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ORIGINAL ARTICLE

Association between Anthropometric Indices, Body Composition and Bone Parameters in Thai Female Adolescents

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Abstract
Objective To investigate correlations between anthropometrics and body composition with bone parameters of the whole-body and lumbar spine in non-obese and obese Thai female adolescents.
Methods This study was performed in 135 female adolescents aged 15 to 18 y enrolled in secondary schools in southern Thailand. Subjects were grouped into non-obesity (underweight and normal-to-overweight) (BMI < 25) and obesity (BMI ≥ 25) groups. Anthropometric indices for obesity [body weight (BW), waist circumference (WC), and body mass index (BMI)] were recorded. Bone parameters (BMC, BMD, and Z-scores) of the whole-body and lumbar spine (L1-L4) and body composition (LBM, BFM, %fat, %lean, and %bone) were assessed by dual-energy X-ray absorptiometry (DXA). Correlations between anthropometrics, body composition, and bone parameters were evaluated and compared between subject groups.
Results The obesity group had significantly higher means of whole-body BMD, BMC and Z-score than non-obese group ($p < 0.05$). BMI and BW were positively associated with BFM and %fat ($p < 0.05$) for non-obese subjects. Obese subjects had greater lumbar spine BMC compared to non-obese subjects. BFM was correlated with whole-body BMC in obese group. BW was a positive determinant of BMC at both sites in all subject groups, particularly for obese subjects; BW had positive associations with all bone parameters at the lumbar spine.
Conclusions BW can be used as a determinant of all bone parameters at lumbar spine, and BFM had a positive effect on whole-body BMC in Thai obese female adolescent subjects.

Keywords Body weight · Body mass index · Bone mineral content · Lumbar spine · Adolescent girls

Abbreviations

BFM	Body fat mass
BMC	Bone mineral content
BMD	Bone mineral density
BMI	Body mass index
BW	Body weight
DXA	Dual-energy X-ray absorptiometry
FFM	Fat-free mass
LBM	Lean body mass
WC	Waist circumference
%Bone	Bone percentage
%Fat	Body fat percentage
%Lean	Lean percentage

Introduction

Obesity is often considered to have a protective effect against osteoporosis while thinness is negatively associated with bone mass [1]. There has been an increase in the prevalence of overweight among adolescents. Previous studies have reported that obesity during childhood and adolescence is associated with increased vertebral density and whole-body bone density [2]. However, a high incidence of fractures in overweight children has been reported recently [3]. Obesity is most often defined by body mass index (BMI), which is calculated by

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dividing body weight (BW) in kilograms by height in meters squared (kg/m^2). BMI has a high correlation with adiposity and also correlates well with excess weight at the population level. It is accordingly recommended as a method for diagnosing overweight and obesity [4]. BW is largely made up of two components: fat mass and lean mass. Total body fat mass (BFM) is one of the most important indices of obesity, and it has been previously reported that percentage of total body fat increased along with BMI in girls aged 9–18 y [5]. Associations between BMI, body fat, and bone parameters in adolescents remain controversial, whereas BW is known to be positively correlated with bone mineral density (BMD). A previous study showed that high BMI is associated with normal BMD and Z-scores, positively correlated with body fat percentage (%fat) and waist circumference (WC), and negatively associated with lean percentage (%lean) [6]. Compared with overweight and obese adolescents, the odds of low BMD were 4 times greater in normal weight group and 4.6 times greater in females, compared with males [7]. In overweight girls (BMI ≥ 25), low BMC or BMD at all bone sites has not been found [7]. In addition, high BMI and hip circumference have been associated with increased BMD at femoral neck than lumbar spine [8].

Although several studies have reported that high BMI correlated with normal bone density, excessive fat mass may not protect against osteoporosis or osteoporotic fracture [9]. The negative results showed that overweight and obese children and adolescents have decreased bone mass relative to BW, and the influence of overweight on BMD might be site-specific [10], and fat mass is not related to bone density in children aged 4–16 y [11]. Previous studies have posited that the bones of obese children and adolescents adapt to lean mass whereas excess body mass in the form of fat is inversely related to bone parameters [12, 13]. In addition, recent studies found that both BMI and lean mass or fat-free mass (FFM) are important mediators in the BMC/BMD association in late adolescents (18 y of age) [14], and lean mass has a stronger positive correlation with BMC and BMD than BFM in females [1, 15, 16].

However, the association between obesity including BMI, BW and fat mass, and bone parameters in adolescents remains inconsistent. This study aims to investigate correlations between anthropometric indices indicating obesity and body

Table 1 Descriptive data of anthropometrics, body composition and bone mass at whole body and lumbar spine (L1-L4) of all subjects and subject groups classified by BMI (kg/m^2)

Parameters	Total subjects (n = 135)	Underweight subjects (BMI < 18.5) (n = 53)	Normal-to-overweight subjects (18.5 ≤ BMI < 25) (n = 52)	Obese subjects (BMI ≥ 25) (n = 30)	p value
Anthropometrics					
BMI (kg/m^2)	21.09 ± 4.42	17.10 ± 0.98	21.13 ± 1.86	28.06 ± 1.79^{a,b}	< 0.001
BW (kg)	53.01 ± 11.63	43.51 ± 4.05	52.59 ± 5.62	70.53 ± 7.56^{a,b}	< 0.001
WC (cm)	73.40 ± 9.88	65.92 ± 4.81	72.87 ± 5.99	87.53 ± 6.13^{a,b}	< 0.001
Body composition					
%Lean (%)	63.10 ± 6.83	69.52 ± 3.76	63.40 ± 5.03	55.28 ± 3.31^{a,b}	< 0.001
%Fat (%)	32.61 ± 7.11	26.90 ± 3.89	33.13 ± 5.20	41.81 ± 3.37^{a,b}	< 0.001
%Bone (%)	3.35 ± 0.37	3.59 ± 0.26	3.35 ± 0.30	2.91 ± 0.24^{a,b}	< 0.001
BFM (g/cm^2)	3.68 ± 1.26	2.62 ± 0.46	3.72 ± 0.76	5.51 ± 0.60^{a,b}	< 0.001
LBM (g /cm^2)	6.65 ± 0.61	6.43 ± 0.67	6.73 ± 0.54	6.91 ± 0.52^{a}	= 0.001
Bone parameters of whole body					
BMD (g/cm^2)	0.86 ± 0.10	0.79 ± 0.06	0.87 ± 0.07	0.95 ± 0.10^{a,b}	< 0.001
BMC (g)	1376.96 ± 259.67	1181.24 ± 135.16	1393.14 ± 168.90	1694.71 ± 231.76^{a,b}	< 0.001
Z-score	−0.73 ± 0.63	−1.18 ± 0.44	−0.58 ± 0.53	−0.18 ± 0.52^{a,b}	< 0.001
Bone parameters of lumbar spine (L2-L4)					
BMD (g/cm^2)	0.97 ± 0.12	0.90 ± 0.08	1.00 ± 0.12	1.04 ± 0.13^{a}	< 0.001
BMC (g)	47.61 ± 8.57	43.60 ± 5.86	48.05 ± 7.70	53.94 ± 10.12^{a,b}	< 0.001
Z-score	0.41 ± 1.09	−0.21 ± 0.72	0.70 ± 1.05	0.10 ± 1.19^{a}	< 0.001

Values are mean ± SD

BFM Body fat mass; *BMC* Bone mineral content; *BMD* Bone mineral density; *BMI* Body mass index; *BW* Body weight; *LBM* Lean body mass; *WC* Waist circumference; *%Bone* Bone percentage; *%Fat* Body fat percentage; *%Lean* Lean percentage

[a] Significant difference ($p < 0.05$) compared with underweight subjects using Bonferroni post hoc test

[b] Significant difference ($p < 0.05$) compared with normal-to-overweight subjects using Bonferroni post hoc test

Table 2 Correlation between BMI, BW, WC and BFM and %Fat of all subjects and subject groups classified by BMI (kg/m^2)

Anthropometrics	Total subjects (n = 135)		Underweight subjects (BMI < 18.5) (n = 53)		Normal-to-overweight subjects (18.5 ≤ BMI < 25) (n = 52)		Obese subjects (BMI ≥ 25) (n = 30)	
	BFM	%Fat	BFM	%Fat	BFM	%Fat	BFM	%Fat
BMI (kg/m^2)	0.89*	0.83*	0.37*	0.29*	0.74*	0.61*	0.49*	0.25
BW (kg)	0.89*	0.83*	0.51*	0.39*	0.76*	0.61*	0.51*	0.25
WC (cm)	0.81*	0.76*	0.23	0.18	0.68*	0.57*	0.39*	0.16

BFM Body fat mass; *BMI* Body mass index; *BW* Body weight; *WC* Waist circumference; *%Fat* Body fat percentage

Significance level at 0.05 *$p < 0.05$

composition variables with bone parameters of the whole-body and lumbar spine (L1-L4) in Thai female adolescents by comparing between non-obese and obese groups. Moreover, results obtained from this study will be used to further promote bone health and reduced body fat in female adolescents.

Material and Methods

The participants were 135 healthy female students aged 15 to 18 y from five secondary schools in southern Thailand. Criteria for exclusion were any chronic or bone diseases, other conditions such as asthma, allergies, or gastritis, and use of steroid or anticonvulsant drugs. Data on exercise and milk intake from six months prior to the survey were collected. Optimal to high levels of weight bearing exercise and milk intake were accepted when exercise was performed ≥30 min/d and >3 d/wk [17, 18], and consumption of milk was ≥1 pack (200 ml)/d [19]. The study protocol was approved by the Ethics Committee on Human Rights Related to Research Involving Human Subjects, Walailak University, Thailand (WU56108). A consent form was obtained from all the subjects or their legal representative before enrollment.

Body weight was measured in light clothing to the nearest 0.1 kg using an electronic calibrated scale (SC-330ST, Tanita Corporation). Height was measured to the nearest 0.5 cm with a stationary vertical height board with participants standing without shoes. BMI was calculated by dividing BW (kg) by the square of height (m^2). The subjects were classified into two groups: obesity (BMI ≥ 25) and non-obesity (BMI < 25). Based on BMI, the non-obese group was divided into underweight (BMI < 18.5) and normal-to-overweight (18.5 < BMI < 25) (defined as control group) [20, 21]. Waist circumference (WC) was measured with a metal measuring tape to the nearest 0.1 cm at a level midway between the lowest lateral border of the ribs and the uppermost lateral iliac crest with subjects in a standing position.

Body composition, including lean body mass (LBM) (g/cm^2), BFM (g/cm^2), %fat [(fat mass / total mass) × 100], %lean [(lean mass / total mass) × 100], and bone percentage (%bone), and bone parameters, including BMC (g), BMD

Table 3 Correlation between anthropometrics, body composition, and bone parameters at whole-body and lumbar spine (L1-L4) of all female adolescent subjects (n = 135)

Parameters	Correlation Coefficient						
	%Bone	Whole-body			Lumbar spine		
		BMD	BMC	Z-score	BMD	BMC	Z-score
BMI (kg/m^2)	−0.76*	0.66*	0.77*	0.65*	0.50*	0.49*	0.51*
BW (kg)	−0.74*	0.69*	0.89*	0.68*	0.52*	0.59*	0.53*
WC (cm)	−0.76*	0.56*	0.68*	0.54*	0.37*	0.40*	0.38*
%Lean (%)	0.80*	−0.48*	−0.65*	−0.47*	−0.35*	−0.31*	−0.37*
%Fat (%)	−0.81*	0.46*	0.64*	0.44*	0.34*	0.30*	0.36*
BFM (g/cm^2)	−0.82*	0.55*	0.72*	0.53*	0.41*	0.39*	0.42*
LBM (g/cm^2)	−0.09	0.49*	0.46*	0.48*	0.38*	0.53*	0.37*

BFM Body fat mass; *BMC* Bone mineral content; *BMD* Bone mineral density; *BMI* Body mass index; *BW* Body weight; *LBM* Lean body mass; *WC* Waist circumference; *%Bone* Bone percentage; *%Fat* Body fat percentage; *%Lean* Lean percentage

Significance level at 0.05 *$p < 0.05$

(g/cm^2), and Z-score at the whole-body and lumbar spine (L2–L4) were measured by dual-energy X-ray absorptiometry (DXA) using the pediatric mode of Stratos, a pencil-beam densitometer (Diagnostic Medical Systems, Perols, France) [22]. The Z-score is the reported value which is given as a percentile or a standard deviation score. A Z-score of zero is equivalent to the mean, and Z-scores of −1 and +1.5 are equivalent to values one standard deviation below and 1.5 standard deviations above the mean, respectively [23]. Scanner stability was checked throughout the course of the study with plots of daily spine phantom scans [5].

The results are presented as mean ± standard deviation (SD). Data analysis was performed using SPSS version 17.0 software (SPSS, Illinois, United States). Differences in parameters among groups, non-obesity (underweight and normal-to-overweight) and obesity, were compared by one-way analysis of variance (ANOVA) followed by Bonferroni post hoc test to compare the possible differences between the groups. The correlations between anthropometric data and body composition and bone mass were calculated by Pearson's correlation coefficient. A *p*-value <0.05 was considered statistically significant.

Results

The study sample comprised 135 female adolescent subjects (mean age 16.10 ± 0.49 y). The subjects were divided into three groups based on BMI, underweight (BMI < 18.5, $n = 53$), normal-to-overweight ($18.5 \leq$ BMI < 25, $n = 52$), and obesity (BMI ≥ 25, $n = 30$). Percentages of subjects who performed weight bearing exercise and milk intake were 15.09% and 47.17%; 26.92% and 61.54%, and 20% and 53.33% in groups of underweight, normal-to-overweight, and obesity, respectively. Table 1 shows that the mean BMI of underweight, normal-to-overweight, and obese subjects were 17.10 ± 0.98, 21.13 ± 1.86, and 28.06 ± 1.79, respectively. There were statistically significant differences of anthropometrics, body composition and bone parameters between all the groups and the control group ($p < 0.05$). The mean values of %fat, BFM, LBM, BMC and BMD were highest in obese subjects whereas these values were the lowest in underweight subjects. At whole-body, the mean Z-score for the underweight was below −1 (−1.18 ± 0.44), which indicates low BMD, whereas those for the normal-to-overweight and obesity were above −1 (normal BMD). At the lumbar spine, all subject groups had normal lumbar spine BMD (means of Z-score > −1). In addition, there were significant differences of mean whole-body and lumbar-spine BMD among three groups ($p < 0.05$), and a higher mean BMC was found for the obese group. Table 2 shows that BMI and BW were positively associated with BFM and %fat ($p < 0.05$) for all groups, except for obese subjects. WC was significantly correlated with both BFM and %fat in the normal-to-overweight group and BFM in the obese group ($p < 0.05$).

All anthropometrics (BMI, BW, WC) and body composition (%fat, BFM, LBM) of all subjects were positively correlated with bone parameters (BMD, BMC, Z-score) at both the whole-body and lumbar spine, but they were strongly negatively associated with %bone ($p < 0.05$) (Table 3). Table 4 shows that, for the underweight group, LBM was significantly positively correlated with all bone parameters ($p < 0.05$) except lumbar spine Z-score. BMI was significantly positively correlated with whole-body BMC ($p < 0.05$), and BW was significantly positively correlated with BMC of both whole-body and lumbar

Table 4 Correlation between anthropometrics, body composition, and bone parameters at whole-body and lumbar spine (L1-L4) of underweight, normal-to-overweight, and obese subject groups

Anthropometrics	Correlation Coefficient					
	Whole-body			Lumbar spine		
	BMD	BMC	Z-score	BMD	BMC	Z-score
Underweight (BMI < 18.5) ($n = 53$)						
BMI (kg/m^2)	0.11	0.34*	0.17	0.15	0.25	0.22
BW (kg)	0.20	0.73*	0.23	0.14	0.38*	0.19
WC (cm)	0.02	0.05	−0.03	−0.17	−0.10	−0.16
%Lean (%)	0.15	−0.10	0.12	0.01	0.11	−0.03
%Fat (%)	−0.19	0.07	−0.17	−0.05	−0.13	−0.01
BFM (g/cm^2)	−0.11	0.19	−0.09	0.01	−0.05	0.05
LBM (g/cm^2)	0.50*	0.44*	0.47*	0.29*	0.48*	0.26
Normal-to-overweight ($18.5 \leq$ BMI < 25) ($n = 52$)						
BMI (kg/m^2)	0.25	0.30*	0.22	0.13	0.08	0.14
BW (kg)	0.37*	0.73*	0.37*	0.24	0.38*	0.28*
WC (cm)	0.21	0.45*	0.24	0.06	0.15	0.10
%Lean (%)	0.00	−0.27	0.05	0.03	0.08	−0.00
%Fat (%)	−0.05	0.21	−0.08	−0.03	−0.10	0.00
BFM (g/cm^2)	0.09	0.37*	0.06	0.05	0.03	0.09
LBM (g/cm^2)	0.40*	0.26	0.45*	0.26	0.41*	0.26
Obese (BMI ≥ 25 kg/m^2) ($n = 30$)						
BMI (kg/m^2)	0.04	0.24	−0.03	0.12	0.19	0.07
BW (kg)	0.27	0.66*	0.21	0.46*	0.54*	0.42*
WC (cm)	−0.06	0.13	−0.12	0.22	0.28	0.18
%Lean (%)	0.01	−0.24	−0.02	0.09	0.07	0.05
%Fat (%)	−0.06	0.20	−0.04	−0.12	−0.08	−0.09
BFM (g/cm^2)	0.11	0.38*	0.10	0.02	0.10	0.03
LBM (g/cm^2)	0.22	0.13	0.17	0.25	0.31	0.20

BFM Body fat mass; *BMC* Bone mineral content; *BMD* Bone mineral density; *BMI* Body mass index; *BW* Body weight; *LBM* Lean body mass; *WC* Waist circumference; *%Fat* Body fat percentage; *%Lean* Lean percentage

Significance level at 0.05 * $p < 0.05$

Table 5 Correlation between anthropometrics, body composition, and bone parameters at whole-body and lumbar spine (L1-L4) of female adolescent subjects with non-obesity (BMI < 25) (*n* = 105) and obesity (BMI ≥ 25) (*n* = 30)

Anthropometrics	Correlation Coefficient											
	Whole-body						Lumbar spine					
	BMD		BMC		Z-score		BMD		BMC		Z-score	
	BMI < 25	BMI ≥ 25	BMI < 25	BMI ≥ 25	BMI < 25	BMI ≥ 25	BMI < 25	BMI ≥ 25	BMI < 25	BMI ≥ 25	BMI < 25	BMI ≥ 25
BMI (kg/m^2)	0.56*	0.04	0.64*	0.24	0.55*	−0.03	0.45*	0.12	0.33*	0.19	0.47*	0.07
BW (kg)	0.57*	0.27	0.83*	0.66*	0.57*	0.21	0.44*	0.46*	0.46*	0.54*	0.46*	0.42*
WC (cm)	0.40*	−0.06	0.49*	0.13	0.38*	−0.12	0.22*	0.22	0.19	0.28	0.24*	0.18
%Lean (%)	−0.27*	0.01	−0.45*	−0.24	−0.26*	−0.02	−0.23*	0.09	−0.08	0.07	−0.25*	0.05
%Fat (%)	0.23*	−0.06	0.42*	0.20	0.22*	−0.04	0.21*	−0.12	0.07	−0.08	0.23*	−0.09
BFM (g/cm^2)	0.36*	0.11	0.55*	0.38*	0.35*	0.10	0.30*	0.02	0.18	0.10	0.33*	0.03
LBM (g/cm^2)	0.45*	0.22	0.40*	0.13	0.45*	0.17	0.30*	0.25	0.47*	0.31	0.29*	0.20

BFM Body fat mass; *BMC* Bone mineral content; *BMD* Bone mineral density; *BMI* Body mass index; *BW* Body weight; *LBM* Lean body mass; *WC* Waist circumference; *%Fat* Body fat percentage; *%Lean* Lean percentage

Significance level at 0.05 * $p < 0.05$

spine ($p < 0.05$). For the normal-to-overweight group, BW was significantly positively correlated with all bone parameters ($p < 0.05$) except lumbar spine BMD. BMI, WC, and BFM were significantly associated with whole-body BMC ($p < 0.05$). LBM was significantly positively correlated with lumbar spine BMC ($p < 0.05$). For the obese group, BW was significantly positively correlated with all bone parameters at the lumbar spine and whole-body BMC ($p < 0.05$), while BFM was correlated with whole-body BMC ($p < 0.05$).

Furthermore, when comparing between non-obese and obese subjects using BMI of 25 kg/m^2 as a cut-off point (Table 5), the data clearly shows that BMI, BW, and LBM were strongly positively correlated with all bone parameters for both the whole-body and the lumbar spine in subjects with BMI < 25 while in subjects with BMI ≥ 25, only BW was positively correlated with BMC of whole-body, and BMD and BMC of lumbar spine ($p < 0.05$). Moreover, for obese subjects, there was a positive correlation between BFM and whole-body BMC ($p < 0.05$).

Discussion

This study aimed to determine whether anthropometric indices indicating obesity and body composition correlated with bone parameters at the whole-body and lumbar spine (L1-L4) of 135 Thai female adolescents (mean age 16.10 ± 0.49 y). Data for underweight (BMI < 18.5), normal-to-overweight (18.5 ≤ BMI < 25), and obese (BMI ≥ 25) subjects as well as non-obese (BMI < 25) and obese (BMI ≥ 25) subjects were compared. The main findings of this study showed that all anthropometric indices (BMI, BW, and WC) and body composition parameters (%fat, BFM, and LBM) were positively associated with bone parameters in all subject groups. The obese subjects had high BMD, BMC, and whole-body Z-score values, and had greater lumbar spine BMC compared to non-obese subjects.

Evidence revealed that associations between lean and fat mass and bone density are different between overweight and obesity group, and low or normal weight group [6, 16, 24], and overweight and obesity during childhood and adolescence are associated with increased vertebral bone density and whole-body bone mass [2, 7]. In this study, the key findings indicate that obese subjects with BMI ≥ 25 had high BMD, BMC, and Z-score values of the whole-body, and high lumbar spine BMC compared to non-obese subjects with BMI < 25. Moreover, results demonstrated that BMI and BW, not WC, were positively associated with BFM for all groups, particularly for the obese subjects. These suggest that BMI and BW are possibly better indices for predicting amount of excess fat than WC in adolescent girls and this supports the previous reports; BMI is highly correlated with adiposity and %fat increase, along with BMI and BFM is one of the most important indices of obesity [4, 5].

The relationship between lean mass, fat mass, and bone mass has been a controversial issue. In this study, it was found that all parameters of body composition except %lean were positively correlated with bone parameters for all subjects, but this result was different when subjects were grouped by BMI. Particularly in the underweight subjects, LBM had strong positive correlations with BMD and BMC at the whole-body and lumbar spine. However, this result does not confirm previous evidence indicating a close relationship between LBM and bone development during puberty [25, 26] as this association was not found in subjects with BMI > 18.5. It is possible that an association between LBM and bone mass was not demonstrated in high BMI subjects whose body mass is composed of more fat mass than lean mass because lean mass is defined as total BW less fat mass and BMC.

As concluded above, BW was a positive determinant of BMC in all subject groups, particularly in subjects with BMI ≥ 25, and had positive associations with all bone parameters at the lumbar spine. Moreover, BFM was correlated with whole-body BMC of obese subjects. This finding can be explained by the fact that BW is composed mainly of lean mass and fat mass, and greater BW or obesity offers increased mechanical loading on the bones, stimulating bone formation and increasing BMD for a site-specific bone adaptation response at the lumbar spine [27, 28]. Moreover, it is consistent with a previous report that overweight girls (BMI ≥ 25) had heavier, larger, and denser bones than control subjects (BMI < 25), meaning that the bones of overweight girls adapt to increased BW [7]. A new theory has emerged from the finding that weight and BMI are positively correlated with BMD, but large population-based studies have not verified or confirmed a positive correlation between bone mass and BMI [29]. In addition, the results also showed a positive correlation between BMI and whole-body BMC only in subjects with BMI < 25, on the other hand, in subjects with BMI ≥ 18.5, BFM has been positively correlated with whole-body BMC. Both positive and negative relationships between body fat and bone mass have been found; some studies have found excess weight is associated with lower bone mass [12, 30] whereas others have revealed a positive correlation between fat mass (%fat) and bone accretion [31, 32].

Conclusions

This study revealed that BMI and BW may be better indices than WC for predicting amount of excess fat. There were significant positive correlations between BW and BMC at both sites in all groups of adolescent subjects. Particularly in obese subjects, BW was positively associated with all bone parameters at the lumbar spine (L1-L4), and BFM was correlated with whole-body BMC. These findings suggest that BW can be used as a determinant of bone parameters in Thai female adolescent subjects.

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Contributions RK carried out design of the project, and was responsible for acquisition, analysis and data interpretation. She drafted and critically revised the manuscript. CP participated in analysis and data interpretation, drafted and critically revised the manuscript. Both the authors approved the final version of the manuscript. Assoc Prof. Wibool Ridthitid, Faculty of Medicine, Siam University, Bangkok, Thailand and Asst Prof Phanchai Rattanasuwan, School of Medicine, Walailak University, Thailand will act as guarantor for the paper.

Compliance with Ethical Standards

Conflict of Interest None.

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References

1. Gjesdal CG, Halse JI, Eide GE, Brun JG, Tell GS. Impact of lean mass and fat mass on bone mineral density: the Hordaland health study. Maturitas. 2008;59:191–200.
2. Leonard MB, Shults J, Wilson BA, Tershakovec AM, Zemel BS. Obesity during childhood and adolescence augments bone mass and bone dimensions. Am J Clin Nutr. 2004;80:514–23.
3. Gettys FK, Jackson JB, Frick SL. Obesity in pediatric orthopaedics. Orthop Clin N Am. 2011;42:95–105, vii.
4. Güngör NK. Overweight and obesity in children and adolescents. J Clin Res Pediatr Endocrinol. 2014;6:129–43.
5. Jeddi M, Dabbaghmanesh MH, Ranjbar Omrani G, Ayatollahi SM, Bagheri Z, Bakhshayeshkaram M. Body composition reference percentiles of healthy Iranian children and adolescents in southern Iran. Arch Iran Med. 2014;17:661–9.
6. Blanco E, Reyes M, Burrows RA, Martinez SM, Gahagan S. Low bone mineral density in a cohort of normal, overweight and obese Chilean adolescents. J Clin Nurs. 2011;20:3577–9.
7. El Hage R, Jacob C, Moussa E, Benhamou CL, Jaffré C. Total body, lumbar spine and hip bone mineral density in overweight adolescent girls: decreased or increased? J Bone Miner Metab. 2009;27:629–33.
8. Yang S, Shen X. Association and relative importance of multiple obesity measures with bone mineral density: the National Health and Nutrition Examination Survey 2005-2006. Arch Osteoporos. 2015;10:14.
9. Zhao LJ, Jiang H, Papasian CJ, et al. Correlation of obesity and osteoporosis: effect of fat mass on the determination of osteoporosis. J Bone Miner Res. 2008;23:17–29.
10. Rocher E, Chappard C, Jaffre C, Benhamou CL, Courteix D. Bone mineral density in prepubertal obese and control children: relation to body weight, lean mass, and fat mass. J Bone Miner Metab. 2008;26:73–8.
11. El Badri D, Rostom S, Bouaddi I, et al. Effect of body composition on bone mineral density in Moroccan patients with juvenile idiopathic arthritis. Pan Afr Med J. 2014;17:115.
12. Mosca LN, Goldberg TB, da Silva VN, et al. Excess body fat negatively affects bone mass in adolescents. Nutrition. 2014;30:847–52.
13. Zhang P, Peterson M, Su GL, Wang SC. Visceral adiposity is negatively associated with bone density and muscle attenuation. Am J Clin Nutr. 2015;101:337–43.
14. Muniz LC, Menezes AM, Assuncao MC, et al. Body mass index at 11 years and bone mass at age 18: path analysis within the 1993 Pelotas (Brazil) birth cohort study. BMC Musculoskelet Disord. 2015;16:71.
15. Maisnam I, Dutta D, Mukhopadhyay S, Chowdhury S. Lean mass is the strongest predictor of bone mineral content in type-2 diabetes and normal individuals: an eastern India perspective. J Diabetes Metab Disord. 2014;13:90.

16. Ho-Pham LT, Nguyen UD, Nguyen TV. Association between lean mass, fat mass, and bone mineral density: a meta-analysis. J Clin Endocrinol Metab. 2014;99:30–8.
17. Bachrach LK. Acquisition of optimal bone mass in childhood and adolescence. Trends Endocrinol Metab. 2001;12:22–8.
18. Vicente-Rodriguez G, Ortega FB, Rey-Lopez JP, et al. Extracurricular physical activity participation modifies the association between high TV watching and low bone mass. Bone. 2009;45:925–30.
19. Khwanchuea R, Thanapop S, Samuhasaneeto S, Chartwainhgam S, Mukem S. Waist circumference: a key determinant of bone mass in university students. Walailak J Sci Tech. 2013;10:665–76.
20. El Hage R, Jacob C, Moussa E, et al. Influence of the weight status on bone mineral content and bone mineral density in a group of Lebanese adolescent girls. Joint Bone Spine. 2009;76:680–4.
21. WHO Expert Consultation. Appropriate body-mass index for Asian populations and its implications for policy and intervention strategies. Lancet. 2004;363:157–63.
22. Nalda E, Mahadea KK, Dematteï C, Kotzki PO, Pouget JP, Boudousq V. Assessment of the Stratos, a new pencil-beam bone densitometer: dosimetry, precision, and cross calibration. J Clin Densitom. 2011;14:395–406.
23. Binkovitz LA, Henwood MJ. Pediatric DXA: technique and interpretation. Pediatr Radiol. 2007;37:21–31.
24. Jeon HC, Lee K, Kim J, Park TJ, Kang DW, Park DJ. The relationship between body fat percent and bone mineral density in Korean adolescents: the Fifth Korea National Health and Nutrition Examination Survey (KNHANES V-1), 2010. Korean J Fam Med. 2014;35:303–8.
25. Sudhagoni RG, Wey HE, Djira GD, Specker BL. Longitudinal effects of fat and lean mass on bone accrual in infants. Bone. 2012;50:638–42.
26. Zemel B. Bone mineral accretion and its relationship to growth, sexual maturation and body composition during childhood and adolescence. World Rev Nutr Diet. 2013;106:39–45.
27. Kuruvilla SJ, Fox SD, Cullen DM, Akhter MP. Site specific bone adaptation response to mechanical loading. J Musculoskelet Neuronal Interact. 2008;8:71–8.
28. Zernicke R, MacKay C, Lorincz C. Mechanisms of bone remodeling during weight-bearing exercise. Appl Physiol Nutr Metab. 2006;31:655–60.
29. Sharma S, Tandon VR, Mahajan S, Mahajan V, Mahajan A. Obesity: friend or foe for osteoporosis. J Midlife Health. 2014;5:6–9.
30. Janicka A, Wren TA, Sanchez MM, et al. Fat mass is not beneficial to bone in adolescents and young adults. J Clin Endocrinol Metab. 2007;92:143–7.
31. Clark EM, Ness AR, Tobias JH. Adipose tissue stimulates bone growth in prepubertal children. J Clin Endocrinol Metab. 2006;91:2534–41.
32. Heidemann M, Holst R, Schou AJ, et al. The influence of anthropometry and body composition on children's bone health: the childhood health, activity and motor performance school (the CHAMPS) study. Denmark Calcif Tissue Int. 2015;96:97–104.