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Posted Date: 25 December 2024

doi: 10.20944/preprints202412.2145.v1

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Relationship Between Bone Mineral Density and Body Composition According to Obesity Status in School-Age Children

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Abstract: Objective To investigate the bone mineral density (BMD) and body composition of school-age children with different obesity levels and explore the influencing factors of bone mineral density in obesity children. **Method** A total of 217 school-aged children (ages 6-12) visiting the clinic at Beijing Jishuitan Hospital, Capital Medical University, were enrolled. They underwent a series of examinations, including assessments of body composition, BMD at the distal ulna and radius, abdominal ultrasound, and blood levels of fasting insulin, calcium, 25-OH-D, etc. Statistical analysis was performed using R 4.0.3 software. **Result** The extreme obesity group (ExOb) exhibited statistically significantly higher body weight, BMI z-score, body fat index, muscle mass index, fat-free body mass index, body fat percentage, waist-hip ratio, fasting insulin, insulin resistance index, uric acid, and fatty liver incidence compared to the simple obesity group (SmOb) ($P < 0.05$). No statistical differences were found in height, BMD, BMD z-score, 25-OH-D, blood sugar, calcium, phosphorus, alkaline phosphatase, and puberty development between ExOb and SmOb ($P > 0.05$). BMI z-score, body fat index, muscle mass index, and fat-free body mass index were positively correlated with BMD z-score in all samples and girls ($P < 0.05$). Body fat percentage and body fat index were identified as independent influencing factors of BMD z-score in SmOb and boys ($P < 0.05$). **Conclusion** In obese school-aged children, the BMD increases with the body mass index, and the percentage of body fat may be a negative factor affecting the BMD of school-age children with obesity.

Keywords: obesity; school-aged children; bone mineral density; body composition

1. Introduction

Obesity and osteoporosis are prevalent public health issues worldwide [1]. The incidence of childhood obesity has been rising globally, with a continuous increase in the detection rate of overweight and obesity among Chinese children and adolescents over the past three decades [2] Obesity tracks from childhood to adulthood, increasing the risk of chronic non-communicable diseases in later life [3]. Inflammatory responses, insulin resistance, and nonalcoholic fatty liver disease associated with obesity may impact the absorption of bone minerals, particularly during the critical period of bone mass accumulation in children and adolescents [4]. Obese children may be more susceptible to general discomfort, pain, and even fractures of the joint muscles. BMD indicates the bone minerals contained within a certain volume of tissues and organs and reflects changes in bone tissue quantity. Some studies paradoxically suggest that obesity is a risk factor for fractures in children but a protective factor for adults, as the influence of fat on bones and fracture risk may vary by bone site [5]. Additionally, there are racial differences in BMD, muscle mass, and body fat percentage, and data on the BMD and body composition of obese children in Asia are limited. The relationship between obesity and bone health in children remains controversial, with inconsistent conclusions regarding the relationship between BMD and body composition in obese children.

 doi:10.20944/preprints202412.2145.v1

Therefore, we observed and analyzed the BMD and body composition of 271 school-age children with varying degrees of obesity and present our findings below.

2. Materials and Methods

2.1. Study Population

The subjects were obese children aged 6-12 who underwent physical examinations at the Department of Pediatrics, Beijing Jishuitan Hospital, Capital Medical University, from October 2018 to December 2022. The diagnostic criteria for childhood obesity were based on the body mass index (BMI) boundary points proposed by the Expert Group on 'Evaluation, Treatment, and Prevention of Childhood Obesity in China' [6]. Exclusion criteria included children with liver and kidney dysfunction, endocrine and metabolic diseases, autoimmune diseases, or other conditions that might affect bone metabolism, a history of drug poisoning, and secondary obesity due to other factors. A total of 271 subjects were included and divided into the simple obesity group (SmOb) and extreme obesity group (ExOb) based on BMI criteria: SmOb: obesity BMI boundary point < BMI < obesity BMI boundary point × 120%; ExOb: BMI ≥ obesity BMI boundary point × 120% [7]. The study was approved by the Institutional Review Board of Beijing Jishuitan Hospital, Capital Medical University, and informed consent was obtained from all participants and their guardians before enrollment.

2.2. Methods

2.2.1. Physical Examination, Body Composition and Bone Density Measurement

All subjects underwent physical examinations, body composition, and bone density measurements independently completed by the same investigator, with quality control checks to ensure the precision and accuracy of the instruments. Subjects wore light clothing and had their height (cm) and weight (kg) measured, taking the average of two readings. BMI was calculated as weight (kg) divided by the square of height (m). Bioelectrical impedance analysis (BIA) was used to measure body composition using the Sihai Huachen H-Key350 eight-electrode BIA detector. Subjects, having fasted and emptied their bladders (and refraining from drinking water for 30 minutes before measurement), wore light clothing, removed all metal objects and accessories, stood barefoot on the measurement panel, and were measured after full electrode contact, recording body fat, visceral fat, muscle mass, body fat percentage, and waist-hip ratio. Body fat index was defined as body fat (kg) divided by the square of height (m). Muscle mass index was defined as muscle mass (kg) divided by the square of height (m). Fat-free body mass index was defined as fat-free weight (kg) divided by the square of height (m). Z score = (measured value - average value of this value) / standard deviation, representing the difference between the measured value and the average value for each subject divided by the standard deviation of the value. Bone mineral density was measured at the distal third of both ulna and radius using the EXA-3000 X-ray bone mineral density tester produced by OsteoSys.

2.2.2. Determination of Fasting Insulin, Blood Lipid, Blood Glucose, Uric Acid, Serum Calcium, Serum Phosphorus and Alkaline Phosphatase

After a 12-hour fast, 5 ml of venous blood was collected and tested by the Laboratory of Beijing Jishuitan Hospital, Capital Medical University. Serum calcium and phosphorus were detected by complexation methods, fasting insulin (FIN) by chemiluminescence methods, uric acid by uricase methods, blood sugar by glucose oxidase methods, and alkaline phosphatase by NTP substrate-AMT buffer methods. The instrument used was the Hitachi 7600 automatic biochemical detector. Homeostasis model assessment insulin resistance (Homa-IR) = fasting blood glucose (mmol/L) × fasting insulin (uU/ml) / 22.5.

2.2.3. Determination of Serum 25-OH-D

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After a 12-hour fast, 5 ml of venous blood was collected, centrifuged to obtain serum, and detected by Beijing Hehe Medical Diagnostic Technology Co., Ltd. using liquid chromatography.

2.2.4. Abdominal Ultrasound Examination

Subjects fasted for 12 hours and were examined by the same ultrasound physician at Beijing Jishuitan Hospital, Capital Medical University, to assess fatty liver.

2.2.5. Assessment of Adolescent Development

Girls with breast development and boys with testicular volume equal to or greater than 4 ml were considered to have adolescent development.

2.3. Statistical Analysis

Statistical analysis was conducted using R 4.0.3 statistical software, with Shapiro-Wilk tests to assess data normality. Normally distributed data was represented by x ± s, and non-normally distributed data by M (P25, P75). Independent sample t-tests, Mann-Whitney U tests, and chi-square tests were used to compare group differences. No significant difference in bone mineral density at the distal 1/3 of the ulna and radius of the left and right forearm was found between boys and girls (P > 0.05), so the mean bone mineral density of the distal 1/3 of the ulna and radius of the left and right forearm was used to represent the bone mineral density value for subsequent related data analysis. Spearman and multiple linear regression analyses were used to assess the correlation between bone mineral density and body composition. A difference was considered statistically significant with P < 0.05.

3. Result

3.1. Basic Situation of Subjects

There were 271 obese school-age children, with 152 boys (56%) including 90 cases in the SmOB group and 62 cases in the ExOB group, and 119 girls (44%), including 81 in the SmOB group and 38 in the ExOB group. Regardless of gender, weight, BMI z-score, body fat index, muscle mass index, fat-free body mass index, body fat percentage, waist-hip ratio, fasting insulin, insulin resistance index, uric acid, and fatty liver incidence were higher in the ExOB group than in the SmOB group, with statistically significant differences (P < 0.05). No statistical differences were found in height, BMD, BMD z-score, 25-OH-D, blood sugar, calcium, phosphorus, alkaline phosphatase, and puberty development incidence between the two groups (P > 0.05) (Table 1).

Table 1. Comparison of the Basic Situation of School-age Children with Different Obesity Degrees.

Factors	Male		*p*	Female		*P*
	SmOB(n=90)	ExOB(n=62)		SmOB(n=81)	ExOB(n=38)	
Age (year)	10 (8.8,11.9)	9.4 (8,10.4)	0.016	9 (8,10)	8 (7,9.9)	0.16
Weight (kg)	52.4 (45.1,60)	63.9 (52.6,72.9)	<0.001	41.4 (35.5,53.8)	51.4 (44.4,64.6)	0.001
Height (cm)	147.1±11.5	147.8±12.3	0.723	140.8±12.1	141.5±12.4	0.746
BMI	24 (22.5,25.6)	28.7 (26.2,30.5)	<0.001	21.8 (20.2,23.6)	25.9 (24.1,28.4)	<0.001

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Factors	Male		p	Female		P
	SmOB(n=90)	ExOB(n=62)		SmOB(n=81)	ExOB(n=38)	
BMI z-score	-0.2 (-0.6,0.2)	1 (0.4,1.5)	<0.001	-0.8 (-1.2,-0.3)	0.3 (-0.2,0.9)	<0.001
BMD (g/cm²)	0.3 (0.2,0.3)	0.3 (0.2,0.3)	0.797	0.3 (0.2,0.3)	0.3 (0.2,0.3)	0.881
BMD z-score	0 (-0.7,0.4)	-0.1 (-0.6,0.6)	0.799	-0.1 (-0.8,0.7)	-0.3 (-0.8,0.6)	0.881
Body fat index(kg/m²)	8.6 (7.1,10)	12.3 (10.1,13.7)	<0.001	7.2 (6.3,8.3)	10.5 (8.8,12.3)	<0.001
Muscle mass index(kg/m²)	14.3 (13.5,15)	15.3 (14.8,16.3)	<0.001	13.5 (13,14.4)	14.4 (13.7,15.7)	<0.001
Fat-free body mass index(kg/m²)	15.2 (14.5,16)	16.2 (15.6,17.2)	<0.001	14.3 (13.8,15.2)	15.2 (14.6,16.6)	<0.001
Body fat percentage (%)	35.8 (32,39.1)	41.6 (39.1,45.5)	<0.001	32.8 (30.8,35.9)	40.7 (36.9,42.3)	<0.001
Waist-hip ratio	0.8 (0.8,0.9)	0.9 (0.8,0.9)	0.004	0.8 (0.8,0.8)	0.8 (0.8,0.9)	0.011
25-OH-D(ng/mL)	20.9±7.1	20±8.1	0.468	20.9±7.3	19.7±7.2	0.394
Fasting insulin(uU/ml)	17 (11.6,26.6)	25.4 (15.3,34)	0.003	16.2 (11,26)	21.1 (13.5,44.8)	0.029
Blood sugar(mmol/L)	5±0.4	5±0.4	0.199	5 (4.8,5.2)	5 (4.7,5.3)	0.731
HOMA-IR	3.9 (2.6,6.1)	5.7 (3.3,7.7)	0.006	3.4 (2.5,5.5)	5.2 (2.9,10.2)	0.023
Uric acid (umol/L)	364.5 (314.5,411)	397.5 (332,437.8)	0.035	329.5 (292.8,377.5)	366.5 (311.5,430.5)	0.041
Calcium (mmol/L)	2.5±0.1	2.4±0.1	0.608	2.4 (2.4,2.5)	2.4 (2.4,2.5)	0.484

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Factors	Male		p	Female		P
	SmOB(n=90)	ExOB(n=62)		SmOB(n=81)	ExOB(n=38)	
Phosphorus (mmol/L)	1.6 (1.5,1.7)	1.6 (1.5,1.7)	0.907	1.6±0.2	1.6±0.2	0.84
Alkaline phosphatase (IU/L)	257.5 (216,290.2)	255 (227.2,300.8)	0.942	252.6±71.1	238.4±74.2	0.320
Puberty developmen t incidence	42 (46.7%)	27 (43.5%)	0.704	63 (77.8%)	26 (68.4%)	0.273
Fatty liver incidence	23 (25.6%)	30 (48.4%)	0.004	5 (6.2%)	10 (26.3%)	0.005

3.2. Correlation Between BMD z-Score, BMI z-Score, and Body Composition

In all subjects and girls, BMD z-score was positively correlated with BMI z-score, body fat index, muscle mass index, and fat-free body mass index ($P < 0.05$). In boys, BMD z-score was only positively correlated with muscle mass index and fat-free body mass index ($P < 0.05$) (Table 2).

Table 2. Correlation between BMD z score, BMI z score and Body composition.

Factors	All（n=271）	Male（n=152）	Female（n=119）
BMD z-score			
BMI z-score	0.235 (p<0.001)	0.129 (p=0.118)	0.343(p<0.001)
Body fat index(kg/m^2)	0.143 (p=0.024)	0.045 (p=0.594)	0.266 (p=0.006)
Muscle mass index(kg/m^2)	0.344 (p<0.001)	0.295 (p=0)	0.384 (p<0.001)
Fat-free body mass index(kg/m^2)	0.335(p<0.001)	0.271 (p=0.001)	0.388 (p<0.001)
Body fat percentage	0.011 (p=0.867)	-0.073 (p=0.382)	0.127 (p=0.197)

3.3. Multiple Linear Regression Analysis of BMD z-Score and Body Composition

After controlling for potential confounding factors such as age, height, puberty development, obesity, HOMA-IR, and uric acid, body fat percentage and body fat index were identified as independent influencing factors of BMD z-score among boys (Table 3). After controlling for confounding factors such as age, height, puberty development, sex, HOMA-IR, and uric acid, body fat percentage and body fat index were independent influencing factors of BMD z-score in the SmOB group (Table 4).

 doi:10.20944/preprints202412.2145.v1

Table 3. Multiple Linear Regression Analysis of BMD z-score and Body Composition of Different Sexes.

	Factors	B	S.E.	t	P
Male	constant	-0.014	1.353	-0.010	0.992
	Age	0.108	0.066	1.644	0.102
	Height	0.011	0.011	1.016	0.311
	Puberty development	-0.088	0.163	-0.537	0.592
	Obesity degree	0.199	0.221	0.901	0.369
	HOMA-IR	-0.037	0.018	-2.047	0.043
	Body fat percentage	-0.104	0.020	-5.277	0.000
	Fat-free body mass index	-0.090	0.124	-0.726	0.469
	Body fat index	0.179	0.044	4.048	0.000
	Muscle mass index	0.059	0.119	0.498	0.620
Female	constant	-4.452	1.915	-2.325	0.022
	Age	0.160	0.121	1.314	0.192
	Height	-0.010	0.019	-0.565	0.573
	Puberty development	0.167	0.254	0.660	0.511
	Obesity degree	-0.623	0.336	-1.853	0.067
	HOMA-IR	0.002	0.003	0.520	0.604
	Body fat percentage	0.022	0.035	0.615	0.540
	Fat-free body mass index	-2.387	3.001	-0.796	0.428
	Body fat index	0.008	0.116	0.067	0.947

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	Muscle mass index	2.846	3.108	0.916	0.362

Table 4. Multiple Linear Regression Analysis of BMD z-score and Body Composition in Different Obesity Degrees.

	Factors	B	S.E.	t	P
SmOB	constant	-3.883	1.353	-2.870	0.005
	Age	0.077	0.070	1.098	0.274
	Height	0.013	0.011	1.219	0.225
	Puberty development	-0.094	0.183	-0.512	0.610
	Gender	0.400	0.172	2.327	0.021
	HOMA-IR	-0.019	0.022	-0.854	0.394
	Body fat percentage	-0.064	0.017	-3.696	0.000
	Fat-free body mass index	0.029	0.144	0.198	0.843
	Body fat index	0.200	0.053	3.737	0.000
	Muscle mass index	0.104	0.138	0.751	0.454
ExOB	constant	-8.093	4.545	-1.781	0.079
	Age	0.201	0.121	1.664	0.100
	Height	-0.039	0.020	-1.965	0.053
	Puberty development	0.232	0.229	1.013	0.314
	Gender	-0.057	0.239	-0.239	0.811
	HOMA-IR	0.001	0.003	0.508	0.613
	Body fat percentage	0.209	0.111	1.892	0.062

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Fat-free body mass index	0.348	0.397	0.875	0.384
Body fat index	-0.433	0.228	-1.901	0.061
Muscle mass index	0.167	0.369	0.452	0.652

4. Discuss

With the global increase in childhood obesity, there is growing attention on the impact of weight and fat distribution on bone mineral density. Obese children have higher areal bone density and bone mineral quantity than normal weight children, yet their risk of limb fractures may be higher. The influence of obesity on children's bone health is complex and contradictory [8]. Our study utilized dual-energy X-ray absorptiometry to detect children's bone mineral density, the gold standard for diagnosing osteoporosis, known for its high accuracy, fast scanning speed, low radiation dose, high child cooperation, and ease of operation [9,10]

4.1. Relationship Between Bone Mineral Density and Body Composition in Children with Different Obesity Degrees

We found that the incidence of body weight, BMI z-score, body fat index, muscle mass index, fat-free body mass index, body fat percentage, waist-hip ratio, fasting insulin, insulin resistance index, uric acid, and fatty liver was higher in the extremely obese group than in the general obese group. However, height, BMD, BMD z-score, 25-OH-D, blood sugar, calcium, phosphorus, alkaline phosphatase, and adolescent development did not differ between the two groups. Franceschi et al. [11]proposed no significant difference in forearm volumetric bone density, total bone area, and cortical area between overweight and obese children and those of normal weight, consistent with our study's findings on forearm bone density across different weight groups. However, overweight and obese children are at greater risk of forearm fractures, possibly due to the imbalance between forearm bone strength and excessive mechanical load from increased local fat-muscle ratio. Another cross-sectional study on skeletal parameters of normal-weight and overweight adolescents also showed no difference in total skull-removed density and lumbar bone mineral density between different groups [12]. However, a retrospective study from South Korea analyzed the body composition and decapitated bone mineral density of children and adolescents with different obesity degrees, pointed out that the bone mineral density of extremely obese children was higher than that of ordinary obese children, and it was positively correlated with their muscle mass, but excessive body fat seemed to be negatively correlated with bone mineral density, which might weaken the positive correlation between muscle mass and bone mineral density of extremely obese children [4]. Samantha et al. [13] in their study of decapitated whole-body bone mineral density and lumbar bone mineral density of normal weight, overweight, and obese children, found that the bone mineral density of obese children was higher. The differing conclusions on the impact of obesity on children's bone mineral density may be related to the gender, age, adolescent status, fat type (visceral or subcutaneous), bone parameters (bone mineral density, bulk bone mineral density, or bone mineral content), and bone structure (trabecular or cortical bone) of the enrolled subjects, as well as the bone regions (whole body, lumbar vertebrae, femur, tibia, forearm bone, etc.) studied, leading to different comparisons of bone mineral density differences.

4.2. Effect of Adipose Tissue on Bone Mineral Density in Children and Adolescents

There is increasing evidence that excessive fat, rather than obese weight itself, may have a negative impact on the bone health of children and adolescents [1]. We observed that the BMD z score of distal forearm bone was positively correlated with BMI z-score, body fat index, muscle mass index and fat-free body mass index in univariate analysis of all samples. After adjusting for potential confounding factors, body fat percentage and body fat index were independent influencing factors of BMD z-score, suggesting that a higher body fat percentage may be associated with worse bone mineral density of the distal forearm. Our findings are supported by previous studies. A retrospective study from the United States also found that fat quality is slightly negatively correlated with bone development in children and adolescents. The accumulation of trunk fat, especially visceral adipose tissue, is related to low bone mineral density, particularly in overweight and obese children [14]. Krishnan et al. also confirmed a significant negative correlation between whole-body bone mineral density and the percentage of trunk fat in overweight children [12]. After adjusting for weight and potential confounding factors, a significant negative correlation between body fat and bone mineral density was also observed in normal weight children [15,16]. The negative effect of fat on bone is thought to be due to the inflammatory effect of adipose tissue on bone cells, leading to increased bone absorption and decreased bone formation. Excessive adipose tissue, especially visceral adipose tissue, secretes various inflammatory cytokines, such as interleukin-6 and tumor necrosis factor, which may reduce bone density by increasing bone absorption [17]. Insulin resistance associated with obesity disrupts normal bone metabolism, leading to impaired bone formation and further aggravating bone density damage [18]. Additionally, the diet of obese children is often particularly rich in fat, which may reduce intestinal calcium absorption, leading to decreased calcium availability for bone formation and further aggravating the inflammatory response [19]. Different from the above conclusions, some researchers believe that the bone mineral density of obese children is not significantly related to fat mass but more closely related to muscle mass [20,21]. Lee et al. [1] described an inverted "U" curve relationship between body weight and bone mineral density, proposing that the average density of whole-body decapitated bone has an upward trend from the underweight group, normal body weight to super-recombination. With the development of BMI to obesity, bone mineral density decreases, and there may be an optimal obesity parameter range to maintain the best bone health. However, deviating from this range (underweight or obesity) may lead to bone health damage.

The limitations of this study are as follows: (1) This study failed to monitor inflammatory cytokines, sex hormones, and other indicators that may affect bone metabolism; (2) It is necessary to use computed tomography or magnetic resonance imaging to determine the distribution of regional fat, which may better reveal the influence of fat in different parts on bone mineral density. Increasing the monitoring of bone mineral density in other parts, such as the lower limbs, spine, and even the whole body, is more helpful to comprehensively explain the relationship between childhood obesity and bone mineral density. (3) The cross-sectional nature of this study did not capture the dynamic changes of body weight and bone mineral density during the growth of children and adolescents. Despite these shortcomings, this study is also valuable. As far as we know, previous studies on bone mineral density of obese children and adolescents mainly focused on normal weight, overweight, and obese subjects. This study divided obese children into extremely obese groups according to BMI and preliminarily explored the relationship between obesity severity and bone mineral density. In addition, we included indicators of children's adolescent development and insulin resistance and adjusted the influence of related confounding factors using multiple regression models, which improves the scientific nature of the statistical results to some extent.

5. Conlusion

In conclusion, the bone mineral density of obese school-age children increases with the increase of BMI, and the percentage of body fat may be an unfavorable factor for the bone mineral density of obese children. Obesity in childhood and adolescence will persist into adulthood, having a greater harmful effect on health. It is crucial to further study all aspects of body composition and the mechanism of obesity affecting bone mineral accumulation to promote bone health in adolescence and reduce the risk of fracture in later years.

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