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The Association Between Adiposity and Bone Mineral Density in Chinese Children

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Abstract ***Purpose:*** To investigate the association between bone mineral density (BMD) and anthropometric and body compositional characteristics in obese Chinese children. ***Methods:*** 100 obese children (73 boys and 27 girls) were recruited (age range 9 to 17 years, median BMI 31 kg/m^2). All children underwent dual-energy X-ray absorptiometry to measure body composition and BMD and bone mineral apparent density (BMAD) of the whole body, lumbar vertebrae and femoral neck. ***Findings:*** Percentage total body fat and BMI were useful predictors for BMD in boys. Increasing % ideal BMI was associated with increases in all BMD values ($P \leq 0.001$) except femoral neck BMAD *z* score ($P=0.113$). Increasing percentage body fat was associated with decreases in all BMD values ($P \leq 0.002$), except for femoral neck BMAD *z* score ($P=0.058$). Data for girls were insufficient for multivariate analyses. ***Conclusion:*** Increasing adiposity is associated with decreased BMD and BMAD in obese boys. Conversely, in this group, increasing body size, when corrected for % body fat was associated with increasing BMD and BMAD.

Key words Adiposity; Bone mineral density; Childhood obesity; Dual-energy X-ray absorptiometry

Introduction

Apart from the well-known complications of childhood obesity such as worsening of cardiovascular risk factors,[1,2] psychological morbidity,[3] and increased risk of developing type 2 diabetes mellitus,[4] orthopaedic problems such as forearm fractures have been shown to be more common in obese children.[5,6] Previous studies have attributed such skeletal problems to biomechanical factors[5,7] and decreased bone mineral content (BMC) relative to weight in obese children.[8]

There is conflicting evidence in the literature regarding the effect of childhood obesity on BMD. Some studies report a relative decrease in BMD in obese children,[8,9] while a recent study shows a mild increase.[10] Part of the problem with the lack of agreement between studies is the inaccuracy of using measurements generated by dual-energy X-ray absorptiometry (DXA) as estimates of BMD in children. While true density is a three-dimensional, "volumetric" parameter, density data generated by DXA are calculated by dividing the bone mineral content (BMC, usually measured in grams) by the measured bone area (Ap, usually measured in squared centimetres).[11,12] DXA density data are therefore two-dimensional, "areal" measurements and can lead to underestimating BMD in physically small subjects.[12] Failure to adjust the areal measurements to more closely reflect volumetric BMD in paediatric studies therefore leads to systematic bias. This is important, as unlike the tendency of DXA to overestimate fat free mass and underestimate fat mass shown in a recent study,[13] the

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degree of overestimation of BMD, although comparatively smaller, increases non-linearly with increasing body size. Using bone mineral apparent density (BMAD), a calculated parameter based on mathematical assumptions and DXA measurements, some authors have been able to estimate volumetric BMD at certain regions such as the lumbar spine and femoral neck.[11] As the femoral neck and lumbar spine do not conform exactly to the geometric assumptions made to calculate BMAD some systematic bias is still inevitable. Nevertheless use of BMAD can still help minimise the degree of change in systematic bias associated with the wide range of body sizes of paediatric subjects.

It is possible that if childhood obesity has an adverse effect on the density of the developing bony skeleton, the final adult peak bone mass achieved may be affected. Low peak bone mass in adults who were obese children may ultimately lead to increased risk of fractures and osteoporosis. In order to better understand the effects of childhood obesity on BMD, we designed the current study to assess the associations between anthropometric and body compositional characteristics of a cohort of obese Chinese children and their BMD. In order to avoid variable systematic errors that may occur with the use of areal BMD values, conversion to BMAD was performed.

Methods

All patients (≥85th percentile for BMI) presenting at our Obesity and Lipid disorder clinic for assessment and advice on healthy living were eligible, except those with diabetes mellitus, obesity secondary to an organic condition, and those children who suffered from skeletal abnormalities or congenital defects. A total of 100 consecutive obese subjects were invited and agreed to participate. All were ethnic Chinese and aged 9 to 17 years. There were 73 boys and 27 girls. Ethics approval was obtained from the Joint The Chinese University of Hong Kong-New Territories East Cluster Clinical Research Ethics Committee. Informed consent from the subjects and their parents was obtained at the beginning of the assessment.

Anthropometric Measurements

During the visit for assessment, each subject underwent a complete physical examination. Weight and standing height were measured with a calibrated weighing scale and stadiometer by standard methods.[14] The waist circumference was measured with a non-stretchable tape measure. The waist circumference was measured halfway between the upper border of the iliac crest and the lower border of the rib cage. The body mass index (BMI) was calculated as weight (kg) divided by height (m) squared. Percentage ideal BMI (% ideal BMI) was derived by dividing the actual BMI by the local population median BMI expected for the subject's age and gender.[15]

Dual-energy X-ray Absorptiometry (DXA)

BMD and body adiposity measurements were determined with a total body scanner (QDR4500A, software version V8.26a:3; Hologic, Waltham, MA, USA) using array mode. This equipment used a switched pulse stable dual-energy X-ray operating at 100 and 140 kV. An automatic internal reference system with a calibration wheel achieved the bone density measurement. This is a different machine from that used to obtain the normative data used in this study.[16] In view of resource limitation we could not purchase the same device and software to perform the study or obtain normative data with our own device. The equipment determined whole body as well as regional measurements of bone mass, lean mass, and fat mass. BMD was specifically measured at the femoral neck and the lumbar spine. Total fat mass was expressed in kg and as a percentage of body mass. These were calculated by integrating the measurements for the whole body and different automatic default regions such as arms, trunk, and legs. The trunk region consisted of the area bordered by a horizontal line below the chin, vertical borders lateral to the ribs, and oblique lines passing through the femoral necks. The leg region included all tissue below these oblique lines. The total radiation dose per scan was <1 mSv. Low density software was used to analyse the vertebral bodies as the standard software could not map these out adequately in many instances.

As with other scanners, the BMD measurements obtained were areal values (BMC/Ap). BMAD values were calculated using formulae derived by Katzman et al[11]: (i) L2-4 lumbar vertebral BMAD = $BMC/Ap^{1.5}$ (ii) Femoral neck BMAD = BMC/Ap^2. With a paucity of local population norms for BMD and BMAD, these values were converted into *z* scores specific for age, gender and ethnicity based on Bachrach et al's data.[16]

Statistical Analysis

As the subject characteristics were not Normally distributed, Mann-Whitney U test was performed in the univariate analyses (Tables 1 to 3) to detect distributional differences between subjects with positive and negative BMD *z* scores.

Multivariate linear regression analyses were performed on the data. The data from both male and female subjects were analysed separately. Subject characteristics such as anthropometric parameters, and percentage body fat as measured with DXA were chosen from the univariate analyses ($P<0.1$) to fit as predictors into the regression models. The models were further refined using a backward selection method. Collinearity between predictors was excluded. A *P*-value <0.05 was defined as significant. SPSS 11.5 for Windows (SPSS Inc., Chicago, Illinois) was used for the statistical analyses.

Results

The subject characteristics are summarised in Table 1. Girls with positive *z* scores for BMD and BMAD were younger than those with negative *z* scores (Table 2). This trend was statistically significant for lumbar BMD and BMAD, but not for total hip, femoral neck, and whole body BMD results. For boys (Table 3), this trend was reversed. Boys with positive *z* scores for BMD were older than boys with negative *z* scores. This trend was statistically significant for both lumbar and femoral neck BMAD, but not BMD. Boys with positive *z* scores for BMD were generally heavier and taller than those with negative *z* scores. This was statistically significant for lumbar BMD and BMAD, femoral neck BMD (for weight), and whole body BMD (for height). The % ideal BMI was greater in boys with positive *z* scores for lumbar BMD, femoral neck BMD and BMAD, total hip BMD, and whole body BMD. The difference was statistically significant for lumbar and femoral BMD. The differences in these parameters for girls were inconsistent and were not statistically significant (except for height and whole body BMD).

Of the various subject characteristics studied percentage total body fat as measured by DXA (% fat DXA) and % ideal BMI were found to be useful predictors for BMD and BMAD in boys (Table 4). Increasing % ideal BMI was associated with increases in all BMD values ($P\leq0.001$) except femoral neck BMAD *z* score (not significant). In contrast, increasing % fat DXA was associated with decreases in all BMD/BMAD *z* scores ($P\leq0.002$), except for femoral neck BMAD *z* score, which was not statistically significant ($P=0.058$). In girls, none of these subject characteristics were significantly associated with BMD and therefore did not serve as useful predictors in multiple linear regression models (results not shown).

Discussion

Similar to previous studies in children, our study shows that age, gender, body size and body composition are important predictors of bone mineral density.[11,17,18] There is good evidence from previous studies that obese children tend to exhibit advanced bone age and undergo puberty earlier than normal weight children.[10] Furthermore bone mineral accretion has been shown in longitudinal studies to be substantially influenced by pubertal development.[16,18] It may therefore be expected that obese children should have relatively increased BMD compared with non-obese children. There have even been studies which suggest that obese patients have relatively increased bone mineral density.[19]

Our data, however, do not show this to be the case, and are in agreement with previous studies showing an association between increasing obesity and decreasing BMD.[8,9] Our regression models included BMI and % fat DXA as predictors. These models therefore suggest that for a given BMI, boys with increasing percentage of body fat have decreased BMD values. This association was shown to be statistically significant. The association between % fat DXA and BMD values remained statistically significant even after converting BMD to BMAD. Although BMI and % fat DXA are associated, the correlation coefficient is only 0.25 in boys. Furthermore these two predictors are associated with BMD differently according to the multivariate regression models. These results suggest that BMI and % fat DXA measure different characteristics of the individual. BMI is a measure of the physical dimensions of an individual while the % fat DXA more closely reflects adiposity. Individuals with similar BMIs may have widely differing adiposity. Our results suggest that increasing physical size and increasing adiposity have opposite associations with BMD. These effects may contribute to varying degrees at different regions of the skeletal structure. This may explain why the associations were shown to be statistically significant at the lumbar region, but not at the femoral neck. We speculate that non-weight bearing bony regions of an obese child such as the radius would not "benefit" from the increased stress forces of the increased physical dimensions, and therefore be adversely affected by the adiposity to a greater degree than weight bearing bony regions. Further data from different regions of the body would therefore provide us with further insight into such interactions.

The mechanism linking increasing adiposity and decreasing BMD is unclear. It has been shown that in

Table 1 Summary of distributions of subject characteristics and bone mineral density values

Gender	Female			Male		
	Median	25th Percentile	75th Percentile	Median	25th Percentile	75th Percentile
Subject characteristics						
Age, years	13.29	12.07	14.73	12.55	10.82	14.27
Weight, kg	75.30	67.00	85.80	76.20	61.75	90.20
Height, cm	156.00	151.00	162.00	155.50	146.50	165.00
BMI, kg/m^2	31.01	28.79	33.94	30.75	28.37	34.19
% ideal BMI	167.11	152.78	179.82	172.13	154.79	191.00
% fat DXA	39.10	37.50	41.40	38.90	34.70	42.15
Waist circumference, cm	90.50	86.13	95.63	94.00	85.38	100.00
Bone mineral density values						
Lumbar BMD z score	-0.48	-1.11	0.21	-0.87	-1.48	0.01
Lumbar BMAD z score	-1.08	-2.04	-0.44	-1.68	-2.52	-0.68
Total hip BMD z score	0.82	0.25	1.53	0.43	-0.36	1.16
Femoral neck BMD z score	1.11	0.33	1.55	0.20	-0.33	1.04
Femoral neck BMAD z score	0.79	-0.04	1.63	0.15	-0.40	0.78
Whole body BMD z score	0.16	-0.44	0.96	-0.25	-1.01	0.57

BMAD=bone mineral apparent density, BMD=bone mineral density, BMI=body mass index, DXA=dual-energy X-ray absorptiometry, % ideal BMI=percentage of ideal body mass index, % fat DXA=percentage body fat composition by DXA.

Table 2 Univariate analyses for female subjects comparing characteristic distribution between subjects with positive and negative bone mineral density *z* scores

Characteristics	Lumbar BMD						P-value
	negative *z* score (N = 19)			positive *z* score (N = 8)			
	Median	25th Percentile	75th Percentile	Median	25th Percentile	75th Percentile	
Age, years	13.90	12.40	15.58	12.15	11.57	13.16	0.02
Weight, kg	78.90	67.00	87.60	73.50	67.20	76.25	0.46
Height, cm	156.00	149.50	162.00	157.50	152.00	162.00	0.77
BMI, kg/m^2	31.75	28.93	34.32	29.91	27.21	32.30	0.43
% ideal BMI	167.11	152.78	175.85	166.29	148.76	180.99	0.96
% fat DXA	39.10	37.50	41.60	38.95	36.85	41.35	0.71
Waist circumference, cm	90.75	85.88	97.75	89.50	84.88	94.13	0.69

	Lumbar BMD						
	negative *z* score (N = 22)			positive *z* score (N = 5)			
	Median	25th Percentile	75th Percentile	Median	25th Percentile	75th Percentile	
Age, years	13.56	12.32	15.51	12.00	11.16	12.83	0.03
Weight, kg	75.90	65.23	86.25	73.80	73.05	87.15	0.90
Height, cm	157.50	150.63	162.25	156.00	151.00	162.00	0.88
BMI, kg/m^2	30.90	28.35	34.03	32.10	29.91	34.33	0.38
% ideal BMI	160.74	147.70	174.94	179.82	165.14	189.84	0.15
% fat DXA	38.85	37.45	41.15	41.20	38.40	43.35	0.29
Waist circumference, cm	90.00	85.75	95.25	93.00	91.00		0.28

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Table 2 Univariate analyses for female subjects comparing characteristic distribution between subjects with positive and negative bone mineral density *z* scores (cont'd)

	Femoral neck BMD						**P-value**
	negative *z* score (N = 4)			**positive *z* score (N = 23)**			
	Median	**25th Percentile**	**75th Percentile**	**Median**	**25th Percentile**	**75th Percentile**	
Age, years	13.26	10.08	14.37	12.99	12.05	14.92	0.78
Weight, kg	73.40	49.30	81.68	75.10	67.85	89.78	0.52
Height, cm	147.00	130.75	159.50	157.50	151.00	163.00	0.18
BMI, kg/m^2	29.82	26.84	38.91	30.90	28.90	34.03	0.62
% ideal BMI	164.31	151.63	199.82	169.21	151.03	180.21	0.94
% fat DXA	40.90	39.83	43.25	38.85	37.45	41.45	0.23
Waist circumference, cm	89.50	78.38	95.00	91.00	86.00	97.50	0.57
	Femoral neck BMD						
	negative *z* score (N = 7)			**positive *z* score (N = 20)**			
	Median	**25th Percentile**	**75th Percentile**	**Median**	**25th Percentile**	**75th Percentile**	
Age, years	14.14	13.53	14.73	12.57	12.00	13.59	0.17
Weight, kg	82.30	78.90	87.60	73.20	65.30	76.50	0.17
Height, cm	159.00	139.00	167.50	156.00	151.00	160.00	0.79
BMI, kg/m^2	33.70	28.93	34.32	29.96	28.51	32.37	0.37
% ideal BMI	173.35	161.52	175.85	159.96	148.34	181.38	0.47
% fat DXA	39.80	39.00	41.00	38.70	37.50	41.60	0.62
Waist circumference, cm	92.00	86.00	96.00	90.25	85.75	96.38	0.79
	Total hip BMD						
	negative *z* score (N = 5)			**positive *z* score (N = 22)**			
	Median	**25th Percentile**	**75th Percentile**	**Median**	**25th Percentile**	**75th Percentile**	
Age, years	13.53	11.05	15.91	12.70	12.03	14.44	0.58
Weight, kg	75.30	55.20	81.05	74.90	67.00	91.95	0.58
Height, cm	155.00	133.50	160.50	156.00	151.00	163.00	0.36
BMI, kg/m^2	29.41	27.19	36.53	31.01	28.86	34.13	0.49
% ideal BMI	161.52	144.88	188.92	171.09	154.28	180.60	0.54
% fat DXA	41.00	40.15	42.80	38.70	37.40	41.30	0.11
Waist circumference, cm	92.00	81.25	94.25	90.50	85.88	98.88	0.77
	Whole body BMD						
	negative *z* score (N = 13)			**positive *z* score (N = 14)**			
	Median	**25th Percentile**	**75th Percentile**	**Median**	**25th Percentile**	**75th Percentile**	
Age, years	13.29	12.08	14.40	13.03	11.95	15.58	0.88
Weight, kg	72.60	61.80	81.05	76.00	73.13	96.93	0.10
Height, cm	153.00	143.00	159.50	159.50	154.75	163.50	0.03
BMI, kg/m^2	31.01	27.28	33.82	30.96	28.90	34.82	0.56
% ideal BMI	167.11	147.07	175.24	166.29	155.63	185.61	0.53
% fat DXA	39.10	37.90	41.30	39.25	36.03	42.38	0.66
Waist circumference, cm	89.50	85.75	93.50	91.00	86.50	106.50	0.28

BMAD=bone mineral apparent density, BMD=bone mineral density, BMI=body mass index, DXA=dual-energy X-ray absorptiometry, % ideal BMI=percentage of ideal body mass index, % fat DXA=percentage body fat composition by DXA.

Table 3 Univariate analyses for male subjects comparing characteristic distribution between subjects with positive and negative bone mineral density *z* scores

Characteristics	Lumbar BMD						P-value
	negative *z* score (N = 54)			positive *z* score (N = 19)			
	Median	25th Percentile	75th Percentile	Median	25th Percentile	75th Percentile	
Age, years	12.30	11.36	13.86	13.91	10.37	15.39	0.42
Weight, kg	70.10	57.80	85.50	89.35	73.63	121.93	<0.01
Height, cm	155.00	145.00	163.00	164.50	149.75	177.25	0.03
BMI, kg/m^2	29.48	26.97	33.06	33.95	30.88	37.55	<0.01
% ideal BMI	167.96	151.95	185.90	191.16	171.42	209.27	<0.01
% fat DXA	39.10	34.40	42.10	38.70	36.60	42.80	0.72
Waist circumference, cm	91.75	83.13	99.00	99.50	92.00	106.05	0.01
	Lumbar BMD						
	negative *z* score (N = 64)			**positive *z* score (N = 9)**			
	Median	**25th Percentile**	**75th Percentile**	**Median**	**25th Percentile**	**75th Percentile**	
Age, years	12.17	10.79	13.85	15.18	13.91	15.88	0.01
Weight, kg	73.55	58.58	86.03	95.60	83.30	126.10	<0.01
Height, cm	153.50	145.00	162.50	176.00	164.50	177.50	<0.01
BMI, kg/m^2	30.34	27.78	33.91	32.93	30.80	39.16	0.04
% ideal BMI	172.25	153.64	190.97	171.78	159.14	203.59	0.41
% fat DXA	39.35	35.43	42.20	37.20	30.55	38.30	0.10
Waist circumference, cm	93.00	85.00	100.00	100.00	91.50	108.25	0.05
	Femoral neck BMD						
	negative *z* score (N = 34)			**positive *z* score (N = 39)**			
	Median	**25th Percentile**	**75th Percentile**	**Median**	**25th Percentile**	**75th Percentile**	
Age, years	12.58	11.41	14.11	12.20	10.79	14.39	0.87
Weight, kg	67.25	56.48	84.53	80.20	69.50	92.90	0.01
Height, cm	154.50	144.50	164.25	156.00	149.00	167.00	0.17
BMI, kg/m^2	29.42	26.23	32.37	32.93	29.46	34.99	<0.01
% ideal BMI	157.69	147.71	182.20	184.96	166.07	200.77	<0.01
% fat DXA	39.20	34.38	42.33	38.50	34.80	41.70	0.93
Waist circumference, cm	91.00	82.00	96.50	97.00	89.25	101.50	0.06
	Femoral neck BMD						
	negative *z* score (N = 30)			**positive *z* score (N = 43)**			
	Median	**25th Percentile**	**75th Percentile**	**Median**	**25th Percentile**	**75th Percentile**	
Age, years	11.69	10.44	13.18	13.34	11.36	15.18	0.01
Weight, kg	70.75	56.78	85.05	78.40	65.20	94.70	0.06
Height, cm	152.00	146.75	161.50	157.50	145.00	174.00	0.10
BMI, kg/m^2	29.43	26.23	33.73	32.05	29.13	34.38	0.09
% ideal BMI	167.02	151.41	189.09	174.49	157.53	191.02	0.42
% fat DXA	40.60	36.68	43.10	38.10	33.90	41.20	0.03
Waist circumference, cm	91.50	84.25	100.00	94.00	86.90	101.00	0.35

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Table 3 Univariate analyses for male subjects comparing characteristic distribution between subjects with positive and negative bone mineral density *z* scores (cont'd)

	Total hip BMD						**P-value**
	negative *z* score (N = 24)			**positive *z* score (N = 49)**			
	Median	**25th Percentile**	**75th Percentile**	**Median**	**25th Percentile**	**75th Percentile**	
Age, years	12.86	11.69	14.11	12.19	10.39	14.41	0.22
Weight, kg	76.40	62.28	84.48	75.50	60.65	92.60	0.32
Height, cm	155.50	147.75	162.50	155.50	145.00	169.50	0.69
BMI, kg/m^2	29.69	27.27	33.58	30.89	28.68	34.46	0.26
% ideal BMI	165.36	148.11	185.15	174.49	157.25	199.64	0.08
% fat DXA	39.90	34.30	44.13	38.50	35.55	41.65	0.42
Waist circumference, cm	94.25	86.25	99.00	93.50	85.38	100.00	0.90
	Whole body BMD						
	negative *z* score (N = 43)			**positive *z* score (N = 30)**			
	Median	**25th Percentile**	**75th Percentile**	**Median**	**25th Percentile**	**75th Percentile**	
Age, years	12.30	10.80	13.86	12.93	10.77	15.20	0.57
Weight, kg	71.60	58.20	86.60	79.30	69.45	94.93	0.06
Height, cm	154.00	144.00	161.00	160.00	149.00	175.63	0.03
BMI, kg/m^2	30.19	26.97	34.00	31.47	29.12	34.52	0.21
% ideal BMI	170.97	146.87	190.98	172.25	159.47	199.60	0.24
% fat DXA	40.00	35.30	42.70	38.00	34.53	39.90	0.12
Waist circumference, cm	93.00	83.88	99.75	94.25	87.35	100.75	0.26

BMAD=bone mineral apparent density, BMD=bone mineral density, BMI=body mass index, DXA=dual-energy X-ray absorptiometry, % ideal BMI=percentage of ideal body mass index, % fat DXA=percentage body fat composition by DXA.

Table 4 Multivariate linear regression models for male subjects using body fat composition and body mass index as predictors and various bone mineral density estimates as outcomes

	% fat DXA				**% ideal BMI**				**R2**
	Coefficient	**95% CI**		**P-value**	**Coefficient**	**95% CI**		**P-value**	
		lower	**upper**			**lower**	**upper**		
Lumbar BMD *z* score	-0.103	-0.145	-0.061	<0.001	0.031	0.021	0.041	<0.001	0.344
Lumbar BMAD *z* score	-0.1	-0.15	-0.049	<0.001	0.022	0.009	0.034	0.001	0.177
Total hip BMD *z* score	-0.076	-0.125	-0.028	0.002	0.034	0.022	0.046	<0.001	0.293
Femoral neck BMD *z* score	-0.078	-0.126	-0.03	0.002	0.035	0.023	0.046	<0.001	0.315
Femoral neck BMAD *z* score	-0.065	-0.133	0.002	0.058	0.013	-0.003	0.03	0.113	0.028
Whole body BMD *z* score	-0.099	-0.142	-0.057	<0.001	0.023	0.013	0.034	<0.001	0.256

BMAD=bone mineral apparent density, BMD=bone mineral density, BMI=body mass index, DXA=dual-energy X-ray absorptiometry, % ideal BMI=percentage of ideal body mass index, % fat DXA=percentage body fat composition by DXA.

Chinese adolescents physical fitness was positively associated with vertebral BMD.[17] Further, obese children tend to lead more sedentary life-styles.[20] This may contribute to the adverse effects of obesity on BMD. In addition, children with greater body fat composition for a given BMI also have comparatively less muscle mass, leading to less active forces acting on the developing skeleton, adversely affecting BMD. Hormonal effects may also play a role. There is evidence in the literature that blood oestrogen levels are significantly associated with bone mass accretion in pubertal children.[21] Gender-related differences in pubertal development and hormonal profiles would therefore be expected. It is unclear whether the differences in associations between predictors and BMD between the sexes in multiple linear regression analyses were attributable to small number of female subjects in our study or pubertal or hormonal effects. A previous study[22] demonstrates that early sexual maturity is positively associated with obesity in girls, but negatively associated in boys. It is possible that the hormonal effects associated with this may partly explain our results.

This study has several limitations. As we recruited the subjects from a hospital-based clinic, the sample could not be as representative as a sample derived from the community. Furthermore, girls were underrepresented in this study, leading to difficulty in applying multiple linear regression models to the data. Therefore our conclusions can only apply to obese Chinese boys. As our study was cross-sectional in nature, we are unable to conclude whether the association between adiposity and BMD in obese Chinese boys was causal or not. A longitudinal study could help us evaluate the effects of weight-reduction or exercise regimes on the BMD of obese children and may allow us to explore the causal associations between these characteristics. The lack of formal pubertal staging of the subjects is another limitation of our study. Puberty is a major confounding factor and interpretation of our results should therefore be exercised with caution.

In conclusion, our study shows that increasing adiposity is associated with decreased BMD in boys even after the areal measurements are converted to volumetric estimates. This may have long term effects on an individual's peak bone mass and subsequent risk of developing osteoporosis or fractures. In view of the lack of female subjects, further study is required to adequately investigate these effects in girls.

References

1. Freedman DS, Serdula MK, Srinivasan SR, Berenson GS. Relation of circumferences and skinfold thicknesses to lipid and insulin concentrations in children and adolescents: the Bogalusa Heart Study. Am J Clin Nutr 1999;69:308-17.
2. Lindsay RS, Hanson RL, Roumain J, Ravussin E, Knowler WC, Tataranni PA. Body mass index as a measure of adiposity in children and adolescents: relationship to adiposity by dual energy x-ray absorptiometry and to cardiovascular risk factors. J Clin Endocrinol Metab 2001;86:4061-7.
3. Strauss RS. Childhood obesity and self-esteem. Pediatrics 2000; 105:e15.
4. Young TK, Dean HJ, Flett B, Wood-Steiman P. Childhood obesity in a population at high risk for type 2 diabetes. J Pediatr 2000; 136:365-9.
5. Davidson P, Goulding A, Chalmers D. Biomechanical analysis of arm fracture in obese boys. J Paediatr Child Health 2003;39: 657-64.
6. Goulding A, Jones IE, Taylor RW, Williams SM, Manning PJ. Bone mineral density and body composition in boys with distal forearm fractures: a dual-energy X-ray absorptiometry study. J Pediatr 2001;139:509-15.
7. Goulding A, Jones IE, Taylor RW, Piggot JM, Taylor D. Dynamic and static tests of balance and postural sway in boys: effects of previous wrist bone fractures and high adiposity. Gait Posture 2003;17:136-41.
8. Goulding A, Taylor RW, Jones IE, McAuley KA, Manning PJ, Williams SM. Overweight and obese children have low bone mass and area for their weight. Int J Obes Relat Metab Disord 2000;24:627-32.
9. Nagasaki K, Kikuchi T, Hiura M, Uchiyama M. Obese Japanese children have low bone mineral density after puberty. J Bone Miner Metab 2004;22(4):376-81.
10. Klein KO, Larmore KA, de Lancey E, Brown JM, Considine RV, Hassink SG. Effect of obesity on estradiol level, and its relationship to leptin, bone maturation, and bone mineral density in children. J Clin Endocrinol Metab 1998;83:3469-75.
11. Katzman DK, Bachrach LK, Carter DR, Marcus R. Clinical and anthropometric correlates of bone mineral acquisition in healthy adolescent girls. J Clin Endocrinol Metab 1991;73:1332-9.
12. Fewtrell MS; British Paediatric & Adolescent Bone Group. Bone densitometry in children assessed by dual X-ray absorptiometry: uses and pitfalls. Arch Dis Child 2003;88(9):795-8.
13. Schoeller DA, Tylavsky FA, Baer DJ, et al. QDR 4500A dual-energy X-ray absorptiometer underestimates fat mass in comparison with criterion methods in adults. Am J Clin Nutr 2005;81(5):1018-25.
14. Dattani MT, Preece MA. Physical growth and development. In: Campbell AGM, McIntosh N, Editor. Forfar and Arneil's Textbook of Pediatrics. 5th edition. Edinburgh: Churchill Livingstone, 1998:349-80.
15. Leung SS, Cole TJ, Tse LY, Lau JT. Body mass index reference curves for Chinese children. Ann Hum Biol 1998;25(2):169-74.
16. Bachrach LK, Hastie T, Wang MC, Narasimhan B, Marcus R. Bone mineral acquisition in healthy Asian, Hispanic, black, and Caucasian youth: a longitudinal study. J Clin Endocrinol Metab

1999;84:4702-12.
17. Cheng JC, Leung SS, Lee WT, et al. Determinants of axial and peripheral bone mass in Chinese adolescents. Arch Dis Child 1998;78:524-30.
18. Cheng JC, Maffulli N, Leung SS, Lee WT, Lau JT, Chan KM. Axial and peripheral bone mineral acquisition: a 3-year longitudinal study in Chinese adolescents. Eur J Pediatr 1999; 158:506-12.
19. 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.
20. Patrick K, Norman GJ, Calfas KJ, et al. Diet, physical activity, and sedentary behaviors as risk factors for overweight in adolescence. Arch Pediatr Adolesc Med 2004;158:385-90.
21. Yilmaz D, Ersoy B, Bilgin E, Gumuser G, Onur E, Pinar ED. Bone mineral density in girls and boys at different pubertal stages: relation with gonadal steroids, bone formation markers, and growth parameters. J Bone Miner Metab 2005;23: 476-82.
22. Wang Y. Is obesity associated with early sexual maturation? A comparison of the association in American boys versus girls. Pediatrics 2002;110:903-10.