原　著

# Contribution of the BMI Level or the Body Fat Percentage Level to Bone-Mass Development in Young Women

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## Abstract

It is unclear which body mass index (BMI) or body fat percentage level has the strongest effect on the bone mass in young women. We examined the data gathered from 233 adolescent girls in a junior high, high school, and university to ascertain the relationship between BMI or body fat percentage and bone mass.

The transmission index (TI) of the calcaneus was measured using an ultrasound bone densitometer. The subjects were classified into 3 groups by BMI and body fat percentage separately. The data was analyzed by using the analysis of variance and an unpaired t-test.

The bone mass differed significantly between each BMI group and a significant difference was observed between the groups associated with the body fat percentage of the Average group and the Obese group in junior high school students. There was also a significant difference between the Average group and the Obese group in both groups associated with a BMI and the body fat percentage in high school students. The subjects in the Average or the Obese group obtained their peak bone mass during high school. The subsequent reduction in bone mass following the peak level differed significantly in the Average and Obese groups.

In summary, the variation of bone mass in the Average group appears to be the optimal pattern in comparison with the other BMI or body fat percentage groups. Keeping the BMI or body fat percentage level near an average level should therefore be a top priority for the prevention of osteoporosis.

Key words: bone mass, calcaneus, ultrasound bone densitometer, BMI level, body fat percentage level

# 若年女性の骨発達におけるBMIと体脂肪率の影響

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## 要　旨

これまで，体重，BMI，体脂肪率の高さは，思春期女子や若年女性の骨量の高さに影響することが明らかにされている一方で，肥満が骨量の低さに影響をおよぼすのではないかという見解もある．これら相反する見解があることから，今回，中学生，高校生，大学生の233名を対象に，BMIと体脂肪率の骨量に与える影響について検討した．

骨量測定には超音波骨評価装置を使用し，TI値をその指標とした．なお，対象については，BMIと体脂肪率それぞれによって３つの体格グループ（痩せ，標準，肥満）に分け，検討した．分析にはStat View-J5.0を用い，対応のない分散分析およびt検定を行った．

中学生・高校生では，BMIおよび体脂肪率により分けた標準グループと肥満グループ間の骨量には，有意差があった．また，大学生では，BMIにより分けた痩せグループと標準グループ間の骨量に有意差が見られた．次に，BMIおよび体脂肪率により分けた３グループそれぞれについて，多重比較により骨発達について検討した．痩せグループに属する対象の最大骨密度を獲得する時期は，大学もしくはそれ以降であることが示唆された．その一方で，標準グループおよび肥満グループに属する対象のそれは，高校時代であることが明らかとなった．加えて，標準グループと肥満グループでは，大学での骨量減少に差があることが示唆され，肥満グループのその幅は大きかった．

本調査では，骨量とBMIおよび骨量と体脂肪率との関係性について検討したが，BMI，体脂肪率ともに標準群の対象者が高い骨量を維持できることが示唆された．

**キーワード**：骨量，踵骨，超音波測定，BMI，体脂肪率

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## Introduction

The number of overweight children and underweight adult women is currently increasing in Japan. Obesity is a significant factor in the development of life-style related diseases, and is a serious problem throughout the developed world. Both obese and underweight conditions are associated with an increase in the mortality rate. We also have a serious problem in people aged 65 years or over suffering from osteoporosis. Osteoporosis is not an immediate cause of death but it can generate pain and fractures which reduce the activity level, and can weaken the elderly, particularly if it causes them to become bedridden. It is much easier to obtain bone mass levels in the adolescent than in the older adult. Moreover, some studies have indicated that an increase in peak bone mass should decrease the risk of osteoporosis (Bonjour, 1991; Hansen, 1991; Hirota, 1991; Johnston, 1992; Katahira, 1994; Takahashi, 1996). If it is clarified that being obese or underweight has a negative effect on bone mass in consideration of the growth rate, in addition to contributing to the development of life-style related diseases, we can work for the prevention of osteoporosis, beginning in early childhood. There is a lack of information to determine if the bone mass of the obese adolescent is appropriately adapted to the increased load, or if the underweight adolescent has a lower bone mass than average by focusing on a particular term. Evidence generally suggests that the weight, body mass index (BMI), and body fat percentage are positive predictors of bone mass in girls and adolescents (Ackerman, 2006; Okano, 2004; Takahata, 2007). However, there is little conflicting evidence suggesting that obesity may be negatively related to bone mass (Goulding, 2000; Zhao, 2007) or how such an effect on the bone mass may change after puberty (Nagasaki, 2004). In addition, there are also considerable differences on the effects on bone mass between fat mass and lean tissue mass (Petit, 2005; Wang, 2005; Yokouchi, 2003). To ascertain the relationship between BMI or body fat percentage and bone mass, we examined data gathered from 233 adolescent girls in junior high school, high school, and young adults attending university.

If we can clarify whether an obese condition is associated with relatively higher bone mass and underweight condition is associated with lower bone mass in adolescents and early adults, it should be possible to intervene in osteoporosis prevention for specific subjects. We sought to confirm the reported findings regarding which BMI or body fat percentage level and composition is a positive predictor of bone mass. It would therefore be easy to help increase the bone mass by identifying risky subjects with these factors at a particular age group.

## Methods:

### *Subjects*

The data were gathered from 233 adolescent girls (junior high school students: 60, high school students: 55, college students: 118) in a junior high, high school, and a university. All subjects were selected randomly and they were in excellent health and free of chronic disease affecting bone metabolism. Informed consent was obtained from all adult subjects and from the parents and guardians for the junior high and high school students in accordance with the Helsinki Declaration. The study was approved by the Ethics Committee of Oita University and Prefectural University of Hiroshima.

### *Bone Mass Measurement*

The transmission index (TI) of the calcaneus was measured using an ultrasound bone densitometer (AOS100, Aloka Corp.). An ultrasound bone densitometer was selected because it does not have any side effects and it has a proven correlation with the bone mineral density using Dual-energy X-ray Absorption (DXA) (Goulding, 2000; Nagasaki, 2004; Petit, 2005; Wang, 2005; Yokouchi, 2003; Zhao, 2007). The measurement with the densitometer was practiced in order to reduce the measurement

error before starting the research.

### *Physical Examination*

The height（DST-210N, Muratec-KDS Corp.）, weight, and body fat percentages（TBF-546, Tanita Corp.）were measured and the BMI was calculated. The BMI is used as an indicator of the degree of obesity but it does not distinguish between body fat and lean body mass. By combining the BMI and the body fat percentage we were able to estimate the subject's lean mass without directly measuring the lean mass. Moreover this estimation is sufficient as the lean mass does not correlate with eventual health problems. We classified the subjects into 3 groups; namely, an Underweight group, Average group, and Obesity group based on the results of the BMI and body fat percentages. Since the criteria regarding body fat percentage have not been provided, we decided not to combine the BMI and body fat percentage together as an indicator of the degree of obesity. The subjects in the Underweight group had a BMI below 18.5 kg/m$^2$ or the body fat percentage below 20 %. The subjects in the Average group had a BMI 18.5 kg/m$^2$ to 25 kg/m$^2$ exclusive or the body fat percentage 20 % to 30 % exclusive. The subjects in the Obesity group had a BMI above 25 kg/m$^2$ or the body fat percentage above 30 %. These groups were also considered by age group; junior high school students, high school students, and college students. The classification method for BMI was modified based on the data from the Japanese Society for the Study of Obesity and the body fat percentage was modified based on the data from Jikei University School of Medicine.

### *Statistical Analysis*

The statistical analyses were carried out with Stat View-J5.0 programs. Descriptive statistics（mean ±SD）were reported for the subjects' characteristics. The analyses of variance and an unpaired t-test were used to test the differences of bone mass between the groups associated with BMI or body fat percentage used to test the differences in bone-mass development between groups associated with BMI or body fat percentage. A value of $p < 0.05$ was considered to be significant.

## Results

### 1）Subjects' characteristics

The subjects' characteristics were reported in Table 1. The numerical results of the factors besides bone mass were almost the same in every age group.

### 2）Differences in the bone mass between the groups associated with BMI or body fat percentage in the same age groups

The differences of bone mass between the groups associated with BMI or body fat percentage in the same age groups were analyzed by using the analysis of variance and an unpaired t-test then are displayed in Table 2. In these analyses, the BMI level and body fat percentage level were categorized separately into 3 groups; underweight group, average group, and obese group in each age group; junior high school students, high school students, and college students. The bone mass differed significantly between each group associated with BMI（Underweight vs. Average: $p<0.0001$ and Average vs. Obesity: $p<0.0001$）and a significant difference was observed between the groups associated with body fat percentage in the Average group and the Obese group（Average vs. Obesity: $p<0.05$）in the junior high school students. In other words, an increase in the BMI or body fat percentage was the deciding factors in the bone mass increase. In the high school students, there was a significant difference between bone mass in both groups associated with BMI and body fat percentage in the Average group and the Obesity group（Average in BMI vs. Obesity in BMI: $p<0.0001$ and Average in body fat percentage vs. Obesity in body fat percentage: $p<0.05$）. In college students, there was only a significant difference between

Table 1. Subjects' characteristic means± SD(minimum-maximum)

| Factors | Junior high school students (60) | High school students (55) | College students (118) |
|---|---|---|---|
| Age (years) | 14.2±0.9(13-16) | 16.9±0.7 (16-18) | 20.7±1.1 (19-22) |
| Bone mass (μ sec) | 1.044±0.081(0.93-1.305) | 1.125±0.142(0.91-1.718) | 1.062±0.88(0.88-1.379) |
| Height (cm) | 154.8±5.5(138.8-166.0) | 158.2±5.4 (148.1-171.4) | 157.7±5.3 (131.6-171.5) |
| Weight (kg) | 49.0±7.9(30.1-79.0) | 54.7±8.4 (38.6-84.8) | 51.9±6.9 (38.9-73.4) |
| BMI ($kg/m^2$) | 20.4±2.9(15.4-30.7) | 21.8±2.9 (15.9-32.2) | 20.8±2.4 (17.1-30.6) |
| Body fat percentage(%) | 27.2±6.7(15.5-48.0) | 27.9±6.1 (9.5-50.0) | 26.8±4.5 (20-45.5) |
| Menarche (years) | 11.7±1.0(9-14) | 11.9±0.9(10-15) | 12.0±1.2 (9-15) |

Table 2. The differences of bone mass between the groups associated with BMI or body Fat percentage: the analysis of variance and an unpaired *t*-test

Bone mass:($\mu$ sec)

| | Junior high school students | High school students | College students |
|---|---|---|---|
| Underweight | *1.002±0.07(n=12)* | *1.004±0.07 (n=4)* | *1.012±0.08 (n=22)* |
| | 0.994±0.07(n=7) | 1.113±0.29 (n=2) | - |
| Average | *1.039±0.06(n=44)* | *1.106±0.11 (n=44)* | *1.073±0.09 (n=89)* |
| | 1.034±0.06(n=37) | 1.095±0.11 (n=37) | 1.057±0.09 (n=94) |
| Obesity | *1.225±0.09(n=4)* | *1.314±0.22 (n=7)* | *1.089±0.07 (n=7)* |
| | 1.089±0.11(n=16) | 1.194±0.18 (n=16) | 1.081±0.07 (n=24) |

Underweight – Average: ***; Underweight – Obesity: n.s; Average – Obesity: ***
Underweight – Average: n. z; Underweight – Obesity: *; Average – Obesity: ***
Underweight – Average: **; Underweight – Obesity: n.s; Average – Obesity: n.s

*p<0.05, **p<0.01, ***p<0.0001 means± SD
n.s.: not significant

※ The numbers in italics show the me an and standard deviation of bone mass in each group associated with BMI.
※ The numbers not in italics show the mean and standard deviation of bone mass in each group associated with Body Fat Percentage.

bone mass in the Underweight group and the Average group associated with only BMI（p<0.01）. In addition, there was no subject who is categorized as underweight by body fat percentage in college students.

### 3） The differences in bone-mass development between the groups associated with BMI or body fat percentage

The differences in bone-mass development between groups associated with BMI and body fat percentage were analyzed by a multiple comparison as shown in Fig.1 and Fig.2. According to this analysis, BMI, body fat percentage, and age were categorized in the same way as in the analysis above. The distinction derived from this is to see a change of bone mass according to age in the groups associated with BMI and body fat percentage. The bone mass increased with age in the Underweight group; however, there was no significant difference in both of the Figures. In other words, the subjects of the Underweight group would acquire their peak bone mass in college or later（Fig.1）. In addition, the Underweight group as shown in Fig. 2. does not have any college students. There were significant differences of bone mass between each age group in both groups associated with BMI and body fat percentage in the Average group（Junior high school students vs. High school students: p<0.001 and High school students vs. College students: p<0.05（Fig.1） Junior high school students vs. High school students: p<0.01 and High school students vs. College students: p<0.05（Fig.2））. The results showed that the bone mass in the Average group reaches its highest value in

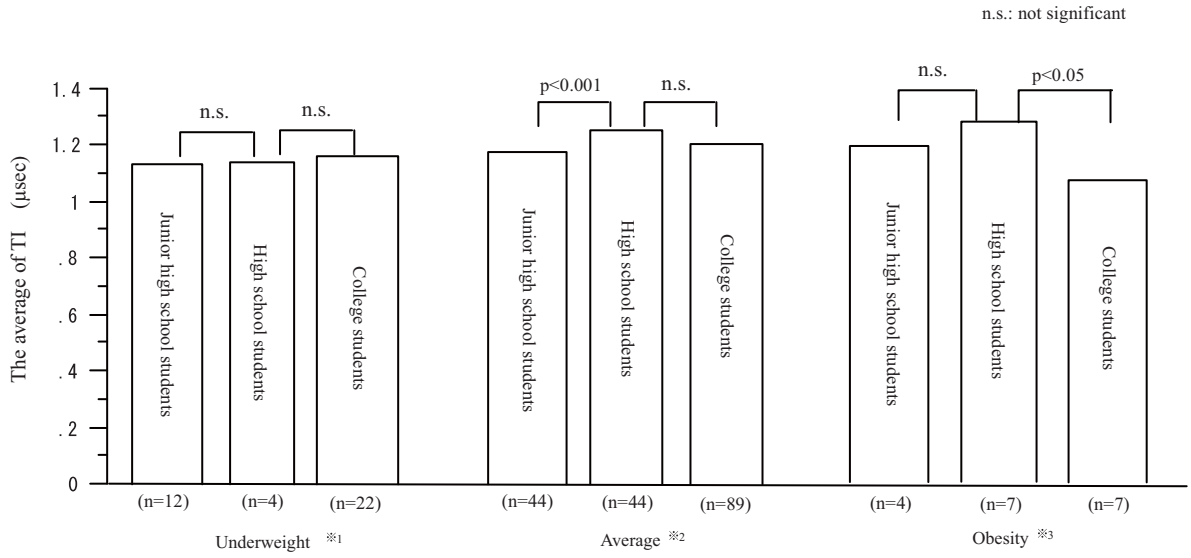


Fig.1 The relationship between 3 age groups in the groups associated with BMI:the analysis of a multiple comparison

※1: The subjects in this group had a BMI below 18.5 kg/m2.
※2: The subjects in this group had a BMI 18.5 kg/m2 to 25 kg/m2 exclusive.
※3: The subjects in this group had a BMI above 25 kg/m2.
The classification method for BMI was modified based on data from the Japanese Society for the Study of Obesity.

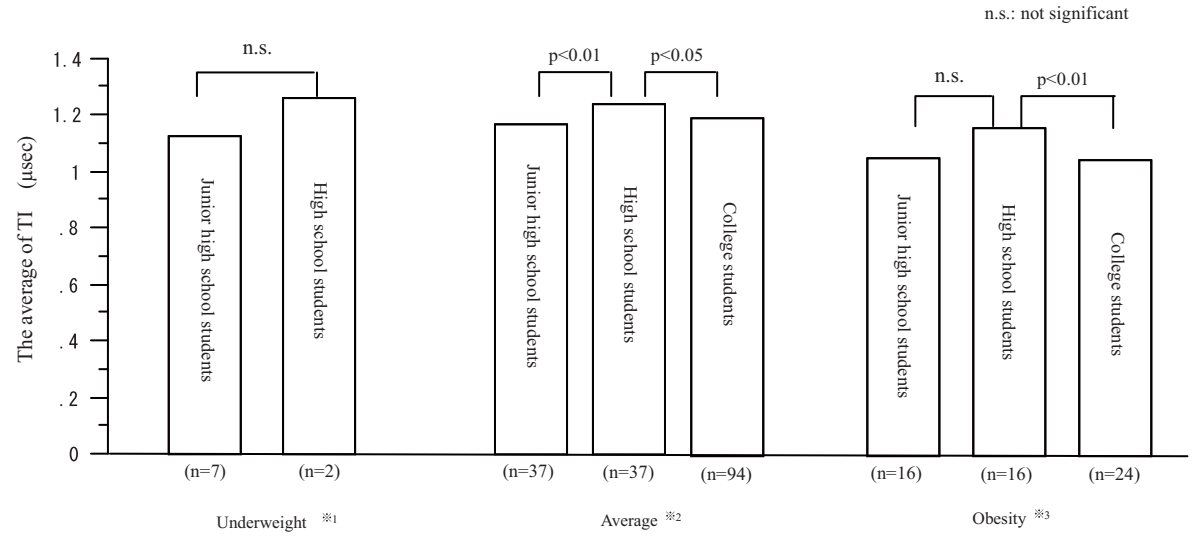


Fig.2 The relationship between 3 age groups in the groups associated with body fat percentage:the analysis of a multiple comparison

※1: The subjects in this group had a body fat percentage below 20%.
※2: The subjects in this group had a body fat percentage 20% to 30% exclusive.
※3: The subjects in this group had a body fat percentage above 30%.
The classification method for body fat percentage was modified based on data from Jikei University School of Medicine.

high school. There was a significant difference in bone mass between high school students and college students in the group associated with BMI ($p<0.05$) and there were also significant differences in the group associated with body fat percentage (Junior high school students vs. High school students: $p<0.05$

and High school students vs. College students: $p<0.01$) in the Obesity group. The results showed that the bone mass in the Obesity group reached its highest value in high school. Although both the subjects in the Average group and the Obesity group acquired their peak bone mass at almost the same time, the decline in the bone mass after its peak was different, as a remarkable decrease occurred in the Obesity group.

## Discussion

### 1) The differences of bone mass between the 3 age groups associated with BMI and body fat percentage

The female sex hormone levels are closely related to bone mass and fat mass. Most girls experience menarche during junior high school. In the time just before menarche, female sex hormone levels increase suddenly (Emans, 1990) and it are unstable, and moreover, have a strong effect on bone mass (Mesaki, 1994; Nakata, 2003) and fat mass (Bates, 1982). The bone mass of the obese group was significantly higher than the others in junior high and high school students in this study. In other words, the fat mass was the greatest factor effecting the bone mass until the female sex hormone levels became stable, but the effect slightly changed when the subjects became older (Bonjour, 1991; Nagasaki, 2004) as the effect of obesity was evident in the college students (Fig.2). The problem of controlling body fat percentage within a proper amount tends to become more difficult as people get old. In the next paragraph, we show some of the variations in bone-mass development and the interventional strategy of the specific subjects.

### 2) Differences in bone-mass development between groups associated with BMI and body fat percentage

#### (1) *Underweight group*

The bone mass increased slightly as the subjects aged even if there was no significant difference between the 3 age groups associated with BMI or between 2 age groups associated with body fat percentage. We predict that they would reach their peak bone mass in college or later by just thinking BMI level. As the Underweight group associated with body fat percentage disappeared in college students, the group associated with BMI was only focused in this age group. From these results, the underweight group has a much longer time than the other groups to work toward the prevention of osteoporosis if efforts are initiated earlier. In addition, a long-term interventional strategy should lead to an ample bone mass gain, until the peak bone mass is attained.

#### (2) *Average group*

The subjects in the average group reached their peak bone mass during high school. By intervention initiated in junior high school, there is a long-term possibility for an increase of bone mass. This implies that adolescents in the Average group will maintain their bone mass at a high level by intervention, even though it will decrease by university or college age. In addition, intervention when they acquire their peak bone mass might help them to avoid a sudden decrease in their bone mass with age.

#### (3) *Obese group*

The subjects in the obese group reach their peak bone mass during high school as did the subjects in the average group. The advantage for people who are obese is to acquire much more bone mass than the people who belong to the underweight group or the average group up until the time when they attain their peak bone mass. On the other hand, the phenomenon of a sudden decrease in bone mass in the obese group after they reach their highest level was the most severe of all of the groups. To assist in maintaining a high bone density level, we suggest intervention by encouraging exercise, the consumption

of calcium rich foods, and adequate vitamin D in take during college, before the decline in bone mass begins.

According to the above findings, we conclude that the variation of bone mass in the Average group is the ideal condition of all of the groups associated with BMI and body fat percentage. In some studies, nearly the same results were obtained supporting the contention that a decreased bone mass results if the BMI or body fat percentages are above or below the average range（Goulding, 2000）. To identify the students who are underweight or obese during early childhood, and to modify their BMI or body fat percentages toward and into the average will be a top priority. However, if there is not enough time to intervene or if it is not effective the above described course is to be expected. In addition, to modify their body fat percentages toward the average level is difficult because women tend to have a much higher body fat percentage than when they are young since the Underweight group associated with body fat percentage was no longer observed among college students. In this study the BMI level and body fat percentage were found to affect the same subjects differently, such as some people have below BMI than average and have a much higher body fat percentage than average at the same time. It is therefore important to focus on increasing the bone mass from various viewpoints. It is also important to find a tried and tested method for classifying the body fat percentage since this factor is one of the deciding factors in increasing or decreasing bone mass in adolescents and young adult females.

## Limitations

About measurements ― In this study, we chose the least invasive techniques for measurement of bone mass and for the physical examination since we included subjects who were still immature. We tried to reduce the bone mass measurement error before starting this research as much as possible by practicing and improving our skill. Moreover, the technology we incorporated has a proven correlation with the bone mineral density using DXA. However, we could not avoid a small risk of error in the results of this study because of these measurements. About the methods ― We were not able to prove cause and effect because the cross-sectional nature of our data is a limitation and also the subjects of limitation number. Longitudinal data will show the accurate relationship between bone-mass development and the groups associated by BMI and body fat percentage by intervention in the subjects who are in underweight or obese.

## Summary and conclusions

In summary, we showed that differences exist regarding the stage when people acquire peak bone mass by comparing BMI and body fat percentage. Staying in the average range of BMI or body fat percentage appears to be a top priority in order to attain bone mass effectively or not to reduce bone mass suddenly. In addition, our findings suggest that timely intervention into BMI or body fat percentage issues is needed in order to acquire and maintain optimal bone mass. However, we need to continue this research in future studies by changing the subjects and methods to confirm these results. It is therefore considered to be useful to increase the bone mass by finding risky subjects with the above described factors because these factors can be identified during an annual physical checkup for students which take place every year. In addition, it is also important to inform adolescents of the effect that such factors can have on the bone mass to help them to increase their bone mass by themselves.

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