ORIGINAL RESEARCH ARTICLE

Associations between body fat and bone mineral density in children and adolescents aged 6-17 years in an urban city in China: A cross-sectional study

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Abstract

A cross-sectional study was conducted using a multistage cluster random sampling technique to investigate the association between body fat and forearm bone mineral density (BMD) among children and adolescents aged 6–17 years in urban China. Body fat was determined by bioelectrical impedance analysis (BIA), and forearm BMD was measured by dual-energy X-ray absorptiometry (DEXA). 342 students were included in the study. Significant positive correlations were observed between BMI and forearm BMD in boys (β=0.465, p<0.001) and girls (β=0.496, p<0.001), and between body fat and forearm BMD (boys: β=0.312, p<0.001; girls: β=0.550, p<0.001). However, these associations were no longer significant after adjusting for age (boys: β=0.089, p=0.151; girls: β=0.102, p=0.151). Forearm BMD increased progressively with age, peaking at 16 years in boys and 15 years in girls. Girls showed earlier BMD accumulation during puberty compared to boys, whereas boys exhibited higher BMD values during late adolescence. No significant differences in forearm BMD were observed across BMI groups (all p>0.05), though a downward trend in BMD with increasing BMI was noted among girls. These findings suggest that body fat may influence BMD in an age-dependent manner, highlighting the importance of early-life interventions to support optimal skeletal development. *(Afr J Reprod Health 2025; 29 [8s]: 94-104)*

Keywords: Body Fat, Bone Mineral Density, children, adolescents

Résumé

Une étude transversale A été menée à l'aide d'une technique d'échantillonnage aléatoire en grappes à plusieurs étapes pour étudier l'association entre la masse grasse corporelle et la densité minérale osseuse de l'avant-bras (dmo) chez les enfants et les adolescents âgés de 6 à 17 ans dans les villes de la Chine. La graisse corporelle a été déterminée par analyse d'impédance bioélectrique (BIA), et la dmo de l'avant-bras a été mesurée par absorbptiométrie aux rayons x à double énergie (DEXA). 342 étudiants ont été inclus dans l'étude. Des corrélations positives significatives ont été observées entre l'imc et la dmo de l'avant-bras chez les garçons (β= 0,465, p< 0,001) et les filles (β= 0,496, p< 0,001), et entre la graisse corporelle et la dmo de l'avant-bras (garçons: β= 0,312, p< 0,001; Filles: β= 0,550, p< 0,001). Cependant, ces associations n'étaient plus significatives après ajustement en fonction de l'âge (garçons: β= 0,089, p= 0,151; Filles: β= 0,102, p= 0,151). La dmo de l'avant-bras a augmenté progressivement avec l'âge, culminant à 16 ans chez les garçons et à 15 ans chez les filles. Les filles ont montré une accumulation plus précoce de dmo pendant la puberté que les garçons, tandis que les garçons ont montré des valeurs plus élevées de dmo à la fin de l'adolescence. Aucune différence significative dans la dmo de l'avant-bras n'a été observée entre les groupes d'imc (tous p> 0,05), mais une tendance à la baisse de la dmo avec une augmentation de l'imc a été observée chez les filles. Ces résultats suggèrent que la graisse corporelle pourrait influer sur la dmo en fonction de l'âge, ce qui souligne l'importance des interventions précoces pour soutenir le développement optimal du squelette. *(Afr J Reprod Health 2025; 29 [8s]: 94-104).*

Mots-clés: Graisse corporelle, densité minérale osseuse, enfants, adolescents

Introduction

Bone fractures are common among aged populations worldwide. Fractures due to osteoporosis are burdensome on health systems[1, 2]. Osteoporosis affects 200 million people worldwide, while 8.9 million related fractures occur each year. In China, among adults aged 40 years or older, the prevalence

of osteoporosis is 5.0% for males and 20.6% for females[3]. Medical costs for vertebral fractures increased rapidly among people aged 50 years and older in China between 2013 and 2017[4]. One of the key strategies for preventing osteoporotic fractures is to increase the bone mineral density (BMD) of individuals, especially during childhood[5].

In general, the bones of children and adolescents are in a critical period of rapid growth and development, and bone mass accumulation in the early stages is directly proportional to peak bone mass (PBM) acquired in life[6]. Bone mineral density (BMD) is defined as the amount of mineral matter per square centimeter of bone, which is a primary indicator used to evaluate bone strength and the risk of fracture. Peak bone mass (PBM), on the other hand, refers to the maximum bone density and strength an individual achieves during life, typically reached by early adulthood. While BMD provides a measure of current bone health, achieving optimal PBM during childhood and adolescence can significantly reduce future osteoporosis risk.

Importantly, an effective and economical method to reduce the incidence of osteoporosis later in life is to increase bone mass in children and adolescents, to reach the optimal PBM. For every 10% increase in PBM, the risk of developing osteoporotic fractures later in life decreases by 50%, and the onset of osteoporosis is delayed by 13 years[6]. However, 60% to 80% of the BMD is determined by genetic factors, including the sex, ethnicity, and hormonal status[7-10]. Lifestyle factors, including diet, physical activity, cigarette smoking and alcohol consumption, contribute 20% to 40%[11-15]. In particular, inadequate calcium intake during childhood may increase the risk of fractures and rickets, and prevent the achievement of maximal PBM later in life. In this regard, dairy products are the best choice for supplying energy and nutrients-including calcium-for human bone health[16]. Therefore, adequate intake of dairy products is vital to increasing the BMD of children and adolescents. In this study, "children" were operationally defined as participants aged between 6 and 11 years, while "adolescents" included participants aged between 12 and 17 years.

In addition to the factors mentioned above, studies[17-21] have explored the relationship between body fat and BMD. However, the results concerning the impact of body fat on BMD are contradictory. Body fat is positively related to BMD at different sites, including total femur BMD, the total spine BMD and the femoral neck BMD[22]. Conversely, a study conducted among Brazilian women revealed an inverse association between fat mass (FM) and BMD[17]. Fat mass (FM) specifically quantifies the total adipose tissue mass, whereas body fat is a more general term used to describe adiposity levels, often expressed as percentage body fat.). Even among the Chinese population, the association between BMD and body fat is inconsistent. Among postmenopausal women in China, obesity is associated with an increased risk of vertebral fractures, indicating that body fat is negatively associated with BMD, however, this finding was not consistent across all studies involving postmenopausal women[18]. Another study revealed no relationship between body fat and BMD[19]. So far, studies have mostly focused on exploring the subject matter with adults, those with children and adolescents are scarce. A few studies involving children and adolescents have reported contradictory findings. One suggests body fat promoted increase in bone density[20] while the other reported the obverse[21]. Hence, there is a need for this study to explore the phenomenon among younger populations.

Worldwide, obesity among youth continues to be a major public health concern; the global rate of obesity was estimated to be 37.9% in 2020 and may reach 60% in China by 2030[23]. The adverse effects of obesity on the development and health of children and adolescents have been demonstrated, including the fact that obesity might persist into adulthood and predispose individuals to elevated risks of noncommunicable diseases (NCDs)[24]. However, whether body fat can impair BMD or has combined effects with other factors on BMD remains unclear.

Therefore, this study aims to explore the association between body fat and bone health among children and adolescents aged 6–17. The specific objectives of this study are:

1. to investigate the patterns of forearm bone mineral density (BMD) according to age and sex among children (aged 6–11) and adolescents (aged 12–17); and

2. to examine the associations between body fat and forearm bone mineral density (BMD) among children and adolescents, and determine whether these associations are independent of age.

The findings of this study will provide essential insights for developing targeted intervention programs and enhancing health education, emphasizing the importance of optimal BMD accumulation during childhood and adolescence.

Methods

Study design

A cross-sectional study was designed among children and adolescents in Beijing, China.

Sample size calculation

According to China's Report on Nutrition and Chronic Diseases Status of Residents (2020)[25], the prevalence of overweight and obesity among urban children and adolescents aged 6–17 was 23.2%. To determine the minimum required sample size, the standard formula for cross-sectional studies was employed, as shown below:

Formula: Sample Size for Cross-sectional Study

$$N = deff \times \frac{u^2 \times p(1-p)}{d^2}$$

Where:

- N = Minimum required sample size
- deff = Design effect (considering complex sampling), set as 2
- u = Z-score corresponding to the 95% confidence interval (two-sided), equal to 1.96
- p = Estimated prevalence (proportion) of overweight and obesity, 23.2% (0.232)
- d = Allowable absolute error (precision), calculated as relative error × prevalence (here, relative error = 28%)

Substituting the specific values into the formula:

$$N = 2 \times \frac{(1.96)^2 \times 0.232 \times (1-0.232)}{(0.28 \times 0.232)^2}$$

Detailed calculation steps:

- $1.96^2=3.8416$
- $0.232\times(1-0.232)=0.232\times0.768=0.178176$
- Numerator: $3.8416\times0.178176=0.6845$
- Denominator: $(0.28\times0.232)^2=(0.06496)^2=0.004220$
- Division: $0.6845/0.004220=162.2$
- Adjusted by design effect: $162.2\times2=324.4$
- Considering a potential dropout rate of 10%, the final required sample size was calculated as:
- $324.4\times(1+0.10)=356.84$, rounded up to 360 participants.

Thus, a total sample size of 360 subjects was established for this study.

A multistage stratified randomized cluster sampling method was adopted in this study. First, one district was randomly selected from six urban districts in Beijing. Within the selected district, one primary school (six grades, corresponding to students aged 6–11), one junior high school (three grades, aged 12–14), and one senior high school (three grades, aged 15–17) were randomly selected. Then, within each selected school, one class was randomly chosen from each grade. All students in the selected classes who were willing to participate in the study were included as research participants. A minimum of 30 students was included from each grade; if the selected class had fewer than 30 students, additional participants were recruited from neighboring classes within the same grade.

According to the sampling plan, the 360 participants were proportionally allocated across three educational strata: primary school (Grades 1–6), junior high school (Grades 7–9), and senior high school (Grades 10–12). This distribution corresponded with the calculated sample size and ensured adequate age coverage. Of the 360 children and adolescents aged 6 to 17 years who were included in the study, 192 were categorized as children (aged 6–11) and 168 as adolescents (aged 12–17). The study was conducted from November 2022 to April 2023.

Inclusion criteria

Participants were eligible to take part in the study if they met the following criteria:

1) Healthy boys and girls aged 6 to 17 years;

2) Willingness to participate in the study;

3) Provided signed informed consent from both the participant and at least one legal guardian.

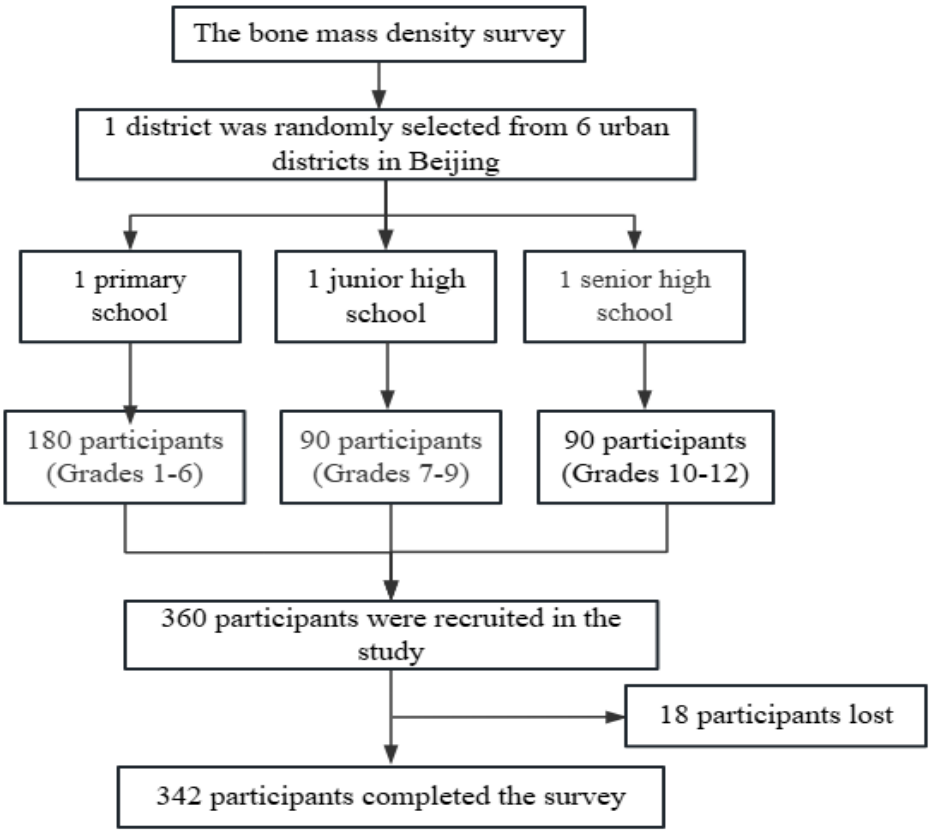

Figure 1: Study flow chart

Exclusion criteria

Participants were excluded from the study if they:
1) with chronic illnesses (e.g., endocrine disorders, metabolic bone diseases);
2) experiencing acute medical conditions at the time of recruitment;
3) those undergoing regular medication use that may affect bone metabolism;
4) those who had suffered a recent fracture;
5) those who refused to participate or who withdrew consent.

Data collection techniques

Data collection in this study was categorized into three dimensions corresponding to the study variables: demographic data, body fat measurements, and bone mineral density (BMD). Standardized protocols and validated instruments were used in school settings by trained staff[26].

Demographic data

Demographic information—including age, sex, and school grade—was collected from school records and confirmed via parent-completed background forms. Age was recorded in full years (6–17 years), and sex was coded as male or female. This information was used to group participants and assess age- and sex-related patterns in bone mineral density and body fat.

Body fat measurements

Body fat and lean mass were measured using bioelectrical impedance analysis (BIA) with the InBody 770 body composition analyzer (InBody

Co., Seoul, South Korea). Participants stood barefoot on the analyzer platform and held the electrodes in both hands. This method was chosen due to its practicality and safety in large-scale, school-based pediatric studies. While DEXA can also provide highly accurate fat mass estimates, it involves radiation exposure and is less feasible for field studies. Therefore, BIA was used due to its portability, non-invasiveness, low cost, and reproducibility, making it especially suitable for mass measurements in healthy youth populations[27].

BMD measurements

Forearm bone mineral density was assessed using dual-energy X-ray absorptiometry (DEXA). A certified technician operated a portable DEXA scanner (Lunar iDXA, GE Healthcare), which provides accurate BMD readings by comparing X-ray attenuation at two energy levels. This method is widely accepted in pediatric skeletal health studies due to its minimal radiation, reliability, and anatomical specificity. The forearm was chosen because it provides a stable measurement site in youth and reflects peripheral bone health[28].

Statistical analyses

SPSS(version 20.0; SPSS, Chicago, IL, USA) was used for the statistical analyses. The quantitative parameters of the participants are presented as means ± standard deviations, and binary classification data are presented as n ± percentages. The participants were divided into three groups according to their body sizes based on the standard of China (Screening for overweight and obesity among school-age children and adolescents: WS/T 586-2018[29] (1: normal weight group; 2: overweight group; 3: obese group). One-way ANOVA and Student's t tests were used to compare differences among groups (One-way ANOVA was used to compare the differences among the three groups including the normal, overweight and obesity groups. The Student's t-test was used to compare the differences between boys and girls). Multivariable regression models were considered to determine the relationship between body fat and forearm BMD, adjusting age, gender and other related confounding factors. Two-sided significance levels were set at 0.05 ($p<0.05$).

Ethical considerations

The protocol of our study was approved by the Medical Ethical Review Committee at the National Institute for Nutrition and Health, Chinese Center for Disease Control and Prevention on March 18, 2019 (No. 2019-009). As the participants were all minors under the age of 18, parents or guardians of the study subjects signed the informed consent form, in accordance with the Helsinki Declaration on research ethics. For children over 8 years of age, both parents/guardians and the child cosigned the informed consent form.

Results

Characteristics of participants

In total, 342 participants, including 167 boys and 175 girls, completed the study, yielding a 95% completion rate. Table 1 shows the characteristics of the participants. Significant differences were found in height, weight, and BMI among the different age groups, both for boys and girls (all $p<0.001$).

BMD of the participants

Figure 2 shows the forearm BMD of boys and girls by age. Significant differences were found between different ages for both boys and girls (all $p<0.001$). For boys, the forearm BMD increased with age, peaking at the age of 16 years and increasing rapidly at the age of 12. However, for girls, a similar trend was observed with age. Specifically, the peak forearm BMD occurred at the age of 15, with a rapid increase at 10 years. Comparing boys and girls at each age, no significant differences were found from ages 6 to 11, as well as at ages 14 and 16 (all $p>0.05$). Statistically significant differences were found at ages 12, 13, 15, and 17 (all $p<0.05$). At ages 12 and 15, girls had forearm BMDs that were greater by values of 0.049 and 0.051 respectively (all $p<0.05$), while inversely at ages 13 and 17 boys had greater forearm BMDs by values of 0.071 and .037 respectively (all $p<0.05$). However, no significant

Table1: Participant characteristics

Age (years)	**Total (n=342) (%)**	**Boys (n=167) (%)**	**Boys Height (cm)**	**Boys Weight (kg)**	**Boys BMI (kg/m²)**	**Boys Body Fat (%)**	**Boys BMD (g/cm²)**	**Girls (n=175) (%)**	**Girls Height (cm)**	**Girls Weight (kg)**	**Girls BMI (kg/m²)**	**Girls Body Fat (%)**	**Girls BMD (g/cm²)**
6	28 (8.2)	14 (8.4)	122.8±5.4	25.8±5.0	17.0±2.1	5.8±3.0	0.236±0.037	14 (8.0)	122.9±5.9	23.6±4.7	15.5±2.3	5.1±3.3	0.243±0.496
7	31 (9.1)	15 (9.0)	133.5±6.9	31.1±7.4	17.2±2.8	8.1±4.1	0.247±0.038	16 (9.1)	129.9±5.5	27.4±4.5	16.2±2.1	6.1±3.4	0.229±0.054
8	25 (7.3)	11 (6.6)	133.8±4.4	29.8±5.6	16.6±2.1	5.8±3.6	0.245±0.046	14 (8.0)	138.2±4.9	32.3±4.3	16.9±2.1	7.5±3.0	0.234±0.033
9	29 (8.5)	15 (9.0)	142.2±6.5	40.1±8.6	19.7±3.4	13.3±7.8	0.249±0.030	14 (8.0)	141.9±5.1	36.5±7.2	18.1±2.9	9.4±3.4	0.226±0.033
10	30 (8.8)	14 (8.4)	146.5±8.9	38.5±10.2	17.7±2.8	9.7±6.1	0.255±0.037	16 (9.1)	148.2±8.4	42.6±7.7	19.3±2.6	12.1±3.6	0.238±0.041
11	28 (8.2)	12 (7.2)	155.7±9.0	57.3±11.1	23.4±3.0	17.4±5.9	0.264±0.034	16 (9.1)	155.1±6.3	45.6±8.1	18.9±2.7	12.0±4.9	0.275±0.056
12	34 (9.9)	16 (9.6)	162.3±7.5	54.8±10.4	20.8±3.6	13.3±7.2	0.263±0.056	18 (10.3)	157.7±5.0	49.7±8.1	19.9±2.6	16.1±6.8	0.312±0.066
13	28 (8.2)	15 (9.0)	171.2±7.2	71.2±17.3	24.2±5.3	17.6±10.3	0.381±0.098	13 (7.4)	159.7±4.9	49.7±6.6	19.5±2.8	14.7±4.6	0.310±0.062
14	25 (7.3)	13 (7.8)	171.6±5.5	70.4±13.2	23.9±4.0	22.5±11.5	0.348±0.088	12 (6.9)	164.9±6.5	56.4±10.0	20.7±3.2	16.6±5.3	0.378±0.053
15	27 (7.9)	14 (8.4)	172.5±7.2	64.6±12.3	21.7±4.1	13.2±7.4	0.341±0.067	13 (7.4)	165.8±5.8	59.0±10.9	21.4±3.7	18.2±5.1	0.392±0.048
16	28 (8.2)	13 (7.8)	174.8±5.6	66.7±11.2	21.8±3.5	12.1±7.3	0.405±0.049	15 (8.6)	163.4±5.1	57.3±9.0	21.5±3.5	19.6±5.7	0.374±0.039
17	29 (8.5)	15 (9.0)	176.0±5.6	70.8±10.7	23.0±3.9	14.9±8.5	0.399±0.055	14 (8.0)	165.1±6.0	56.1±10.2	20.5±2.9	16.6±5.6	0.362±0.040

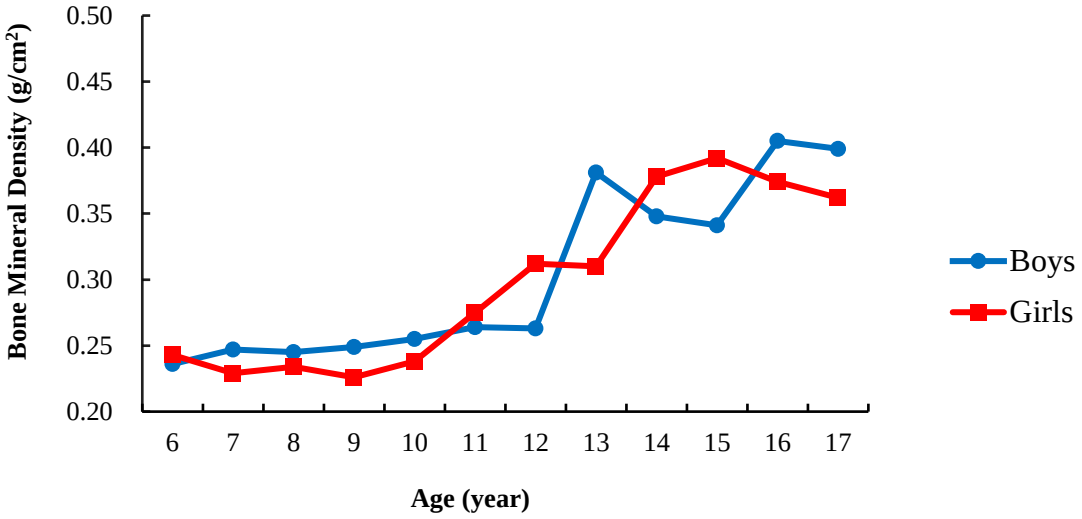

Figure 2: BMD of participants of different ages

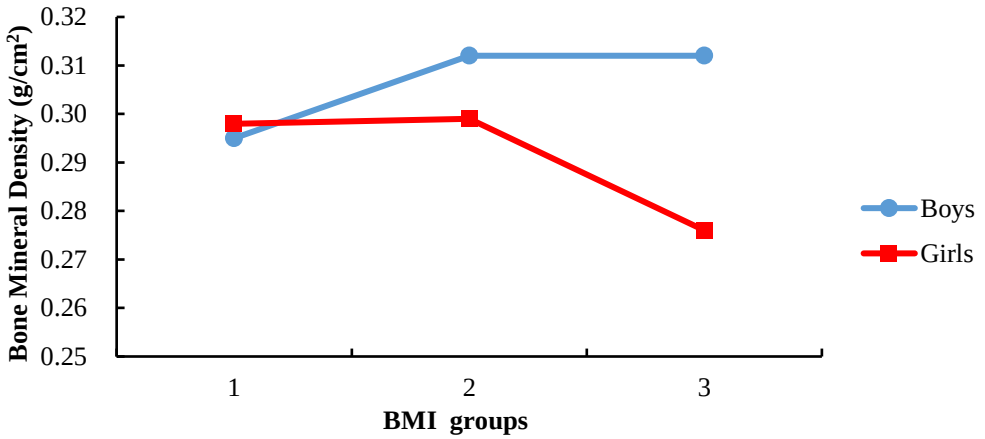

Figure 3: BMD of participants in different BMI groups (1: normal weight group; 2: overweight group; 3: obese group)

Table 2: Associations among body fat, BMI and BMD in boys and girls

Forearm BMD	Boys		Girls	
	β	*p*	*β*	*p*
BMI	0.465	<0.001	0.496	<0.001
Body fat	0.312	<0.001	0.550	<0.001
Body fat (adjusted for age)	0.089	0.151	0.102	0.151

differences were observed among different BMI groups in both boys and girls (all $p>0.05$). Although no significant differences were noted among the girls' groups specifically there was a decrease in forearm BMD moving from normal weight group to obese group as shown in Figure3.

Associations between body fat and BMD

Table 2 below shows positive associations between BMI and forearm BMD in both boys (β=0.465, p<0.001) and girls (β=0.496, p<0.001). Furthermore, positive associations were also observed between body fat and forearm BMD in both boys (β=0.312, p<0.001) and girls (β=0.550, p<0.001). However, when age was used as the covariate, no significant associations were observed between body fat and forearm BMD in either boys or girls (β=0.089, p=0.151; β=0.102, p=0.151).

Discussion

In this study, we investigated the differences in forearm BMD according to sex and age and the associations between body fat mass and forearm BMD. The results showed differences in forearm BMD between participants based on sex, with girls having higher forearm BMD at first, but boys having a great value during late adolescence. The main finding was that body fat was positively associated with forearm BMD, regardless of sex (boys or girls). However, after adjusting for age, the correlation disappeared. More research should be conducted on this issue.

In this study, forearm BMD increased with age in both boys and girls. The forearm BMDs of the children and adolescents in our study were consistent with the reference values of the Chinese forearm BMD reference standards for children aged 3–18 years[30]. Furthermore, our data also suggested that sex was correlated with forearm BMD. Additionally, girls had higher forearm BMD than boys in early adolescence but lower in late adolescence. These findings were consistent with those reported in other studies[31-32]. One study revealed that girls who experienced early puberty had more bone mass than boys at a similar age, indicating that sex hormones, especially estrogen, may affect bone mass accrual[31]. Moreover, in Korean young adults aged 10–25 years, females had higher BMDs by the age of 13 years; however, this reversed after the age of 18 years for the BMD of the lumbar spine[33]. These results indicated a significant age– sex interaction between BMD at all skeletal sites. In the future, studies aimed at increasing the BMD of girls and boys should consider the development of their bone health and identify the best method to promote bone mass accumulation.

Another study conducted among 6,143 adolescents aged 8–19 years, reported that BMI was highly correlated with total BMD, but a saturation effect was observed[34]. A Korean study among 1,063 adolescents demonstrated that body fat and BMI were positively correlated with BMD[35]. However, no significant differences in BMD were observed among children and adolescents in the different BMI groups in the current study. A study among overweight and obese children revealed the boys had higher femoral neck BMD compared with those who have normal weight[31]. Obesity during childhood and adolescence was associated with increased vertebral bone density as well as whole-body bone dimensions and mass[21]. Similar to a previous mentioned study, saturation effect of BMI on BMD may exist in our study. More studies are needed to explore this subject further.

The focus of this study was to explore the relationship between body fat and BMD. To reiterate, the results show that BMD was positively associated with body fat, both in boys (β=0.312) and girls (β=0.550), with a strong correlation noted in girls. This might be due to differences in bone size, obesity type, fat distribution, and sex hormone levels[36, 37]. These results are similar to those of other studies[38]. Similarly, a meta-analysis demonstrated a positive correlation between body fat mass and lumbar spine BMD[39].

A study of 118 adolescents aged 10–14 years revealed that fat mass was correlated with BMD, but only in girls (r=0.314)[40]. In contrast, a cross-sectional study conducted among adults aged 18 years or older in the National Health and Nutrition Survey revealed that body fat was negatively but linearly associated with lumbar spine BMD and positively associated with whole-body BMD[41]. Even among Chinese pre- and postmenopausal women, increased body fat is negatively associated with BMD[42]. Another study involving children aged 8–18 years revealed a decrease in total body BMD and lumbar spine BMD with increasing body fat mass[22]. Therefore, these inconsistent results may be attributed to different study populations and sites of BMD. Although an increase in body fat can lead to

an increase in BMD, a greater increase in body fat is not necessarily better. The accumulation of body fat may result in obesity, which could negatively impact the health of children. Thus, moderate body fat may be beneficial for increasing BMD; and one study demonstrated the positive effects of mechanical loading on bones, lower estradiol levels, and higher lepton levels. However, more studies should further investigate the effects of body fat on bone health outcomes, especially for children and adolescents.

Study strengths and limitations

The present study had both strengths and weaknesses. The study examining the correlation between body fat percentage and bone mineral density (BMD) in children and adolescents highlights a critical opportunity to clarify its clinical implications and policy impacts. From a research perspective, it provides novel evidence on the age- and sex-dependent association between body fat and forearm BMD in Chinese youth, emphasizing the need for longitudinal and mechanistic studies to clarify causal pathways. Clinically, the findings suggest that maintaining an optimal body fat range during key growth periods may be vital for promoting skeletal health, especially in females, supporting targeted nutritional and physical activity interventions. From a policy perspective, public health strategies should integrate routine monitoring of body composition and bone health in children and adolescents to balance obesity prevention with bone development optimization, thereby reducing the future burden of osteoporosis through early intervention and education programs.

However, the study was only a cross-sectional study, which makes it impossible to determine temporal relationships between body fat and forearm BMD. Furthermore, related hormone levels-including estrogen and androgen levels-were not investigated.

Further research is still needed to provide more data for the formulation, implementation, and promotion of relevant policies in urban areas of Beijing or similar regions and countries in the future.

Conclusion

The forearm BMD of children and adolescents aged 6-17 years increased with age in both boys and girls. The forearm BMD accumulation accelerates from adolescence, with girls experiencing earlier forearm BMD accumulation than boys. Positive associations were observed among body fat, BMI, and forearm BMD in both boys and girls. However, after adjusting for age, the correlation disappeared.

Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

The datasets generated and/or analyzed during the current study are available from the corresponding author upon reasonable request.

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None

Authors' contributions

Lulu Meng and Kaichen Gu contributed equally to this work. Lulu Meng and Kaichen Gu was responsible for the implementation of the study and the drafting of the paper. Yiran Li undertook the data cleaning for the paper. Liyu Huang was responsible for monitoring the implementation of the study, finalizing the manuscript, and designing the study and provided substantive revisions to the initial draft of the paper. Lulu Meng and Kaichen Gu and Liyu Huang were responsible for the implementation of the study. All the authors were involved in the revision of the manuscript and approved the final version.

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