Archives of Osteoporosis (2019) 14:78
https://doi.org/10.1007/s11657-019-0606-1

ORIGINAL ARTICLE

The impact of height on low/reduced bone mineral density in Chinese adolescents aged 12-14 years old: gender differences

Chengshu Yu[1] · Shuo Wang[2] · Xuemei Meng[1] · Weiqin Li[2] · Yanmei Deng[1] · Nan Li[2] · Zhongxian Xu[1] · Leishen Wang[2] · Ming Zhao[1] · Junhong Leng[2]

Received: 25 December 2018 / Accepted: 9 May 2019

Abstract

Summary Low/reduced bone mineral density (BMD) is an important predictor of childhood fracture. In this article, we presented the prevalence of BMD in Chinese adolescents and, for the first time, demonstrated the gender disparities in the impact of height on BMD.

Purpose To analyze the gender disparities in the association of low/reduced BMD with height in Chinese adolescents at the stage of growth spurt.

Methods A total of 8152 adolescents aged 12–14 years old were included based on a cross-sectional study in Tianjin, China. Height and weight were measured with standard equipment. BMD was measured using the method of quantitative ultrasound. Adolescents with $Z \leq -2.0$ or $-2.0 < Z \leq -1.0$ were defined as "low BMD" or "reduced BMD".

Results The total low/reduced BMD rate was 22.0% in Chinese adolescents aged 12–14 years old, and boys were more likely to have low/reduced BMD than girls (30.1% vs. 12.9%, $P < 0.001$). The rate of low/reduced BMD significantly increased with age in boys ($P_{trend} = 0.019$), whereas decreased with age in girls ($P_{trend} = 0.018$). We found significant interaction effect between gender and height standard deviation score (height-Z) in the association with low/reduced BMD ($P_{interaction} < 0.001$). There was a positive association of height-Z among boys (OR = 1.30, 95%CI 1.21–1.39, $P < 0.001$), meanwhile low/reduced BMD was inversely associated with height-Z among girls (OR = 0.85, 95%CI 0.78–0.94, $P < 0.001$).

Conclusions Our study suggested strong gender disparities in the impact of height on BMD in Chinese adolescents aged 12-14 years old, where the association between low/reduced BMD and height was positive among boys but inverse among girls. The study provides evidence on the early prevention and the risk factor identification of low/reduced BMD and childhood fractures.

Keywords Bone mineral density · Adolescent · Height · Growth spurt · Gender difference

Introduction

Low or reduced bone mineral density (BMD) is an important predictor of childhood fracture [1]. The incidence of childhood fracture was reported to be 9.5–21.2/1000 per year [2–4], and around one third of all children suffer at least one fracture during the entire childhood [5]. Since fracture was the cause of 9% of all injuries in children that come to the attention of health services [6], low/reduced BMD has become a serious public health issue and led to a heavy burden on the health care system.

Adolescents aged 10–14 years old have the highest risk of fractures among 0–19 years old [2]. A detailed pattern showed the incidence of the childhood fracture increased with age and

Chengshu Yu and Shuo Wang co-first authors contributed equally to this work.

Ming Zhao and Junhong Leng co-corresponding authors contributed equally to this work.

✉ Ming Zhao
reficulx@163.com

✉ Junhong Leng
ljhlzqljhlzq@163.com

[1] Health and Family Planning Service Center for Women and Children in Dongli District, Xianfeng Road, Dongli District, Tianjin 300300, China

[2] Tianjin Women's and Children's Health Center, Guizhou Road, Heping District, Tianjin 300070, China

Published online: 08 July 2019

decreased afterwards, peaking at 12 years in girls and at 14 years in boys, resulting in a large gender disparity in the age group of 12–14 years old [3]. The high rate of fracture in adolescents may be partly attributed to the increase of sports participation, but the gender difference in the timing of the peak incidence may reflect biological factors (e.g., BMD) in growth. However, the gender disparities of BMD during the special period of growth spurt were to some extent neglected in previous studies.

Height is an important impact factor of BMD. A number of previous studies have reported that BMD increased with height [7, 8]. However, it has been reported that the growth of bone mineral content lags behind the growth of height [9]. Faulkner et al. also demonstrated that there was a period of relative skeletal fragility resulting from dissociation between bone expansion and bone mineralization during the growing years [10]. Therefore, in the special period of growth spurt, the impact of height on BMD should be re-evaluated with consideration of gender differences.

In the present study, we investigated the prevalence of low/reduced BMD among Chinese adolescents aged 12-14 years old and the gender disparities in its association with height. The results would shed light on the gender difference in biological factors in growth and provide evidence on the early prevention and the risk factor identification of low/reduced BMD and childhood fractures.

Methods

Subjects

This study is based on data of Youth Health Care Promotion Program (YHCPP). The YHCPP was a cross-sectional study with a total of 8754 adolescents participating in the health examination from 2014 to 2016. The study subjects were recruited from 16 middle schools in Dongli District of Tianjin, China. The age range of the students was 9–19 years old, with most of them being 12–14 years old (8370 students, 95.61% of the 8754). A total of 55 adolescents who lacked height or weight data and 163 adolescents who did not conduct BMD detection were further excluded. Therefore, a total of 8152 adolescents aged 12–14 years old were included in the present study.

The study was approved by the Ethic Committee of Tianjin Women's and Children's Health Center and has been performed in accordance with the ethical standards as laid down in the Declaration of Helsinki and its later amendments or comparable ethical standards. All the individuals were recruited with their voluntary participation, and written informed consent was provided by parents of all the participants.

Measurements

Anthropometrics of height and weight were measured with standard equipment. Body mass index (BMI) was calculated as weight/height squared (kg/m^2). The sex- and age-specific height standard deviation score (height-Z) and BMI standard deviation score (BMI-Z) were calculated using the growth reference data of the World Health Organization for children and adolescents aged 5–19 years (http://www.who.int/growthref/en/).

The BMD was measured by a portable quantitative ultrasound bone device (Sunlight Omnisense 7000), which measures the speed of ultrasonic waves propagating along the bone. Axially transmitted speed of sound (SOS) of the mid-shaft tibia is measured to indicate bone mineral density. The measurements were converted to Z values by using a data bank for age- and gender-matched SOS values in Asian children supplied by the manufacturer. The method of quantitative ultrasound has been used in numerous studies for bone mineral density detection previously [11–13], has been shown to be related to bone mineral density estimated by dual X-ray absorptiometry (DXA) [14], and could be used to resemble the changes in BMC during growth [14]. Children with ultrasound examination Z values less than or equal to -2.0 were defined as "low BMD" as recommended by the International Society for Clinical Densitometry (ISCD) [15], children with Z values less than or equal to -1.0 and greater than -2.0 were defined as "reduced BMD" [16], and children with Z values greater than -1.0 were defined as "normal BMD." All ultrasound measurement was performed by experienced doctors.

Statistical analyses

Descriptive values were given as mean (standard deviation) or number (percentages). Statistical differences in anthropometrics between/among groups of normal BMD and low/reduced BMD were tested using t tests or analysis of variance (ANOVA) for continuous variables and Pearson chi-square tests for categorical variables. Multivariate logistic regression models were used to analyze the association between low/reduced bone mineral density and height-Z with adjustment for age and BMI-Z, and odds ratios (ORs) and 95% confidence intervals (CIs) were calculated. Multiplicative models were used by adding interaction terms (height-Z × gender) to analyze the interaction effect of height and gender on low/reduced bone mineral density. A two-sided $P < 0.05$ was considered as nominally significant. All statistical analyses were performed using Statistical Package for the Social Sciences (SPSS) version 18.0 software (SPSS, Chicago, IL, USA).

Results

General characteristics of the study subjects

A total of 8152 adolescents aged 12–14 years old were included in the analyses, and the general characteristics of the study subjects were shown in Table 1. A total of 4310 adolescents were boys, accounting for 52.9% of the study subjects. The average age was 12.8 ± 0.7 years old, with 3117 (38.2%), 3756 (46.1%), and 1279 (15.7%) of them aged 12, 13, and 14 years old, respectively. The average height, weight, and BMI of the study subjects were 158.8 ± 7.5 cm, 53.1 ± 13.5 kg, and 20.9 ± 4.3 kg/m^2, respectively.

The overall rate of low/reduced BMD in Chinese adolescents aged 12–14 years old was 22.0% (1793/8152), with low BMD rate being 5.3% (429/8152) and reduced BMD rate being 16.7% (1364/8152).

As compared to those with normal BMD, adolescents with low/reduced BMD had a significantly larger proportion of boys (72.3% vs. 47.4%, $P < 0.001$), and in children with low BMD, the proportion of boys was even larger (83.2%). No significant gender difference was observed between adolescents with low/reduced BMD and those with normal BMD ($P > 0.05$). In terms of anthropometrics indicators, adolescents with low/reduced BMD had significantly greater numbers of height (as well as height-Z), weight, and BMI (as well as BMI-Z) as compared with those with normal BMD ($P < 0.001$).

Low/reduced BMD rates in different age and gender groups

Since significant gender proportion difference was found between low/reduced BMD and normal BMD adolescents, we further calculate the low/reduced BMD rates in different gender sub-groups. The low/reduced BMD rates in boys and girls were 30.1% (1296/4310) and 12.9% (497/3842), respectively, with boys significantly exceeding girls ($P < 0.001$). Similarly, the low BMD rate in boys and girls were 8.3% (357/4310) and 1.9% (72/3842), respectively, with boys significantly exceeding girls ($P < 0.001$).

Low/reduced BMD rates were further calculated in different age and gender sub-groups as illustrated in Fig. 1. Linear-by-linear association tests showed that the rate of low/reduced BMD significantly increased with age in boys ($P_{trend} = 0.019$), whereas decreased with age in girls ($P_{trend} = 0.018$), indicating that there might be a gender difference in the trend of low/reduced BMD with age.

Association between height and low/reduced BMD

Considering the gender difference in low/reduced BMD rates as well as the trend with age, the association between height and low/reduced BMD was analyzed in boys and girls separately, as shown in Table 2.

In boys aged 12–14 years old, height-Z was positively associated with low/reduced BMD (OR = 1.30, 95%CI = 1.21–1.39, $P < 0.001$), with each 1 SD in height-Z increasing the risk of low/reduced BMD by 30%. A similar association was found when using different age sub-groups, and boys aged 12 years old had a relatively higher effect coefficient as compared with boys aged 13 or 14 years old. BMI-Z was further adjusted for and height-Z was still positively associated with low/reduced BMD in boys (OR = 1.18, 95%CI = 1.10–1.27, $P < 0.001$).

However, in girls aged 12–14 years old, height-Z was inversely associated with low/reduced BMD (OR = 0.85, 95%CI = 0.78–0.94, $P < 0.001$). Here, height acted as a protective factor instead of a risk factor for low/reduced BMD,

Table 1 General characteristics of the study subjects

Characteristics	Total ($N = 8152$)	Low/reduced BMD			Normal BMD ($N = 6359$)	P*
		Total ($N = 1793$)	Low BMD ($N = 429$)	Reduced BMD ($N = 1364$)		
Gender (boys, %)	4310 (52.9)	1296 (72.3)	357 (83.2)	939 (68.8)	3014 (47.4)	*< 0.001*
Age (years)	12.8 (0.7)	12.8 (0.7)	12.9 (0.7)	12.8 (0.7)	12.8 (0.7)	0.098
Height (cm)	158.8 (7.5)	160.3 (7.8)	161.8 (7.8)	159.8 (7.7)	158.4 (7.4)	*< 0.001*
Weight (kg)	53.1 (13.5)	57.5 (14.3)	61.5 (14.8)	56.2 (14.0)	51.8 (13.0)	*< 0.001*
BMI (kg/m^2)	20.9 (4.3)	22.2 (4.5)	23.4 (4.7)	21.8 (4.4)	20.5 (4.2)	*< 0.001*
Height-Z	0.0 (1.0)	0.1 (1.0)	0.2 (1.0)	0.0 (1.0)	0.0 (1.0)	*< 0.001*
BMI-Z	0.0 (1.0)	0.2 (1.0)	0.4 (1.0)	0.1 (1.0)	− 0.1 (0.9)	*< 0.001*

Data was shown as mean (SD) or number (percentage)

P values < 0.05 were in italics

BMD bone mineral density

**P* values were calculated between children with low/reduced BMD and children with normal BMD

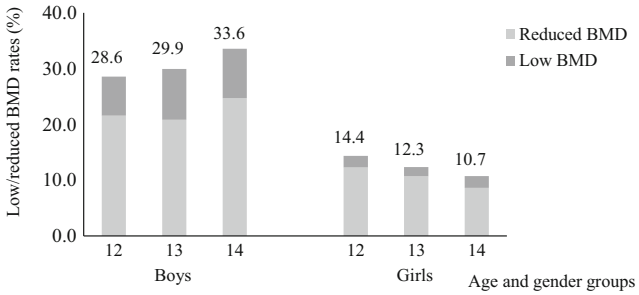

Fig. 1 Low/reduced BMD rates in different age and gender groups. BMD, bone mineral density

and each 1 SD in height-Z decreased the risk of low/reduced BMD by 15%. When using different age sub-groups, although not all sub-groups obtained significant results, the coefficients (ORs) were all below 1. After adjustment for BMI-Z, height-Z was still inversely associated with low/reduced BMD in girls (OR = 0.78, 95%CI = 0.70–0.86, $P < 0.001$).

By further testing the interaction term of height-Z × gender, we found a significant interaction effect between gender and height in the association with low/reduced BMD, no matter analyzed in the overall 12–14 adolescents ($P_{interaction} < 0.001$), or in different age sub-groups ($P_{interaction} < 0.01$), or with adjustment for BMI-Z ($P_{interaction} < 0.01$).

Discussion

In the present study, we analyzed the association between height and low/reduced BMD among Chinese adolescents aged 12–14 years old and the influence of gender. To the best of our knowledge, our study was the first to report the gender difference in the association of BMD with height around the age of growth spurt.

A number of previous studies have reported that bone mineral density may increase with height [7, 8]. In the current study, we found in girls aged 12–14 years old that height was inversely associated with low/reduced BMD, which was in consistency with that in previous studies.

The result of the positive association between height and low BMD in boys aged 12–14 years old was in consistency with the theory that bone mineralization lags behind bone expansion during the growing years, and also in consistency with the increased fracture incidence during the age around 10–14 [2] or 13–14 [3] years old. During the adolescent growth period, there could be a draw on the cortical bone to meet the mineral demands of the expanding skeleton [10], resulting in a temporary period of relative skeletal weakness and a high risk of fracture. Our study was the first to report the positive association between height and low/reduced BMD in boys during the age of growth spurt and may provide import epidemiology evidence for the above theory.

The gender difference of the association directions of low/reduced BMD with height might be attributed to the difference in the starting time of puberty development and peak height velocity (PHV). As Whiting et al. [17] reported, the age of PHV and the age of peak bone mineral content velocity was respectively 13.5 ± 1.0 years old and 14.0 ± 1.0 years old in boys, while 11.8 ± 0.9 years old and 12.5 ± 0.9 years old in girls. Our study recruited middle school students and focused on adolescents aged 12–14 years old. Although the boys and girls were of the same age, the boys aged 12–14 years old may be right now experiencing the PHV, but the girls of the same

Table 2 Association between height-Z and low/reduced BMD in different gender and age groups

Age groups	Boys			Girls			$P_{interaction}$
	N	OR (95% CI)	*P*	*N*	OR (95% CI)	*P*	
Without adjustment for BMI-Z							
12~	1572	1.38 (1.23–1.55)	*< 0.001*	1545	0.93 (0.81–1.07)	0.313	*< 0.001*
13~	1981	1.25 (1.14–1.38)	*< 0.001*	1775	0.81 (0.70–0.93)	*0.002*	*< 0.001*
14~	757	1.26 (1.08–1.47)	*0.004*	522	0.78 (0.59–1.04)	0.090	*0.004*
12–14*	4310	1.30 (1.21–1.39)	*< 0.001*	3842	0.85 (0.78–0.94)	*0.001*	*< 0.001*
With adjustment for BMI-Z							
12~	1572	1.24 (1.10–1.40)	*0.001*	1545	0.82 (0.70–0.95)	*0.008*	*< 0.001*
13~	1981	1.14 (1.03–1.27)	*0.011*	1775	0.74 (0.64–0.85)	*< 0.001*	*< 0.001*
14~	757	1.17 (1.00–1.37)	0.056	522	0.79 (0.59–1.05)	0.108	*0.004*
12–14*	4310	1.18 (1.10–1.27)	*< 0.001*	3842	0.78 (0.70–0.86)	*< 0.001*	*< 0.001*

P values < 0.05 were in italics

BMD bone mineral density

*Age was adjusted for in the 12–14 years adolescents

age may already pass the period of PHV and even entering the period of peak bone velocity. Further studies with a wider age range (especially girls aged 10–12 years old and boys aged 14–16 years old) may provide more evidence for the influence of growth spurt and gender difference on BMD.

The current study had several advantages. First, a relatively large sample size was used. Second, BMI was used as a covariate to analyze the association between height and low/reduced BMD. Overweight/obesity is one of the most important factors that influence BMD [18]. Since height and BMI may increase simultaneously in the process of children's growth and development, the adjustment of BMI in the analyses of the height-BMD association was necessary and may avoid potential confounding factors.

The method of ultrasound was used to test the BMD of participants instead of the method of DXA, which was one of the limitations of the current study. DXA was recommended for bone mineral density testing and has been widely used in previous studies [15]. However, it was argued that the method of DXA may overestimate the actual bone mineral density in growing bones, because bone depth and bone size were not accounted for in DXA scans. Previous studies have suggested that increases in BMD over the growing years can be attributed to the increasing bone size and not BMD [10, 19, 20]. Meanwhile, quantitative ultrasound has the advantage of being cheap and free of radiation, which makes it more suitable for screening in a relatively large population, especially in children and adolescents. During the last years, quantitative ultrasound has been used for bone mineral density testing in different kinds of population like elderly adults [11], pregnant women [12], and postmenopausal women [13].

In conclusion, we presented the gender difference in the association between height and low/reduced BMD among Chinese adolescents aged 12–14 years old. The results may shed light on the gender difference in biological factors in growth, and provide evidence on the early prevention and the risk factor identification of low/reduced BMD and childhood fractures.

Acknowledgements The authors thank all the adolescents who participated in the Youth Health Care Promotion Program (YHCPP).

Compliance with ethical standards

Conflict of interest None.

Ethics approval and consent to participate

The study was approved by the Ethics Committee of Tianjin Women's and Children's Health Center, and written informed consent was provided by all participants.

References

1. NIH Consensus Development Panel on Osteoporosis Prevention D, Therapy (2001) Osteoporosis prevention, diagnosis, and therapy. JAMA. 285(6):785–795
2. Naranje SM, Erali RA, Warner WC Jr, Sawyer JR, Kelly DM (2016) Epidemiology of pediatric fractures presenting to emergency departments in the United States. J Pediatr Orthop 36(4):e45–e48
3. Hedstrom EM, Svensson O, Bergstrom U, Michno P (2010) Epidemiology of fractures in children and adolescents. Acta Orthop 81(1):148–153
4. Moustaki M, Lariou M, Petridou E (2001) Cross country variation of fractures in the childhood population. Is the origin biological or "accidental"? Inj Prev 7(1):77
5. Cooper C, Dennison EM, Leufkens HG, Bishop N, van Staa TP (2004) Epidemiology of childhood fractures in Britain: a study using the general practice research database. J Bone Miner Res 19(12):1976–1981
6. Spady DW, Saunders DL, Schopflocher DP, Svenson LW (2004) Patterns of injury in children: a population-based approach. Pediatrics. 113(3 Pt 1):522–529
7. Naka H, Iki M, Morita A, Ikeda Y (2005) Effects of pubertal development, height, weight, and grip strength on the bone mineral density of the lumbar spine and hip in peripubertal Japanese children: Kyoto kids increase density in the skeleton study (Kyoto KIDS study). J Bone Miner Metab 23(6):463–469
8. Munaisinghe RL, Botea V, Edelson GW (2002) Association among age, height, weight, and body mass index with discordant regional bone mineral density. J Clin Densitom 5(4):369–373
9. Bailey DA, McKay HA, Mirwald RL, Crocker PR, Faulkner RA (1999) A six-year longitudinal study of the relationship of physical activity to bone mineral accrual in growing children: the University of Saskatchewan bone mineral accrual study. J Bone Miner Res 14(10):1672–1679
10. Faulkner RA, Davison KS, Bailey DA, Mirwald RL, Baxter-Jones AD (2006) Size-corrected BMD decreases during peak linear growth: implications for fracture incidence during adolescence. J Bone Miner Res 21(12):1864–1870
11. Barzilay JI, Buzkova P, Cauley JA, Robbins JA, Fink HA, Mukamal KJ (2018) The associations of subclinical atherosclerotic cardiovascular disease with hip fracture risk and bone mineral density in elderly adults. Osteoporos Int 29(10):2219–2230
12. To WW, Wong MW (2012) Bone mineral density changes during pregnancy in actively exercising women as measured by quantitative ultrasound. Arch Gynecol Obstet 286(2):357–363
13. Atteritano M, Lasco A, Mazzaferro S, Macri I, Catalano A, Santangelo A et al (2013) Bone mineral density, quantitative ultrasound parameters and bone metabolism in postmenopausal women with depression. Intern Emerg Med 8(6):485–491
14. Alwis G, Rosengren B, Nilsson JA, Stenevi-Lundgren S, Sundberg M, Sernbo I, Karlsson MK (2010) Normative calcaneal quantitative ultrasound data as an estimation of skeletal development in Swedish children and adolescents. Calcif Tissue Int 87(6):493–506
15. Rauch F, Plotkin H, DiMeglio L, Engelbert RH, Henderson RC, Munns C, Wenkert D, Zeitler P (2008) Fracture prediction and the definition of osteoporosis in children and adolescents: the ISCD 2007 Pediatric Official Positions. J Clin Densitom 11(1):22–28
16. Shaiykova A, Pasquet A, Goujard C, Lion G, Durand E, Bayan T, Lachâtre M, Choisy P, Ajana F, Bourdic K, Viget N, Riff B, Quertainmont Y, Cortet B, Boufassa F, Chéret A (2018) Reduced bone mineral density among HIV-infected, virologically controlled young men: prevalence and associated factors. AIDS. 32:2689–2696

17. Whiting SJ, Vatanparast H, Baxter-Jones A, Faulkner RA, Mirwald R, Bailey DA (2004) Factors that affect bone mineral accrual in the adolescent growth spurt. J Nutr 134(3):696S–700S
18. Yeh LR, Chen CK, Lai PH (2004) Normal bone mineral density in anteroposterior, lateral spine and hip of Chinese men in Taiwan: effect of age change, body weight and height. J Chin Med Assoc 67(6):287–295
19. Fewtrell MS, Gordon I, Biassoni L, Cole TJ (2005) Dual X-ray absorptiometry (DXA) of the lumbar spine in a clinical paediatric setting: does the method of size-adjustment matter? Bone. 37(3): 413–419
20. Leonard MB, Shults J, Elliott DM, Stallings VA, Zemel BS (2004) Interpretation of whole body dual energy X-ray absorptiometry measures in children: comparison with peripheral quantitative computed tomography. Bone. 34(6):1044–1052