Hirosaki Med. J. **63**：28—37，2012

ORIGINAL ARTICLE

# EFFECTS OF CHANGES IN PHYSIQUE AND LIFESTYLE ON BONE MINERAL DENSITY IN THE EARLY TEENS

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**Abstract** The purpose of this longitudinal study was to reveal the effects of physique, body composition, and lifestyles on bone mineral density (BMD) in the early teens. Subjects of the current study were 73 boys and 73 girls. Osteo-sono assessment index (OSI), body mass index (BMI), body fat percentage and fat-free mass index (FFMI) were measures. All subjects were measured at two points; 5th grade and 8th grade. The association between changes in these values and the OSI at 8th grade were evaluated with multiple regression analysis. Positive correlations were observed between the OSI and exercise time/FFMI in both sexes. Furthermore, this trend was also observed between the OSI and BMI in boys. The results suggested that an increase in exercise time and FFMI are factors that may enhance BMD in both sexes. However, the increase in BMI was found to increase BMD only in boys. Such gender difference was suggested to be the result of what BMI represents for each group. For boys, increased BMI reflects the increasing amount of muscle mass, whereas for girls, it mainly reflects an increase in body fat. Therefore, muscle mass needs to be increased by long periods of exercise in order to increase BMD, especially in girls.

Hirosaki Med. J. **63**：28—37，2012

**Key words:** Bone mineral density; Early teens; Lifestyle; Fat-free mass index; Physical exercise.

原 著

# 10代前半の体格と生活習慣の変化が骨密度に及ぼす影響

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**抄録** 本研究の目的は10代前半の体格，体組成と生活習慣が骨密度に及ぼす影響について縦断的に調査・検討することである．対象は岩木健康増進プロジェクト小中学生健康調査において10歳時および13歳時の両方で調査を受けた146名（男子73名，女子73名）である．測定項目は，骨密度と body mass index（BMI），体脂肪率，筋肉指数，生活習慣とした．本調査の結果，男子では10歳から13歳までの間に運動時間，筋肉指数，BMI が増加した者ほど骨密度が高くなる傾向がみられた．一方，女子では運動時間，筋肉指数が増加した者ほど骨密度が高くなる傾向がみられた．このことより，男女共通して運動時間と筋肉指数の増加は10代前半の骨密度増加因子と考えられた．一方，BMI に関しては男子でのみ骨密度増加因子であった．この性差は，10代前半の BMI 変化が男子では主に筋肉量，女子では主に脂肪量の変化を反映するためと考えられた．すなわち，10代前半の子どもの骨密度増加には，運動時間を増やし，筋肉量を増加させることが重要であると考えられた．

弘前医学 **63**：28—37，2012

**キーワード：**骨密度；10代前半；生活習慣；筋肉指数；運動.

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Received for publication, December 22, 2011
Accepted for publication, December 28, 2011

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平成23年12月22日受付
平成23年12月28日受理

## Introduction

Osteoporosis is a disease commonly observed in the elderly. In Japan, the number of osteoporosis patients has been increasing with the growing elderly population[1]. Unfortunately, it is common for them to become bedridden due to low back pain and fractures, leading to a remarkable decrease in their quality of life (QOL)[2]. Thus, it is both medically and socially important to maintain a high bone mineral density (BMD) and prevent osteoporosis especially in the early stages of life.

The incidence of osteoporosis is approximately 3 times higher in females than in males[3], and thus, preventive measures should be determined differently for each gender. Meanwhile, BMD in the elderly largely depends on peak bone mass at around 20 years of age, and the bone mass diminution rate thereafter. Thus, improvement of peak bone mass in the teenage years is considered essential for preventing osteoporosis[4].

The rate of increase in BMD is the highest during the early teenage years but moderates dramatically thereafter[5]. Moreover, approximately half of the peak bone mass is accrued in this period[6], i.e., children during this period are capable of acquiring a greater BMD, which is important to improve peak bone mass. Therefore, it would be extremely beneficial to elucidate the factors that increase BMD in the early teens.

Previous studies regarding BMD in teens have listed lifestyle[7-10], physique[11, 12] and body composition[13, 14], and endocrine function[15-17] as factors influencing BMD. These factors are also known to be interrelated. For example, while adequate sleep promotes the secretion of growth hormones (GH) and sexual hormones[8-10, 18, 19], lack of exercise and shortage of sleep induce changes in physique and body composition such as body weight gain or obesity[20, 21]. Also, excessive decrease of body weight or body fat percentage fat inhibits secretion of sexual hormones[22-24]. Consequently, many closely related factors (e.g., physique, body composition and endocrine function based on lifestyle) influence the increase in BMD during this period. However, few studies have closely investigated the influence of lifestyle and physique and body composition on BMD in teens, or examined the relationship between them.

In addition, differences in growth between the sexes, including secondary sex characteristics, become notable during this period; the difference in the secretion of sexual hormones induces a difference in physique and body composition between boys and girls[25]. More specifically, although the body weight and height increase in both sexes, the body height increases more in boys than in girls. The factor mainly attributed to the increase in body weight is muscle mass in boys and fat in girls[26, 27]. The relationship of physique and body composition with BMD could therefore be different between genders in the early teens. Nevertheless, no study has investigated BMD-related factors by gender in this age group.

Therefore, a longitudinal study was conducted to investigate the effects of physical features and lifestyle on BMD in each sex in their early teenage years. We believed that this study could determine the factors that enhance bone mass in early teens as a preventative factor against osteoporosis in later life, and determine the health guidance on body build and lifestyle that would be appropriate to improve BMD during this period.

## Methods

(1) Subjects

Among 196 children that participated in the health survey for children in elementary and middle school during the Iwaki Health Promotional Project, 146 children (73 boys, 73 girls; age 10–14), who did not have any major organ disease or consumed drugs that would increase/decrease BMD, were enrolled in the study. Seventy-nine subjects (42 boys, 37 girls) were evaluated at the age of 10-11 years in 2006 and at 13-14 years in 2008, and 67 subjects (31 boys, 36 girls) were evaluated at the age of 10–11 years in 2006 and at 13–14 years in 2009.

(2) Measurement items and methods

The survey consisted of an interview and measurement of body composition and BMD.

In the interview, a self-administered questionnaire survey was conducted, and the times taken to exercise, sleep, watch television (TV), and play video games (VG) were recorded. If children had difficulties completing the questionnaire by themselves, their guardians were asked to fill it out instead. To determine the hours of exercise per day, the frequency of participation in sports and the times spent for each activity in sports teams and club activities (lessons or sports organization for children outside school) other than the usual classes were recorded. To obtain sleep time per day, the times they went to bed and wakened during their usual lifestyle patterns were recorded. To calculate TV/VG time per day, the frequency and actual times spent for watching TV and playing VG were recorded.

In the measurement of body composition, the height, weight, body fat percentage, and muscle mass of subjects were determined. Based on obtained weight and height, the body mass index (BMI) was derived as an index of physique. Moreover, based on the obtained muscle mass and height, fat-free mass index (FFMI) was derived[28, 29]. FFMI was calculated by dividing muscle mass (kg) by square of height ($m^2$). Body fat percentage and muscle mass were determined using the Tanita MC-190 body composition analyzer (Tanita Corp., Tokyo, Japan) with bioelectrical impedance analysis (BIA). This device uses multiple frequencies of 5, 50, 250, and 500 kHz, which are effective in measuring body composition more accurately compared with other conventional devices using the BIA method. This device has been already used in several studies for adults[30]. This measurement method has shown a strong correlation between body composition and impedance values in dual X-ray absorptiometry (DXA) [31]. BIA is considered effective as it has been used with children, has a strong correlation with DXA, and because of its simple procedure. In summary, this device is simple and effective in measuring body composition in children[32-35]. Muscle mass measured by this device includes body water of skeletal and smooth muscles (in organs), i.e., tissue mass was computed by subtracting fat and bone mineral content from weight.

BMD was evaluated using the osteo-sono assessment index (OSI) of the calcaneus using the quantitative ultrasound (QUS) method. Using an ultrasonic bone assessment device (AOS-100NW; Hitachi Aloka Medical, Ltd., Tokyo, Japan), ultrasonic waves were transmitted to the right calcaneus for measurement. This device determines the speed of sound (SOS) and transmission index (TI). Then the OSI, which is the operation value of the measurement, was calculated using the equation: $OSI = TI \times SOS^2$. In this survey, the OSI was used as an index of BMD. Because the SOS of ultrasound varies with temperatures, values obtained with the QUS method may have interseason variation errors[36]. However, because the AOS-100NW corrects measurements with a temperature sensor, effects caused by alteration in temperature were negligible.

(3) Statistical analysis

To evaluate the effects of changes in physique, body composition and lifestyle on BMD in the early teens, the association between changes in these values from 10-11 to 13-14 years and the OSI at the age of 13-14 were evaluated with

**Table 1** Characteristics of subjects

| | Boys (n =73) | | Girls (n =73) | |
|---|---|---|---|---|
| | 10-11 y | 13-14 y | 10-11 y | 13-14 y |
| Age (years) | 10.5 ± 0.5 | 13.6 ± 0.5 | 10.5 ± 0.5 | 13.6 ± 0.5 * |
| Height (cm) | 143.4 ± 6.8 | 164.3 ± 6.5 ** | 145.6 ± 6.9 | 156.8 ± 6.2 ** |
| Weight (kg) | 37.6 ± 8.1 | 54.5 ± 8.9 ** | 38.7 ± 10.6 | 50.2 ± 9.9 ** |
| BMI (kg/m$^2$) | 18.2 ± 2.9 | 20.1 ± 2.7 | 18.1 ± 3.9 | 20.4 ± 3.7 ** |
| Body fat percentage (%) | 17.0 ± 8.9 | 17.1 ± 7.4 | 20.0 ± 8.2 | 26.2 ± 7.3 ** |
| FFMI (kg/m$^2$) | 14.0 ± 0.8 | 15.6 ± 0.8 ** | 13.4 ± 1.0 | 13.9 ± 1.0 ** |
| Exercise time (h/day) | 1.4 ± 1.1 | 2.0 ± 1.0 ** | 0.9 ± 1.0 | 1.3 ± 1.4 |
| Sleep time (h/day) | 8.6 ± 0.5 | 7.8 ± 0.7 ** | 8.8 ± 0.5 | 7.6 ± 0.7 ** |
| TV+VG time (h/day) | 3.5 ± 1.5 | 4.3 ± 2.2 ** | 3.3 ± 1.5 | 3.7 ± 1.7 |

Figures are expressed as mean ± standard deviation (SD). Student's unpaired *t*-test was used to compare the values.
BMI = body mass index, FFMI = fat-free mass index
**: p < 0.01

multiple regression analysis. The analysis was performed with the OSI as a dependent variable, and BMI, body fat percentage, FFMI, exercise time, sleep time, and TV/VG time at the age of 10-11 as independent variables using the forced entry method. As multicollinearity was found between BMI, body fat percentage and FFMI, these items were separately analyzed. In addition, partial $R^2$ of the independent variables to the dependent variable was calculated to evaluate the individual degree of correlation of changes in physique and body composition and lifestyle with the OSI.

The relationship between changes in FFMI and body composition/lifestyle were evaluated with an analysis of covariance (ANCOVA) to determine factors related to changes in FFMI among these items. The amount of change in FFMI was divided into two groups at the median, and thus the difference in changes in weight, BMI, body fat percentage, exercise time, sleep time, or TV/VG time between groups were compared with the ANCOVA after correction with values obtained at the age of 10-11 years for each item.

SPSS Statistics 17.0 was used for all statistical tests with the significance with trend levels of 0.05 and 0.1, respectively, in multiple regression analysis. The significance level was set as 0.05 for other tests.

(4) Ethical considerations

The purpose of the study was explained to the subjects and their parents in a written form, assuring their rights to withdraw from the study at any time, and protection of anonymity and personal data. Written consents were obtained from the subjects and their parents prior to the study. The health survey for children in elementary and middle school during the Iwaki Health Promotional Project was approved by the Ethical Committee of Hirosaki University Graduate School of Medicine.

## Results

(1) Subject Characteristics

Table 1 shows the age, height, weight, BMI, body fat percentage, FFMI, exercise time, sleep time, and TV/VG time of subjects at 10-11 and 13-14 years of age. In boys, height, weight and FFMI significantly increased from 10-11 to 13-14 years of age ($p < 0.01$ all). In girls, in addition to the items above, BMI and body fat percentage also increased ($p < 0.01$ all). In terms of lifestyle, boys showed significant prolongation in exercise and TV/VG time at the age of 13-14

**Table 2** Relationship of BMD with BMI and lifestyle

| | B | β | P | Partial $R^2$ | $R^2$ |
|---|---|---|---|---|---|
| Boys | | | | | |
| OSI | | | | | 0.30 |
| Changes in BMI (kg/m$^2$) | 0.05 | 0.23 | 0.07 | 0.04 | |
| Changes in exercise time (h/day) | 0.13 | 0.36 | 0.01 | 0.10 | |
| Changes in sleep time (h/day) | −0.11 | −0.19 | 0.13 | 0.02 | |
| Changes in TV+VG time (h/day) | −0.01 | −0.07 | 0.54 | 0.00 | |
| Girls | | | | | |
| OSI | | | | | 0.46 |
| Changes in BMI (kg/m$^2$) | 0.01 | 0.03 | 0.76 | 0.00 | |
| Changes in exercise time (h/day) | 0.11 | 0.35 | 0.00 | 0.13 | |
| Changes in sleep time (h/day) | −0.05 | −0.11 | 0.33 | 0.01 | |
| Changes in TV+VG time (h/day) | −0.02 | −0.13 | 0.27 | 0.01 | |

Partial regression coefficient (B) and standard partial regression coefficient (β) were derived with a multiple regression analysis. Adjustment items included BMI, exercise time, sleep time, and TV+VG time at the age of 10-11 years.
OSI = osteo-sono assessment index
BMI = body mass index

**Table 3** Relationship of BMD with body fat percentage and lifestyle

| | B | β | P | Partial $R^2$ | $R^2$ |
|---|---|---|---|---|---|
| Boys | | | | | |
| OSI | | | | | 0.26 |
| Changes in body fat percentage (%) | 0.01 | 0.20 | 0.16 | 0.02 | |
| Changes in exercise time (h/day) | 0.13 | 0.35 | 0.01 | 0.09 | |
| Changes in sleep time (h/day) | −0.11 | −0.20 | 0.13 | 0.05 | |
| Changes in TV+VG time (h/day) | −0.02 | −0.10 | 0.42 | 0.00 | |
| Girls | | | | | |
| OSI | | | | | 0.42 |
| Changes in body fat percentage (%) | −0.00 | 0.07 | 0.57 | 0.00 | |
| Changes in exercise time (h/day) | 0.11 | 0.33 | 0.00 | 0.13 | |
| Changes in sleep time (h/day) | −0.05 | −0.11 | 0.35 | 0.01 | |
| Changes in TV+VG time (h/day) | −0.02 | −0.13 | 0.26 | 0.00 | |

Partial regression coefficient (B) and standard partial regression coefficient (β) were derived with a multiple regression analysis. Adjustment items included body fat percentage, exercise time, sleep time, and TV+VG time at the age of 10-11 years.
OSI = osteo-sono assessment index

years compared with that at 10 years ($p < 0.01$ all) and a significant decrease in sleep time ($p < 0.01$). Numerical protraction in exercise and TV/VG time and a significant decrease in sleep time ($p < 0.01$) were observed in girls at 13-14 years of age compared with that at 10-11 years of age.

(2) Relationships between BMD and subjects' physique, body composition and lifestyles (Tables 2–4)

We investigated the relationship of changes in BMI, body fat percentage, FFMI, and lifestyle with the OSI by gender. A positive significant correlation was observed between the OSI and exercise time in both sexes (p=0.01 for boys and p=0.00 for girls) (Table 2). In addition, significant correlation trends between the OSI and FFMI were observed in boys (p=0.06) and in girls (p=0.05) (Table 4). Furthermore, a positive correlation trend was also observed

**Table 4** Relationship of BMD with FFMI and lifestyle

| | B | β | P | Partial $R^2$ | $R^2$ |
|---|---|---|---|---|---|
| Boy | | | | | |
| OSI | | | | | 0.30 |
| Changes in FFMI (kg/m$^2$) | 0.18 | 0.22 | 0.06 | 0.04 | |
| Changes in exercise time (h/day) | 0.12 | 0.33 | 0.02 | 0.06 | |
| Changes in sleep time (h/day) | 0.03 | 0.06 | 0.65 | 0.00 | |
| Changes in TV+VG time (h/day) | 0.00 | 0.00 | 0.98 | 0.00 | |
| Girl | | | | | |
| OSI | | | | | 0.46 |
| Changes in FFMI (kg/m$^2$) | 0.13 | 0.20 | 0.05 | 0.04 | |
| Changes in exercise time (h/day) | 0.10 | 0.30 | 0.00 | 0.17 | |
| Changes in sleep time (h/day) | −0.02 | −0.05 | 0.68 | 0.00 | |
| Changes in TV+VG time (h/day) | −0.02 | −0.13 | 0.26 | 0.00 | |

Partial regression coefficient (B) and standard partial regression coefficient (β) were derived with a multiple regression analysis. Adjustment items include FFMI, exercise time, sleep time, and TV+VG time at the age of 10-11 years.
OSI = osteo-sono assessment index, FFMI = fat-free mass index

**Table 5** Relationship between FFMI changes and weight, BMI, body fat percentage, and lifestyle

| | Boys (n = 73) | | Girls (n = 73) | |
|---|---|---|---|---|
| | Changes in FFMI (kg/m$^2$) | | Changes in FFMI (kg/m$^2$) | |
| | Small increase group (n = 36) | Large increase group (n = 37) | Small increase group (n = 36) | Large increase group (n = 37) |
| Changes in weight (kg) | 14.8 ± 0.7 | 19.0 ± 0.7 * | 8.8 ± 0.8 | 14.0 ± 0.8 * |
| Changes in BMI (kg/m$^2$) | 1.3 ± 0.2 | 2.7 ± 0.2 * | 1.4 ± 0.3 | 3.1 ± 0.3 * |
| Changes in body fat percentage (%) | −0.9 ± 0.8 | 1.1 ± 0.8 | 5.2 ± 0.8 | 7.1 ± 0.8 |
| Changes in exercise time (h/day) | 0.3 ± 0.2 | 0.8 ± 0.2 * | 0.2 ± 0.2 | 0.5 ± 0.2 |
| Changes in sleep time (h/day) | −0.8 ± 0.1 | −0.7 ± 0.1 | −1.2 ± 0.1 | −1.2 ± 0.1 |
| Changes in TV+VG time (h/day) | 0.9 ± 0.4 | 0.7 ± 0.4 | 0.6 ± 0.3 | 0.2 ± 0.3 |

After adjustment with values obtained at the age of 10-11 years for each item was made, comparison was done with the Bonferroni method.
Figures are expressed as corrected mean ± standard deviation (SD).
Small increase group <50 percentile (median), Large increase group ≥50 percentile (median)
50 percentiles were 1.62 kg/m$^2$ and 0.57 kg/m$^2$ in boys and girls, respectively.
*: $p < 0.05$ (versus small increase group)
BMI = body mass index, FFMI = fat-free mass index

between the OSI and BMI in boys (p=0.07) (Table 2). In contrast, the OSI had no significant associations with body fat percentage, sleep time, or TV/VG time in either gender. The partial $R^2$ of exercise time was higher for FFMI compared with that for BMI in both boys and girls.

(3) Relationships between FFMI and subjects' physique, body composition and lifestyles (Table 5)

Subjects were divided into the large increase group and the small increase group at the median of change in FFMI. The comparison between the two groups showed that weight, BMI, and exercise time increased more in the large increase group in boys ($p < 0.05$ all). In girls, weight and BMI significantly increased more in the large increase group compared to the small increase group in girls ($p < 0.05$ all).

## Discussion

In our study population, growth in height accompanied by gain in weight was found in the age group of 10–14 years, which was mainly due to the increased muscle mass in boys (Table 1) and increased muscle mass and body fat in girls (Table 1). It has been reported that children in Japan develop secondary sex characteristics at the mean age of 13.0 and 11.2 in boys and girls, respectively[37]. The results in our survey were similar to these mean ages. In this study, the increases in height and FFMI seemed to be associated with the increase in secretion of GH with growth. Moreover, a high secretion of estrogen may raise the body fat percentage in girls during this period[38].

The results of our study suggested that increased exercise time and FFMI are factors that increased BMD in both sexes (Tables 2–4). Previous studies have demonstrated that an exercise induced BMD through a higher frequency of bone stimulation because of the increase in weight burden[11-14] and muscle activity[39]. On the contrary, there are no reports that have reported the relationship between FFMI and BMD in children. In adults, it has been pointed out that the higher the ratio of muscle mass to body weight, the greater the bone stimulation by muscle activity, because the increase in FFMI may correlate with an increase in BMD[39, 40]. Thus, it is suggested that muscle mass is closely related to increased BMD in children as well as in adults. In addition, the partial $R^2$ was higher with exercise time per day compared with other items of physique and body composition, indicating that daily exercise is particularly important in the development of BMD in early teens (Tables 2-4).

Meanwhile, an increase in BMI was a factor that increased BMD in boys, but not in girls (Table 2). This may be explained by the fact that BMI increase is attributed to sex hormones, i.e., change in BMI during the growth period is mainly caused by the increased muscle mass for boys and body fat mass for girls (Table 1) [26, 27]. Therefore, the positive correlation observed between BMI and BMD was identified only in boys, suggesting that increased muscle mass is a major factor that influences BMD during this period in this gender (Table 4).

The results showed no significant relationship between body fat percentage and BMD in either gender. Adults with high body fat percentage tend to have a higher BMI, as body fat percentage may influence BMD through weight burden[41]. The reason for body fat percentage in the current subjects showing no effect on bones may be due to the unbalanced increase in body fat percentage and BMI during the study period in boys as mentioned above. On the contrary, the increase in body fat percentage was found to be consistent with the increase in BMI in girls, which may be caused by the active release of estrogen with the development of secondary sex characters[16-17, 42-43]. During this period, estrogen has strong effects on bone which makes the effects of weight burden on bone become relatively small[44]. Therefore, the effects of weight burden by body fat on BMD being curbed by estrogen during this period may be the reason why body fat percentage did not affect BMD in girls.

In conclusion, we believe muscle mass is the factor that increases BMD among physique and body composition factors in early teens in both genders. However, at present, BMI is commonly adopted to assess physique and body composition factors that increase BMD in the early teens, as in adults[11, 12]. This study suggested that BMD during this period was mainly increased by muscle mass; therefore, we should consider FFMI as an index for the increase in BMD as well.

In addition, we investigated the relationships between FFMI, which is important to increase

BMD in early teens, and physique, body composition and lifestyle (Table 5). The increase in FFMI was related to increase in weight/BMI, but not in body fat percentage in the two sexes, which suggested that increased muscle mass greatly contributed to the increase in weight. It has been reported that promoting secretion of growth and sexual hormones by adequate exercise and physical load are vital to increase the muscle mass during this period[45-47]. This accepted notion is coherent with our study, where increases in FFMI corresponded with exercise time in young boys. It is reported that muscle mass is associated with high-load and high-resistance exercises[48], therefore FFMI was correlated with extension of exercise time. In boys, it is believed that FFMI improved due to longer exercise times, which consequently increased exercise load. This relationship between FFMI and exercise time was not identified in girls. This may be caused by the generally lower load of exercise in girls during this period compared with that in boys[49]. However, there is a positive correlation between extended exercise time and BMD in girls (Tables 2, 3 and 4). Therefore, the effects of exercise itself should not be denied at this point.

Overall, it is crucial to extend exercise time to increase muscle mass in order to increase BMD in the early teens. In addition, it should be done not only by extending the exercise time, but also by adding high-load and high-resistance exercise to increase muscle mass.

The major limitation of the study is that we didn't have measurement of menarche age and hormones. Therefore, we can't mention the influence of sex hormone on BMD in our study.

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