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ORIGINAL ARTICLE

Bone mineral density in 11–13-year-old boys: relative importance of the weight status and body composition factors

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Abstract This study was aimed to investigate the influence of being overweight on bone mineral status in 11–13-year-old boys, who were divided into overweight (OW; $n = 110$) and normal weight (NW; $n = 154$) groups. Bone mineral density (BMD) at the whole body (WB), lumbar spine (LS) and femoral neck (FN), bone mineral content (BMC) at the WB, and body composition were assessed. Calculation of the bone mineral apparent density (BMAD) was completed for the WB, LS and FN. The BMC/height ratio was also computed. OW boys displayed similar values ($P > 0.05$) for LS and FN BMAD and lower ($P < 0.05$) WB BMAD, despite significantly higher values ($P < 0.05$) for more widely used WB and LS BMD, WB BMC and WB BMC/height in comparison with NW boys. Fat-free mass index (FFMI; kg/m^2) had the highest correlation coefficients from the calculated body composition indices with all bone mineral values in NW boys. In OW boys, the FFMI had the highest correlation only with FN BMD, while other measured bone mineral values had highest correlations with either BMI or FMI indices. In conclusion, OW boys have higher crude WB BMD, BMC and BMC/height ratio in comparison with NW boys. However, the bone growth appears to be insufficient to compensate for the higher mechanical load applied on the bone by higher FM and also FFM values in OW boys. Excessive adiposity does not have a protective effect on the development of BMAD in growing boys reaching puberty.

Keywords Bone mineral density · Bone mineral apparent density · Overweight · Fat-free mass index · Boys

Introduction

Childhood obesity is an increasing problem all round the world. In adults, it is well established that being overweight is associated with a protective effect on osteoporosis because of the increased bone mineral density (BMD) [1, 2]. In contrast, being overweight in childhood has been linked to an increased risk for bone fractures [2, 3], although there are studies to suggest that obesity has a protective effect on BMD in children [4, 5]. In fact, different studies have found that overweight children may have increased [4, 6], equivalent [7, 8] or decreased bone mineral values [2, 9] in comparison with normal weight children. Furthermore, Rocher et al. [2] concluded that obesity does not have a protective effect on BMD in prepubertal boys and girls. While bone mineralization increases with age, height and body mass throughout childhood [10], the maximal BMD accrual occurs in years surrounding puberty [10, 11]. Early puberty is also a period of increased bone adaptation to mechanical loading due to the velocity of bone growth and endocrine changes at this time [12]. Accordingly, increasing peak bone mass is important protection against fracture risk [13] and it is important to evaluate the relative importance of fat mass (FM) and fat-free mass (FFM) on bone growth in boys with different body mass values during pubertal development.

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Dual-energy X-ray absorptiometry (DXA) has widely been accepted as the preferred method for assessing bone mineral values in children [14–16]. Total and areal BMD values have highly been related to body mass [17, 18], FM [19], FFM [1, 20, 21] and also body mass index (BMI) [19] in children. While DXA does not measure volumetric BMD, different models have been developed to estimate volumetric BMD to reduce the influence of growing bone size on DXA measurements [22, 23]. Therefore, relatively little is known about the predictors of volumetric BMD in boys reaching puberty. In addition, the significance of BMI as an index of overweight is not clear during growth and maturation in children, and the fat mass index (FMI) has been proposed to be a better indicator of body fatness [24, 25]. Accordingly, the aim of the present investigation was to study the influence of overweight on whole body (WB), lumbar spine and femoral neck volumetric BMD values in comparison with normal weight boys reaching puberty. The second aim was to analyze the relationships between bone mineral values and calculated new obesity indices in studied boys.

Methods

Participants

In total, 264 boys aged between 11 and 13 years from different schools in Tartu took part in this cross-sectional study. The participants were divided into normal weight (body fat % <20.7–22.8) and overweight (body fat % ≥21.3–22.8) groups according to the age adjusted cutoffs described by McCarthy et al. [26]. All procedures were approved by the Medical Ethics Committee of the University of Tartu and were explained to the children and their parents who signed a consent form.

Anthropometry and sexual maturation

Body height was measured to the nearest 0.1 cm using Martin's metal anthropometer. Body mass was measured to the nearest 0.05 kg using medical scales (A&D Instruments Ltd, Abingdon; UK). The boys were dressed in light clothing and were wearing no shoes. Pubertal development of the participants was assessed by self-report using an illustrated questionnaire of pubertal stages according to Tanner [27]. The pubertal development assessment according to Tanner method, which uses the self-assessment of genitalia and pubic hair stages, has been previously validated [28, 29]. The boys were given photographs, figures, and descriptions, and asked to choose the one that most accurately reflected their appearance. In case of discrepancies between the two variables, a greater emphasis for the determination of the Tanner stage was placed on the degree of genitalia development [28]. The self-assessment of pubertal development in boys has previously been assessed in our laboratory [30, 31]. In addition, bone age was assessed with an X-ray of the left hand and wrist and determined according to the method of Greulich and Pyle [32].

Bone mineral and body composition assessment

Bone mineral density (g/cm^2) of the whole body (WB), lumbar spine (L2–L4) (LS) and femoral neck (FN), and the WB bone mineral content (BMC) (g) were measured by dual-energy X-ray absorptiometry (DXA) using the DPX-IQ densitometer (Lunar Corporation, Madison, WI, USA) equipped with proprietary software, version 3.6. Bone mineral apparent density (BMAD) (g/cm^3), an estimate of volumetric bone density, was calculated as previously described [22]. For WB, the formula WB BMAD = WB BMC/(WB bone area^2/height) was used. For LS, the formula LS BMAD = LS BMC/LS bone area$^{1.5}$, and for FN, the formula FN BMAD = FN BMC/FN bone area^2 were used [22]. The expression of WB BMC/height was calculated to adjust for WB bone size [33]. Whole body fat percentage, FM, FFM, trunk fat (TF) and leg fat (LF) were also measured via a DXA device. Participants were scanned in light clothing while lying flat on the back, with arms at the sides. The fast scan mode and standard subject positioning were used for total body measurements and analyzed using the extended analysis option. DXA measurements and results were evaluated by the same examiner. Coefficients of variations for bone mineral and body composition measurements were less than 2 %.

Body composition indices

Body mass index (kg/m^2) was calculated as body mass (kg) divided by height squared (m^2) and was used as an indicator of obesity [34]. However, the significance of the BMI is not clear as body mass is composed of two distinct components (i.e., FFM and FM). Therefore, FFM index (FFMI) (kg/m^2) and FM index (FMI) (kg/m^2) were also calculated [24, 35]. These indices should better reflect obesity [25]. In addition, TF:LF ratio was calculated as an indicator of body fat distribution [36].

Statistical analysis

Data analysis was performed using SPSS 15.0 for Windows (Chicago, IL, USA). Standard statistical methods were used to calculate means and standard deviations (±SD). Evaluation of normality was performed with the Shapiro–Wilks statistical method and variables that were not normally distributed were log transformed. Statistical comparisons between groups were performed with parametric unpaired *t* tests. In addition, bone parameters between groups were also compared after adjustment for body mass, FM and FFM using a one-way analysis of covariance (ANCOVA) [2, 21]. Relationships between body composition variables and bone data were analyzed using partial correlation analysis after controlling for age and biological maturation [30, 31]. Statistical significance was set at $P < 0.05$.

Results

Characteristics of the participants

The descriptive characteristics in overweight and normal weight boys are presented in Table 1. Age and body height were not different between groups ($P > 0.05$). Bone age was significantly higher in overweight group ($P < 0.05$). Similarly, overweight boys had significantly higher ($P < 0.05$) values for body fat %, body mass, FM, TF, LF, FFM, TF:LF ratio, BMI, FMI and FFMI compared to normal weight controls.

Bone mineral values

Bone mineral measurements expressed as crude values are displayed in Table 2. WB BMD, LS BMD, WB BMC, and WB BMC/height were significantly higher and WB BMAD significantly lower in overweight boys compared to the respective values in normal weight boys ($P < 0.05$). There were no differences ($P > 0.05$) in FN BMD, LS BMAD and FN BMAD values between studied groups.

Table 1 The descriptive characteristics in overweight and normal weight boys (mean ± SD)

Variable	Normal ($n = 154$)	Overweight ($n = 110$)
Age (years)	12.08 ± 0.77	11.96 ± 0.76
Bone age (years)	11.74 ± 1.20	12.21 ± 1.08*
Body height (cm)	153.6 ± 8.7	155.6 ± 7.6
Body mass (kg)	41.75 ± 8.19	56.57 ± 15.36*
Body fat (%)	16.0 ± 4.1	33.9 ± 7.9*
FM (kg)	6.27 ± 2.15	19.02 ± 9.57*
Trunk fat (kg)	2.20 ± 0.84	8.04 ± 4.57*
Leg fat (kg)	3.11 ± 1.09	8.34 ± 4.12*
FFM (kg)	32.75 ± 6.24	34.51 ± 6.37*
TF/LF ratio	0.71 ± 0.14	0.95 ± 0.21*
BMI (kg/m^2)	17.5 ± 2.2	23.1 ± 4.6*
FMI (kg/m^2)	2.64 ± 0.82	7.69 ± 3.34*
FFMI (kg/m^2)	13.73 ± 1.36	14.13 ± 1.57*
Tanner (1/2/3/4/5)	4/57/76/16/1	4/41/54/11/0

FM fat mass, *FFM* fat-free mass, *TF/LF ratio* trunk fat/leg fat ratio, *BMI* body mass index, *FMI* fat mass index, *FFMI* fat-free mass index

* Significant difference between groups; $P < 0.05$

Table 2 Bone mineral measurements expressed as crude values (mean ± SD)

Variable	Normal ($n = 154$)	Overweight ($n = 110$)
WB BMD (g/cm^2)	0.962 ± 0.065	1.007 ± 0.066*
LS BMD (g/cm^2)	0.815 ± 0.103	0.839 ± 0.092*
FN BMD (g/cm^2)	0.895 ± 0.101	0.904 ± 0.095
WB BMC (g)	1623.4 ± 332.0	1850.3 ± 374.7*
WB BMAD (g/cm^3)	0.089 ± 0.006	0.087 ± 0.006*
LS BMAD (g/cm^3)	0.144 ± 0.015	0.147 ± 0.012
FN BMAD (g/cm^3)	0.202 ± 0.023	0.197 ± 0.023
BMC/height ratio	10.50 ± 1.62	11.82 ± 1.89*

BMD bone mineral density, *BMC* bone mineral content, *WB* whole body, *LS* lumbar spine, *FN* femoral neck, *BMAD* bone mineral apparent density

* Significant difference between groups; $P < 0.05$

Adjusted bone mineral values

DXA measurements adjusted for body mass, FFM and FM are shown in Table 3. WB BMD and BMAD values were significantly higher and lower, respectively, between normal weight and overweight groups when adjusted for FFM ($P < 0.05$), but not when adjusted for body mass or FM values ($P > 0.05$). When measurements were adjusted for body mass or FM, WB BMC or WB BMC/height were significantly lower in overweight boys in comparison with normal weight boys ($P < 0.05$). FN BMD and LS BMD were significantly lower in overweight boys when adjusted for body mass or FM, while no differences in these values between groups were seen when adjusted for FFM ($P > 0.05$). Finally, when measurements were adjusted for body mass, FM or FFM, FN BMAD and LS BMAD were not different between the two groups.

Relationships between body composition and bone mineral values

Body mass, FM, FFM, TF, TF:LF ratio, BMI, FMI and FFMI were all positively related ($P < 0.05$) to WB BMD, WB BMC and WB BMC/height in both groups (Table 4). All body composition variables were negatively related ($P < 0.05$) to WB BMAD in overweight group, while body mass, FM, FFM, TF and FFMI were negatively correlated with WB BMAD in normal weight boys. Almost all presented body composition variables were positively related to LS BMD and LS BMAD ($P < 0.05$), except FMI for LS BMD, and FM and FMI for LS BMAD ($P > 0.05$) in

Table 3 Bone mineral values adjusted for body mass, fat-free mass and fat mass in normal and overweight boys

	Adjusted for body mass		Adjusted for fat-free mass		Adjusted for fat mass	
	Normal	Overweight	Normal	Overweight	Normal	Overweight
WB BMD	0.985 ± 0.004	0.974 ± 0.005	0.968 ± 0.004	0.999 ± 0.004*	0.988 ± 0.006	0.971 ± 0.007
WB BMAD	0.088 ± 0.001	0.089 ± 0.001	0.089 ± 0.001	0.087 ± 0.001*	0.088 ± 0.001	0.089 ± 0.001
WB BMC	1777.1 ± 16.9	1635.2 ± 20.6*	1660.5 ± 11.7	1798.3 ± 13.9*	1789.0 ± 27.6	1618.5 ± 34.5*
BMC/height	11.24 ± 0.09	10.79 ± 0.11*	10.67 ± 0.07	11.58 ± 0.08*	11.33 ± 0.14	10.67 ± 0.17*
FN BMD	0.920 ± 0.008	0.870 ± 0.009*	0.902 ± 0.007	0.895 ± 0.008	0.915 ± 0.009	0.876 ± 0.011*
FN BMAD	0.201 ± 0.002	0.198 ± 0.002	0.202 ± 0.002	0.197 ± 0.002	0.200 ± 0.002	0.200 ± 0.003
LS BMD	0.843 ± 0.007	0.799 ± 0.009*	0.822 ± 0.006	0.829 ± 0.007	0.842 ± 0.009	0.801 ± 0.011*
LS BMAD	0.145 ± 0.001	0.145 ± 0.001	0.144 ± 0.001	0.147 ± 0.001	0.145 ± 0.001	0.145 ± 0.002

BMD bone mineral density, *BMC* bone mineral content, *WB* whole body, *LS* lumbar spine, *FN* femoral neck, *BMAD* bone mineral apparent density

* Significant difference between groups; $P < 0.05$

Table 4 Correlations between whole body (WB) bone mineral values and body composition indices in normal weight and overweight boys controlled for age and pubertal status

	WB BMD		WB BMAD		WB BMC		WB BMC/height	
	Normal	Overweight	Normal	Overweight	Normal	Overweight	Normal	Overweight
Body mass	0.607*	0.705*	−0.421*	−0.502*	0.818*	0.856*	0.774*	0.839*
FM	0.381*	0.615*	−0.190*	−0.489*	0.454*	0.756*	0.459*	0.756*
FFM	0.622*	0.735*	−0.532*	−0.431*	0.895*	0.876*	0.834*	0.839*
Trunk fat	0.422*	0.610*	−0.213*	−0.485*	0.495*	0.737*	0.510*	0.746*
TF/LF ratio	0.199*	0.230*	−0.111	−0.214*	0.211*	0.259*	0.246*	0.290*
BMI	0.465*	0.635*	−0.159	−0.427*	0.474*	0.725*	0.534*	0.745*
FMI	0.253*	0.551*	−0.032	−0.464*	0.224*	0.668*	0.273*	0.689*
FFMI	0.531*	0.586*	−0.347*	−0.406*	0.630*	0.663*	0.680*	0.693*

FM fat mass, *FFM* fat-free mass, *TF/LF* ratio trunk fat/leg fat ratio, *BMI* body mass index, *FMI* fat mass index, *FFMI* fat-free mass index, *BMD* bone mineral density, *BMAD* bone mineral apparent density, *BMC* bone mineral content

* $P < 0.05$

normal weight boys (Table 5). All body composition variables except FMI and FFMI were correlated with LS BMD, while only TF and FMI were significantly related to LS BMAD in overweight boys. All measured body composition variables were significantly correlated with FN BMD in both groups ($P < 0.05$), except TF:LF ratio and FMI in normal weight boys. Finally, no relationships between measured and calculated body composition values with FN BMAD were observed in both groups ($P > 0.05$) (Table 5).

Discussion

This study conducted on 264 Estonian peripubertal boys demonstrated no significant differences in LS BMAD and FN BMAD crude values and also when these values were adjusted for body mass, FFM and FM in studied normal weight and overweight boys. Similarly, WB BMAD was not significantly different between studied boys after adjustment for body mass and FM values, while overweight boys had significantly lower crude WB BMAD values in comparison with normal weight boys. In addition, the FFMI had the highest correlation coefficients from the calculated body composition indices with all bone mineral values in normal weight boys. In overweight boys, the FFMI had the highest correlation only with FN BMD, while other measured bone mineral values had highest correlations with either BMI or FMI values. The main findings of present study were that overweight boys displayed similar values for areal BMAD values and lower WB BMAD values, despite significantly higher values for more widely used WB and LS BMD, WB BMC and also WB BMC/height values in comparison with normal weight peers. These results suggest that BMAD values should be computed and adjusted for different body mass values when assessing bone development in boys reaching puberty. Furthermore, FFMI characterizes better than more widely used BMI bone development in normal weight boys reaching

Table 5 Correlations between areal bone mineral values and body composition indices in normal weight and overweight boys controlled for age and pubertal status

	LS BMD		LS BMAD		FN BMD		FN BMAD	
	Normal	Overweight	Normal	Overweight	Normal	Overweight	Normal	Overweight
Body mass	0.558*	0.532*	0.201*	0.161	0.451*	0.412*	−0.053	−0.110
FM	0.279*	0.455*	0.126	0.187	0.160*	0.322*	−0.128	−0.113
FFM	0.634*	0.563*	0.199*	0.103	0.486*	0.480*	−0.048	−0.078
Trunk fat	0.359*	0.457*	0.197*	0.200*	0.165*	0.344*	−0.122	−0.079
TF/LF ratio	0.280*	0.182	0.241*	0.078	0.012	0.273*	−0.035	0.145
BMI	0.360*	0.438*	0.245*	0.171	0.299*	0.357*	0.040	−0.064
FMI	0.131	0.391	0.118	0.192*	0.038	0.278*	−0.097	−0.090
FFMI	0.520*	0.414	0.286*	0.082	0.384*	0.429*	0.066	0.011

FM fat mass, *FFM* fat-free mass, *TF/LF ratio* trunk fat/leg fat ratio, *BMI* body mass index, *FMI* fat mass index, *FFMI* fat-free mass index, *LS* lumbar spine, *FM* femoral neck, *BMD* bone mineral density, *BMAD* bone mineral apparent density

* $P < 0.05$

puberty. In contrast, BMI and FMI are better determinants of bone mineral values than FFMI in overweight boys of the present study.

In our study, overweight boys had higher WB BMD, LS BMD, WB BMC and also BMC/height ratio than normal weight controls, which is in accordance with other studies conducted in prepubertal children [2] and also in adolescents [21, 37]. It has been suggested that body mass might improve bone mineralization in obese children by increasing the mechanical load of increased body weight especially in weight-bearing bones [2, 6, 21]. Therefore, overweight children should have greater bone strength because of the greater muscle force required to move the increased body weight [4, 37]. Overweight children have not only more FM, but also FFM [9, 21], and this was also the case in our study (see Table 1). In overweight boys, the skeleton must be stronger than in normal weight boys to support their higher body mass [2].

It is interesting to note that while significant relationships between measured and calculated body FM and FFM values were also seen in both groups (see Tables 4, 5), FFM values were better determinants of measured bone mineral values than FM measures in normal weight boys. This is in accordance with the results of other studies conducted in normal weight boys [2, 14, 37, 38]. In contrast, measured and calculated FM indices were better determinants of measured bone mineral values than FFM measures in overweight boys. To date, there is a significant disagreement in the literature regarding the relative contributions of fat and fat-free body components to bone mineral values in growing children [21]. While many studies have demonstrated a positive effect of FM on bone mineral values [4, 6, 13, 21], there are also studies showing that body fat may be a negative determinant of BMD in children [38, 39]. However, it has been suggested that increased FM may be related to bone maturation [37] and bone mass gain accelerates earlier than bone mineral accrual [40]. This was also supported by the findings of present study, where crude values of WB BMC and WB BMC/height ratio were significantly higher in overweight boys in comparison with normal weight boys (see Table 1). During puberty, bone maturation may be mediated by the increasing synthesis of estrogen in the adipose tissue that promotes bone mass accrual [41, 42]. In addition, overweight and excessive adiposity are associated with increased secretion of bone active hormones from the pancreatic beta cells and the adipocytes [36, 43]. These factors may explain the strong relationship between increased FM and bone mineral values in our overweight peripubertal boys. In agreement with our results, it has been suggested that the relationships between FM and FFM values with measures of BMD and/or BMC could be dependent on the weight status of the studied population [21].

It appears that there might be a positive site-specific effect of increased adiposity on bone mineral values during puberty as LS BMD values were significantly higher in overweight boys, while no differences were seen in FN BMD values between studied groups (see Table 2). The FN is mainly composed of cortical bones, whereas LS is mainly composed of trabecular bones [44]. In addition, trabecular bone is known to be more metabolically active than cortical bone tissue [44]. It has been suggested that in response to mechanical loading, cortical bone mainly enhances its size, while trabecular bone mainly increases its density [45]. Furthermore, Rocher et al. [2] argued that WB BMC, which is composed of 80 % of cortical bone, would adapt to increased body weight by increasing both BMC and bone area, while LS would react by improving BMC only in obese prepubertal children. However, to minimize the contributions of bone dimensions on BMD values, different equations have been proposed to calculate volumetric BMD in growing children [22, 23]. In our study, LS and FN BMAD values were not different when expressed as crude values (see Table 2) and also when adjusted for body mass, FFM and FM values (see Table 3) between normal weight and overweight peripubertal boys. These results are in accordance with other studies [2] and would suggest that overweight does not have a protective effect on BMAD values at the specific sites of the skeleton in boys during puberty. In contrast, one could argue that the site-specific effect of mechanical loading and bone metabolic activity on bone mineral development has been demonstrated by the fact that in contrast to LS BMAD, no relationship between FN BMAD with measured and calculated body composition values was seen in both groups (see Table 4). Consequently, further studies are needed before any conclusions can be drawn.

The results of present investigation indicate that adipose tissue may even have negative effect on bone mineral values during puberty as body mass, FM and FFM values were negatively associated with WB BMAD in both groups of studied boys. In general, these relationships appeared to be more stronger in overweight boys (see Table 4). These results are in accordance with the results obtained in adolescent boys and girls [14, 21]. In addition, crude WB BMAD and WB BMAD values adjusted for FFM but not when adjusted for body mass or FM were significantly lower in our overweight peripubertal boys when compared with normal weight boys (see Tables 1, 2). These results are in line with those observed in prepubertal boys and girls [2] and in contrast to adolescent girls [21]. Therefore, El Hage et al. [21] suggested that the relation between bone development and obesity may be sex specific. Accordingly, it could be argued that WB adiposity plays a negative role in bone development at least in boys reaching puberty. In addition, the mismatch between body weight and bone mineralization in overweight children in comparison with normal weight peers increases their propensity to sustain fractures [3]. Therefore, Rocher et al. [2] argued that it is not clear whether the association between fracture occurrence and obesity is a consequence of weaker bones or greater forces applied on the skeleton when a fall occurs.

Our findings partly support the recommendations to use FFMI and FMI in determining the deeper meaning of BMI [25, 46] as FFMI were higher correlated with bone mineral values in normal weight boys, while FMI and also BMI were better determinants of measured and calculated bone measures in overweight boys (see Tables 4, 5). It has been suggested that calculation of FFMI and FMI in the context of BMI enables to identify children with normal BMI and excess adiposity to initiate possible intervention [46]. For example, only FMI was correlated with LS BMAD in overweight boys, while FFMI and also BMI were related to LS BMAD in normal weight boys.

In conclusion, the results of present investigation demonstrate that overweight boys have higher crude WB BMD, BMC and BMC/height ratio values in comparison with normal weight boys. However, this bone growth appears to be insufficient to compensate for the higher mechanical load applied on the bone by higher FM and also FFM values in overweight boys. Specifically, excessive adiposity does not have a protective effect on the development of BMAD in growing boys reaching puberty. Moreover, this study suggests that measured and calculated body composition values were negative determinants of WB BMAD in peripubertal boys. However, BMAD was calculated from the DXA measurements and not assessed by computed tomography, which measures volumetric BMD directly. Another limitation was that diet and especially calcium intake was not measured in this study. Accordingly, further studies are needed to better understand bone growth in boys during puberty.

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Conflict of interest The authors declare that they have no conflict of interest.

References

1. Bakker I, Twisk JWR, Van Mechlen W, Kemper HCG (2003) Fat-free body mass is the most important body composition determinant of 10-year longitudinal development of lumbar bone in adult men and women. J Clin Endocrinol Metab 88:2607–2613
2. Rocher E, Chappard C, Jaffre C, Benhamou CL, Courteix D (2008) Bone mineral density in prepubertal obese and control children: relation to body weight, lean mass, and fat mass. J Bone Miner Metab 26:73–78
3. Goulding A, Jones IE, Taylor RW, Manning PJ, Williams SM, Manning PJ (2001) Bone mineral density and body composition in boys with distal forearm fractures: a dual-energy X-ray absorptiometry study. Pediatrics 139:509–515
4. Leonard MB, Shults J, Wilson BA, Tershakovec AM, Zemel BS (2004) Obesity during childhood and adolescence augments bone mass and bone dimensions. Am J Clin Nutr 80:514–523
5. Heaney R, Abrams S, Dawson-Hughes B, Looker A, Mercus R, Matkovic V, Weaver C (2000) Peak bone mass. Osteoporos Int 11:985–1009
6. Ellis KJ, Shypailo RJ, Wong WW, Abrams SA (2003) Bone mineral mass in overweight and obese children: diminished or enhanced? Acta Diabetol 40:274–277
7. Manzioni P, Brambilla P, Pietrobelli A, Beccaria L, Bianchessi A, Mora S, Chiumello G (1996) Influence of body composition on bone mineral content in children and adolescents. Am J Clin Nutr 64:603–607
8. Hasanoglu A, Bideci A, Cinaz P, Tumer L, Unal S (2000) Bone mineral density in childhood obesity. J Pediatr Endocrinol Metab 13:307–311
9. Goulding A, Taylor RW, Jones IE, McAuley KA, Manning PJ, Williams SM (2000) Overweight and obese children have low

bone mass and area for their weight. Int J Obes Relat Metab Disord 24:627–632
10. Gordon CL, Halton JM, Atkinson SA (1991) The contributions of growth and puberty to peak bone mass. Growth Dev Aging 55:257–262
11. Ausili E, Rigante D, Salvaggio E, Focarelli B, Rendeli C, Ansuini V, Paolucci V, Triarico S (2012) Determinants of bone mineral density, bone mineral content, and body composition in a cohort of healthy children: influence of sex, age, puberty, and physical activity. Rheumatol Int 32:2737–2743
12. Hind K, Burrows M (2007) Weight-bearing exercise and bone mineral accrual in children and adolescents: a review of controlled trials. Bone 40:14–27
13. Clark EM, Ness AR, Bishop NJ, Tobias JH (2006) Association between bone mass and fractures in children: a prospective cohort study. J Bone Miner Res 21(9):1489–1495
14. El Hage R, Moussa E, El Hage Z, Theunynck D, Jacob C (2011) Influence of age and morphological characteristics on whole body, lumbar spine, femoral neck and 1/3 radius bone mineral apparent density in a group of Lebanese adolescent boys. J Bone Miner Metab 29:477–483
15. Gutin B, Litaker M, Islam S, Manos T, Smith C, Treiber F (1996) Body-composition measurement in 9–11-y-old children by dual-energy X-ray absorptiometry, skinfold-thickness measurements, and bioimpedance analysis. Am J Clin Nutr 63:287–292
16. Thomas SR, Kalkwarf HJ, Buckley DD, Heubi JE (2005) Effective dose of dual-energy X-ray absorptiometry scans in children as a function of age. J Clin Densitom 8:415–422
17. Hasselstrøm H, Karlsson KM, Hansen SE, Grønfeldt V, Froberg K, Andersen LB (2006) Sex differences in bone size and bone mineral density exist before puberty. The Copenhagen School Child Intervention Study (CoSCIS). Calcif Tissue Int 79:7–14
18. Reid IR (2002) Relationships among body mass, its components and bone. Bone 31:547–555
19. Reid IR, Lindsay DP, Margaret CE (1992) Fat mass is an important determinant of whole body bone density in premenopausal women but not in men. J Clin Endocrinol Metab 75: 779–782
20. Wang MC, Bachrach LK, Van Loan M, Hudes M, Flegal KM, Crawford PB (2005) The relative contributions of lean tissue mass and fat mass to bone density in young women. Bone 37:474–481
21. El Hage RP, Courteix D, Benhamou CL, Jacob C, Jaffre C (2009) Relative importance of lean and fat mass on bone mineral density in a group of adolescent girls and boys. Eur J Appl Physiol 105:759–764
22. Katzman DK, Bacrach LK, Carter DR, Marcus R (1991) Clinical and anthropometric correlates of bone mineral acquisition in healthy adolescent girls. J Clin Endocrinol Metab 73:1332–1339
23. Kroger H, Vainio P, Niminen J, Kotaniemi A (1995) Comparison of different models for interpreting bone mineral density measurements using DXA and MRI technology. Bone 17:157–159
24. Gaba A, Kapus O, Pelclova J, Reigerova J (2012) The relationship between accelerometer-determined physical activity (PA) and body composition and bone mineral density (BMD) in postmenstrual women. Arch Gerontol Geriatr 54:e315–e321
25. Kelly TL, Wilson KE, Heymsfield SB (2009) Dual energy X-ray absorptiomerty body composition reference values from NHANES. PLoS ONE 4(9):e7038
26. McCarthy HD, Cole TJ, Fry T, Jebb SA, Prentice AM (2006) Body fat reference curves for children. Int J Obes 30:598–602
27. Tanner J (1962) Growth at adolescence, 2nd edn. Blackwell Scientific Publications, Oxford
28. Duke PM, Litt IF, Gross RT (1980) Adolescents' self assessment of sexual maturation. Pediatrics 66:918–920
29. Saito MT (1984) Sexual maturation: self-evaluation of the adolescent. Pediatrica 6:111–115
30. Lätt E, Jürimäe J, Haljaste K, Cicchella A, Purge P, Jürimäe T (2009) Longitudinal development of physical and performance parameters during biological maturation of young male swimmers. Percept Motor Skills 108:297–307
31. Pomerants T, Tillmann V, Karelson K, Jürimäe J, Jürimäe T (2006) Ghrelin response to acute aerobic exercise in boys at different stages of puberty. Horm Metab Res 38:752–757
32. Greulich WW, Pyle SI (1959) Radiographic atlas of skeletal development of hand and wrist, 2nd edn. Stanford University Press, Stanford
33. Bachrach LK, Hastie T, Wang MC, Narasimhan B, Marcus B (1999) Bone mineral acquisition in healthy Asian, Hispanic, black, and Caucasian youth: a longitudinal study. J Clin Endocrinol Metab 84:4702–4712
34. Haslam DW, James WPT (2005) Obesity. Lancet 366:1197–1209
35. van Itallie TB, Yang MU, Heymsfield SB, Funk RC, Boileau RA (1990) Height-normalized indices of the body's fat-free mass and fat mass: potentially useful indicators of nutritional status. Am J Clin Nutr 52:953–959
36. Jürimäe J, Jürimäe T, Ring-Dimitriou S, LeMura LM, Arciero PJ, Von Duvillard SP (2009) Plasma adiponectin and insulin sensitivity in overweight and normal-weight middle-aged premenopausal women. Metabolism 58:638–643
37. El Hage RP, Jacob C, Moussa E, Benhamou CL, Jaffre C (2009) Total body, lumbar spine and hip bone mineral density in overweight adolescent girls: decreased or increased? J Bone Miner Metab 27:629–633
38. Hrafnkelsson H, Sigrudsson G, Magnusson KT, Johannsson E, Sigurdsson EL (2010) Factors associated with bone mineral density and content in 7-year-old children. Bone 46:1058–1062
39. Specker BL, Johannsen N, Binkley T, Finn K (2001) Total body bone mineral content and tibial cortical bone measures in preschool children. J Bone Miner Res 16:2298–2305
40. Bass S, Delmas PD, Pearce G, Hendrich E, Tabensky A, Seeman E (1999) The differing tempo of growth in bone size, mass, and density in girls is region specific. J Clin Invest 104:795–804
41. Cobayashi F, Lopez LA, Taddei JAAC (2005) Bone mineral density in overweight and obese adolescents. J Pediatr 81: 337–342
42. Schoenau E, Neu CM, Rauch F, Manz F (2001) The development of bone strength at the proximal radius during childhood and adolescence. J Clin Endocrinol Metab 86:613–618
43. Artz E, Haqq A, Freemark M (2005) Hormonal and metabolic consequences of childhood obesity. Endocrinol Metab Clin N Am 34:643–658
44. Martin TJ, Ng KW, Nicholson GC (1988) Cell biology of bone. Baillieres Clin Endocrinol Metab 2:1–29
45. Ducher G, Proteau S, Courteix D, Benhamou CL (2004) Cortical and trabecular bone at the forearm show different adaptation patterns in response to tennis playing. J Clin Densitom 7:399–405
46. Eissa MA, Dai S, Mihalopoulos NL, Day RS, Harrist RB, Labarthe DR (2009) Trajectories of fat mass index, fat free-mass index, and waist circumference in children. Am J Prev Med 37:S34–S39