculated the daily intake of the five following vitamins and minerals: calcium, magnesium, phosphorus, and vitamins D and K.

Categories of exercise experience

We categorized subjects who exercised ≥30 min/week in the exercise group and those who did not exercise at all or who exercised <30 min/week in the non-exercise group. We excluded the hours of physical education classes while attending elementary, junior and senior high school from this calculation. For university, we included the hours of university physical education classes because physical education classes were elective at the university where we conducted this survey.

Sports categories by intensity

We categorized the sports played as high- and low-impact groups depending on the intensity of the exercise. The sports played by intensity are shown in Table 1. We took these categories from the study by Hara et al.24, which have been created based on many international studies and were deemed reliable25-32.

Categories by exercising history

We divided the subjects based on their exercising history. The subjects in the non-experience group exercised for <30 min/week from elementary school to university. The subjects in the experience group practiced sports for ≥30 min/week while attending elementary, junior,
We obtained data from 285 subjects for all questions except age at menarche; data for this question were obtained from 220 subjects because some subjects did not want to respond or could not remember when they first started menstruating. The physical characteristics of the subjects were as follows: age, 20.1 ± 1.0 years; body mass index (BMI), 20.4 ± 2.2 kg/m²; age at menarche, 12.5 ± 1.4 years; OSI, 2.8 ± 0.3; and bone mass (% YAM), 103.9 ± 11.5 (Table 2).

Statistical analysis

All values are expressed in mean ± standard deviation. We used the Pearson correlation coefficient as an index of bivariate correlation to test for significance. A comparison between two groups was performed using the Student’s t-test after confirming the normal distribution of data. A comparison among three groups was performed using one-way analysis of variance after confirming the normal distribution of data; the Tukey-Kramer test was used if a significant difference was found. We used the SPSS ver.10.0 and JMP13 for statistical analysis. P-values of <0.05 were considered significant.

Results

Subjects’ physical characteristics

We obtained data from 285 subjects for all questions except age at menarche; data for this question were obtained from 220 subjects because some subjects did not want to respond or could not remember when they first started menstruating. The physical characteristics of the

Figure 1. Relation between exercise hours per week in senior high school and the OSI.

Figure 2. Relation between experience of exercise and the OSI.

Figure 3. Relation between strength of the exercise and the OSI.

Figure 4. Effect of continued physical activity on OSI.

Table 3 shows the relationship between predicted influencing factors and the OSI. There was a significant correlation between body weight and OSI (r = 0.372, p < 0.01). Although weak, we found a correlation between OSI and BMI (r = 0.248, p < 0.01) and between OSI and the amount of time spent while attending junior and senior high school (hours/week) playing sports (r = 0.197, p < 0.01; r = 0.289, p < 0.01; and r = 0.161, p < 0.01, respectively). Among the three, the highest correlation was with the amount of sports played while attending senior high school (Fig. 1). In contrast, there was no correlation between OSI and age at menarche, amount of exercise while attending elementary school (hours/week), milk consumption (200 ml/day), or natto consumption (packs/week).

Table 4 shows the recommended amount of daily intake of calcium, magnesium, phosphorus, and vitamins D and K (2015) in Japan as well as those of the 285 subjects while attending university. The amounts of daily intake of the minerals calcium, magnesium, and phosphorus were 472 ± 172, 193 ± 57, and 873 ± 244 mg, respectively, and those of daily intake of vitamins D and K were 4.4 ± 2.4 and 158 ± 64 µg, respectively.

Table 5 shows the correlation between the amounts of daily intake of calcium, magnesium, phosphorus, and vitamins D and K of the subjects and the OSI. There was no correlation between the OSI and the amount

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of daily intake of the vitamins and minerals.

**Exercising (sports) experience and bone mass (OSI)**

Fig. 2 shows the relationship between exercising (sports) experience and OSI. There was no significant difference between bone mass and exercising experience while attending elementary school, but a significant difference was observed between bone mass and exercising experience while attending junior and senior high school and university (junior and senior high school, p < 0.01; university, p < 0.05).

**Exercise intensity and bone mass (OSI)**

Fig. 3 shows the relationship between exercise intensity and OSI. Bone mass was significantly higher for those who practiced high-impact sports while attending elementary school than for those who practiced low-impact sports (p < 0.05). Those who practiced high-impact sports while attending junior or senior high school had significantly higher bone mass than those in the non-experience and low-impact groups. Furthermore, the difference for those who practiced low-impact sports was even more marked than the difference between those who practiced high- and low-impact sports while attending elementary school (p < 0.01). There was no significant difference among the groups while attending university.

**Exercising history on bone mass (OSI)**

Fig. 4 shows the effects of exercising history on OSI. The subjects in the regular group had significantly higher bone mass than those in the experience group.

**Discussion**

The physical measurements of the subjects, such as height, body weight, and BMI, that we obtained in our study showed values typical to Japanese women. Age at menarche was almost equal to that in a previous study in Japanese women24; therefore, we considered our sample to be a reasonably non-biased, representative sample of Japanese women. Theoretically, bone mass (%YAM) should approach 100% in samples, such as those of the present study, which measure several hundreds of subjects. Our %YAM of 103.9% matched the theoretical Figure, suggesting that the OSI was accurately measured.

The OSI measured by QUS in our study reportedly correlates with the dual X-ray absorptiometry measurement of Bone Mineral Density (BMD) used to diagnose osteoporosis36, 37. It is also reportedly effective in assessing the risk of bone fractures in the proximity of the femur in post-menopausal women33, 34, 35 and predicting the risk of fractures in various ethnicities24, 26.

Table 3 shows the relationship between the predicted influencing factors and the OSI. Although weak, a correlation was found between the OSI and the amount of exercise (sports) practiced while attending junior and senior high school and university (hours/week). Among the three, the highest correlation was with the amount of sports played while attending senior high school (Fig. 1). Results shown in Fig. 2 demonstrate that the impact of exercising while attending junior and senior high school are particularly high. Ho et al.26 reported that exercising during the teens to the 20s increases BMD more than exercising during the 30s and 40s, which is consistent with our findings. High-impact sports played while attending junior and senior high school were particularly conducive for obtaining a high bone mass. Previous reports have also found that high-impact sports including jumping movements increase bone strength13, 16, 20.

Milk (200 mg/day) and natto (packs/week) intake had no correlation with the OSI. In the present study, we based our estimates of calcium and vitamin K intake on the approximate intake of milk and natto, respectively, because it is difficult to obtain detailed and accurate accounts of past nutritional intake through a retrospective survey. However, it was possible to investigate current nutritional intake amounts while attending university. For this, we used the add-in software to Excel Eiyoukun FFQG Ver.3.0 to calculate the daily intake amounts of calcium, magnesium, phosphorus, and vitamins D and K of all 285 subjects surveyed. Table 4 shows the mean ± SD and recommended nutritional intake of the Japanese population (2015). The daily intake amounts found in the present study were approximately equal to the average Japanese intake.

Table 5 shows the correlation between the daily intake amounts of calcium, magnesium, phosphorus, and vitamins D and K among students attending university and the OSI. There was no correlation between the OSI and the intake amount of any of the five vitamins and minerals. Calcium intake has been reported to have an impact on bone mass38, while another report did not find a correlation between the amount of calcium intake and bone mass39. From the results of the present study, we inferred that the impacts of nutrition on bone mass were insignificant.

Finally, Fig. 4 shows the impacts of the history of exercising on the OSI. The subjects in the regular group had significantly higher OSIs than those in the experience group. There was no significant difference between the subjects in the non-experience group, which was very small and only included 11 subjects, and the other groups; however, the results suggested that exercise increased the OSI in a dose-dependent manner. Past studies have reported that the longer the history of practicing sports, the higher the bone mass40, which is consistent with the results of the present study.

In conclusion, our research demonstrated that 1) high-impact sports practiced while attending junior and senior high school increased bone mass, 2) continued practice of sports over many years increases bone mass, and 3) there was little impact of nutritional intake on bone mass.

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**Conflict Interest**

The authors have declared that no COI exists.

**References**


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