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Fat mass is positively associated with bone mass in relatively thin adolescents: Data from the Kitakata Kids Health Study

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ABSTRACT

Epidemiologic studies have found that higher body weight is associated with better bone health. Body weight consists of both fat mass (FM) and lean soft tissue mass (LSTM). Previous studies have examined the effects of FM levels during childhood on bone health, with conflicting results. In the present study, we investigated the independent contributions of FM to bone mass in Japanese adolescents. Subjects were 235 adolescents aged 15–18 years old in August 2010 and in August 2013 from the Kitakata Kids Health Study in Japan. We obtained cross-sectional data on body composition as well as bone mineral density (BMD). Body composition and BMD were measured using a dual-energy X-ray absorptiometry scanner. We found moderate and positive relationships between FM index and LSTM index (males, $r = 0.69$; females, $r = 0.44$). To verify a potentially additive effect of FM on the variance of bone variables beyond LSTM, we assessed the association between FM index and bone variables after stratification by tertiles of the LSTM index. In the lowest tertile of the LSTM index, FM index was significantly ($P < 0.05$) associated with both femoral neck BMD (males, $\beta = 0.48$; females, $\beta = 0.33$) and whole body BMC (males, $\beta = 0.41$; females, $\beta = 0.25$). On the other hand, we found no significant associations between FM index and bone variables in other tertiles of the LSTM index. These findings indicate that FM can influence how high bone mass is obtained among relatively thin adolescents, but not among those who are of normal weight or overweight.

Introduction

Low body weight is thought to be a risk factor for low bone mineral density (BMD) in adult men and women [1,2]. Numerous epidemiologic studies showed a positive association between body weight and bone mass. However, since body weight consists of both fat mass (FM) and lean soft tissue mass (LSTM), limited data are available regarding the independent impact of FM on bone mass in epidemiological studies, especially in a pediatric population.

Previous studies of adult subjects have investigated the independent contributions of FM or LSTM to bone health [3–7]. Several studies suggest that FM has a more trivial effect than LSTM on bone mineral content (BMC) and BMD [4,5,7], and some have reported that the independent contribution of FM to BMD changes with generation in that the effects of FM on bone mass are more prominent in postmenopausal women than in premenopausal women [3,6]. FM that affects BMD may not always influence BMD throughout all stages of the life cycle [3]. Change in the contribution of FM may be attributed to age-related changes in the interrelationships between bone mass, FM, LSTM, physical activity, endocrinology, and certain aging-related factors [6].

Most skeletal mass/density accumulates by late adolescence or, on average, by 18 years of age [8]. Insufficient accumulation of bone mass during skeletal growth and consolidation predisposes one to age-related bone loss and fracture risk, since a critical strategy for osteoporosis prevention is to maximize bone mass during skeletal growth development [9]. Therefore, determination of the independent importance of FM and LSTM in bone mass accumulation during adolescence is necessary.

Previous studies from a pediatric population found that, while the effects of LSTM on bone health are reportedly beneficial [10,11], those for FM have yielded conflicting results [11–19]. Some studies reported that FM is a positive independent determinant of bone mass [11–14], while other studies showed an inverse relationship between FM and

Abbreviations: BMC, bone mineral content; BMD, bone mineral density; BMI, body mass index; DXA, dual-energy X-ray absorptiometry; FM, fat mass; FMI, fat mass index; LSTM, lean soft tissue mass; LSTMI, lean soft tissue mass index.

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Table 1
Study subject characteristics.

Characteristics	Male (N = 106)	Female (N = 129)	P-value[a]
Age (years)	16.6 ± 0.8	17.0 ± 0.8	0.002
Height (cm)	171.4 ± 5.8	158.6 ± 5.8	<0.001
Weight (kg)	59.5 ± 12.1	51.9 ± 8.2	<0.001
BMI (kg/m^2)	20.2 ± 3.6	20.6 ± 2.6	0.382
% fat	15.5 ± 5.4	26.9 ± 4.9	<0.001
FM (kg)	9.9 ± 5.6	14.6 ± 4.5	<0.001
FMI (kg/m^2)	3.4 ± 1.9	5.8 ± 1.6	<0.001
LSTM (kg)	49.3 ± 7.0	37.3 ± 4.7	<0.001
LSTMI (kg/m^2)	16.7 ± 1.9	14.8 ± 1.3	<0.001
Pubic hair appearance (age)	12.5 ± 1.0	11.6 ± 1.2	<0.001
Calcium intake (mg/day)	471 ± 244	401 ± 190	0.017
Sedentary behavior (e.g., media use), N (%)			0.027
<2 h/day	50 (47)	44 (34)	
2–3 h/day	24 (23)	30 (23)	
>4 h/day	32 (30)	55 (43)	
Lumbar spine (L2–L4) BMD (g/cm^2)	0.95 ± 0.14	0.97 ± 0.10	0.119
Total hip BMD (g/cm^2)	0.97 ± 0.15	0.90 ± 0.09	<0.001
Femoral neck BMD (g/cm^2)	0.92 ± 0.15	0.87 ± 0.11	0.003
Whole body BMD (g/cm^2)	0.93 ± 0.09	0.92 ± 0.06	0.321
Whole body BMC (g)	1946 ± 330	1682 ± 213	<0.001

N, number; BMI, body mass index; FM, fat mass; FMI, fat mass index; LSTM, lean soft tissue mass; LSTMI, lean soft tissue mass index; BMD, bone mineral density; BMC, bone mineral content.
FMI was calculated as total fat mass divided by height squared.
LSTMI was calculated as total lean soft tissue mass divided by height squared.
Values represent mean ± standard deviation, or N (%).
[a]The unpaired t-test or the Mann–Whitney U test was performed.

Table 2
Correlation coefficients of bone mass measurements with FMI and LSTMI.

	Pearson's correlation coefficients			
	FMI		LSTMI	
	r	p	r	p
Male (N = 106)				
Lumbar spine (L2–L4) BMD	0.263	0.007	0.571	<0.001
Total hip BMD	0.297	0.002	0.678	<0.001
Femoral neck BMD	0.367	<0.001	0.722	<0.001
Whole body BMD	0.240	0.013	0.650	<0.001
Whole body BMC	0.326	<0.001	0.715	<0.001
Female (N = 129)				
Lumbar spine (L2–L4) BMD	0.130	0.142	0.451	<0.001
Total hip BMD	0.204	0.021	0.538	<0.001
Femoral neck BMD	0.267	0.002	0.529	<0.001
Whole body BMD	0.129	0.146	0.453	<0.001
Whole body BMC	0.279	0.001	0.600	<0.001

FMI, fat mass index; LSTMI, lean soft tissue mass index; N, number; BMD, bone mineral density; BMC, bone mineral density.
FMI was calculated as total fat mass divided by height squared.
LSTMI was calculated as total lean soft tissue mass divided by height squared.

bone health [15–19]. In the present study, we investigated the independent association between FM and bone mass at multiple skeletal locations and in the whole body using dual-energy X-ray absorptiometry (DXA) in Japanese adolescents.

Methods

Study population

Subjects were recruited from the Kitakata Kids Health Study, which has been conducted once every three years since 2001 [20]. The source population in the present study comprised all 622 students in the Shiokawa Junior High School in 2007 and 2010. The Shiokawa Junior High School is a public school in Kitakata City in Fukushima Prefecture, Japan. Most children who live in the school area attend the public junior high school. For all 235 subjects (106 males, 129 females) in the source population aged 15–18 years old in August 2010 and August 2013, we obtained cross-sectional data on body composition, BMD, body mass index (BMI), sedentary behavior, pubic hair appearance, and calcium intake. We obtained signed informed consent documents from all subjects. The study was performed in accordance with the ethical standards set by the 1964 Declaration of Helsinki, and was approved by the Ethics Committee of the Kinki University Faculty of Medicine.

Data collection

Both BMD and body composition components were measured using a single DXA scanner (QDR-4500A; Hologic Inc., Bedford, MA, USA) in a mobile test room. BMD was measured in the lumbar spine (L2–L4), total hip, and femoral neck, as previously described [21]. In addition, whole body BMD and body composition components were measured at the same session as previously described [22]. As a superior measure of whole body adiposity that is independent of overall body size, the FM index (FMI) was calculated as total body fat mass (kg) divided by height squared (m^2) [23,24]. LSTM index (LSTMI) was calculated as well as FMI.

At the same session, height and weight were measured with an automatic digital scale (TK-11868 h; Takei, Tokyo, Japan). The first appearance of pubic hair and sedentary behavior such as media use were also determined by self-reported responses to a questionnaire. Trained health care nurses confirmed their answers by interviews. Calcium intake was also estimated by food frequency questionnaires. Trained dieticians interviewed the subjects to confirm their answers to the questionnaire.

Statistical analysis

Cross-sectional data were analyzed using the unpaired t-test or the Mann–Whitney U-test for comparisons of measurements between boys and girls. Pearson's correlation coefficients were calculated to compare how each of the FMI and LSTMI was associated with bone variables. We also used Pearson's correlation test to examine the relationships between BMI, LSTMI, and FMI. To verify the potential additive effect of FMI on the variance of bone variables beyond LSTMI, multiple regression analysis was used to determine the relationships between FMI and the bone variables following stratification by LSTMI tertiles. Dependent variables were each of the bone variables, and independent variables were age, height, pubic hair appearance, sedentary behavior, calcium intake, and FMI. In addition, mean values of bone variables were calculated using the general linear model, according to the FMI tertile within each LSTMI tertile, after adjusting for potential confounding factors

Table 3
Pearson's correlation coefficients by body weight, FMI, and LSTMI.

	FMI		LSTMI	
	r	p	r	p
Male (N = 106)				
BMI	0.905	<0.001	0.925	<0.001
FMI			0.689	<0.001
Female (N = 129)				
BMI	0.868	<0.001	0.815	<0.001
FMI			0.442	<0.001

FMI, fat mass index; LSTMI, lean soft tissue mass index; N, number; BMI, body mass index.
FMI was calculated as total fat mass divided by height squared.
LSTMI was calculated as total lean soft tissue mass divided by height squared.