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BONE MINERAL CONTENT AND DENSITY IN OBESE, OVERWEIGHT AND NORMAL WEIGHT ADOLESCENT BOYS

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ABSTRACT • AIM OF THE STUDY: The aim of this study was to compare bone mineral content (BMC), bone mineral density (BMD) and bone mineral apparent density (BMAD) in obese, overweight and normal weight adolescent boys.

METHODS & RESULTS : This study included 23 obese, 19 overweight and 25 normal weight adolescents (aged 14-20 years) boys. The three groups (obese, overweight and normal weight) were matched for age and maturation index. Body composition, BMC and BMD were assessed by dual-energy X-ray absorptiometry (DXA). The expressions whole body (WB) BMC/height and WB BMD/height were used to adjust for WB bone size. BMAD was calculated for the WB. WB BMC, WB BMC/height, total hip (TH) BMD, femoral neck (FN) BMD and ultra distal (UD) radius BMD were higher in obese and overweight boys in comparison to normal weight boys ($p < 0.05$). WB BMAD was lower in obese boys in comparison to overweight and normal weight boys ($p < 0.05$). After adjustment for either weight or lean mass, obese boys displayed lower WB BMC, WB BMC/height and WB BMD values in comparison to overweight and normal weight boys ($p < 0.05$).

CONCLUSION : This study suggests that WB BMC, WB BMC/height and WB BMD do not adapt to the increased body weight in obese adolescent boys.

Keywords : adolescence, body composition, body mass index, bone mass, DXA

INTRODUCTION

Osteoporosis is a systemic skeletal disease characterized by low bone mineral density (BMD) and micro-architectural deterioration of bone tissue, leading to decreased bone strength and increased evidence of fragility fractures [1]. Body mass index (BMI) is a strong predictor of BMD in adults and elderly [2]. In fact, obesity and overweight are associated with higher BMD and decreased risk of fracture especially in post-menopausal women [2]. However, the effects of being obese and overweight on bone mineral content (BMC) and BMD in adolescents remain controversial [3-11]. It is argued that obese and overweight adolescents have either higher [5-7, 9], equivalent [8] or lower BMD and BMC in comparison to controls [3]. This may be explained partially by the following fac-

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El Hage Z, Theunynck D, Jacob C, Moussa E, Baddoura R, Zunquin G, El Hage R. Contenu minéral osseux et densité minérale osseuse chez des adolescents obèses, en surpoids et normo-pondérés. J Med Liban 2013 ; 61 (3) : 148-154.

RÉSUMÉ : OBJECTIF : L'objectif de cette étude était de comparer le contenu minéral osseux (CMO), la densité minérale osseuse (DMO) et apparente (DMOA) chez des adolescents obèses, en surpoids et normo-pondérés.

MÉTHODES & RÉSULTATS : 67 adolescents ♂(âgés de 14 à 20 ans) répartis en trois groupes (23 obèses (OB), 19 en surpoids (SUR) et 25 normo-pondérés (NOR)) ont participé à cette étude. Le poids, la taille ont été mesurés et l'indice de masse corporelle (IMC) calculé. La maturation sexuelle a été évaluée par un auto-questionnaire validé. La composition corporelle (masses maigre et grasse) a été évaluée par absorptiométrie biphotonique à rayons-X (DXA). La DMO a été mesurée par DXA au niveau du corps entier, du rachis lombaire (L2-L4), de la hanche, du col fémoral et de l'avant-bras (1/3 radius et radius ultra-distal). L'âge, les stades de Tanner et la taille n'étaient pas significativement différents entre les trois groupes. Le poids, la masse maigre, la masse grasse et le pourcentage de masse grasse étaient significativement différents entre les trois groupes. Le CMO du corps entier (CE), le rapport CMO CE/taille, la DMO de la hanche, du col fémoral et du radius ultra-distal étaient supérieurs chez les groupes OB et SUR par rapport au groupe NOR ($p < 0,05$). Après ajustement pour le poids (en utilisant une analyse de covariance), le CMO CE, le rapport CMO CE/taille, la DMO CE et la DMO du radius ultra-distal étaient inférieurs chez le groupe OB par rapport aux groupes SUR et NOR ($p < 0,05$).

CONCLUSION : Cette étude suggère que le CMO du corps entier, le rapport CMO corps entier/taille et la DMO du corps entier ne s'adaptent pas à l'excès de poids chez les adolescents obèses.

Mots-clés : adolescence, composition corporelle, indice de masse corporelle, masse osseuse, DXA

tors. Firstly, the relation between fat mass and BMD in adolescence is influenced by sex [12-16]. In reality, fat mass is more strongly related to BMD in girls than boys [12-15]. Secondly, body weight is strongly related to the BMD of the weight-bearing bones and to a lesser extent to the BMD of the non-weight-bearing bones [4]. Finally, the question of adjusting BMC and BMD values for either weight, lean mass, height or BMI in order to judge the effects of overweight and obesity on these parameters remains open [4-7]. Recently, we have compared BMC and BMD in obese, overweight and normal-weight girls [5]. We have found that overweight and obesity are associated with significantly higher BMC, BMC/height, and lower bone mineral apparent density of the whole body [5]. In this study, we aimed at verifying whether the same differences are present in boys. We hypothesized that obese and overweight boys should have higher BMD at the weight-bearing sites in comparison to controls because being obese or overweight is usually associated with higher lean mass for height [5, 7]. The second aim of this study was to explore the relative importance of lean mass and fat mass on BMC and BMD in the whole population.

MATERIAL AND METHODS

Subjects and study design

The study participants (n = 67) were recruited from seven private schools (yearly fees between $2,500 and 2,750) in Beirut, Lebanon. Inclusion criteria were being pubertal (Tanner stage between 3 and 5) boys from 14 to 20 years of age with no diagnosis of comorbidities and no history of fracture. The participants were normal for pubertal stage, non-smokers and had no history of major orthopaedic problems or other disorders known to affect bone metabolism. The boys were divided into three groups (obese [n = 23], overweight [n = 19], and normal weight [n = 25]) using international cut-offs for body mass index (BMI) [17]. An informed written consent was obtained from the children and their parents. This study was approved by the University of Balamand Ethics Committee.

Anthropometric measurements

Height (cm) was measured in the upright position to the nearest 1 mm with a Seca standard stadiometer. Body weight (kg) was measured on a Taurus mechanic scale with a precision of 100 g. The boys were weighed wearing only underclothes. Body mass index (BMI) was calculated as body weight divided by height squared (kg/m^2). Body composition (lean mass, fat mass, body fat percentage) was assessed by dual-energy DXA (Hologic QDR-4500W; Waltham, MA). In our laboratory, the in vivo coefficients of variation were < 1% for fat and lean mass [18].

Bone mass measurements

Bone mineral content (BMC, in g), area (BMA, in cm^2) and density (BMD, in g/cm^2) were determined for each individual. The DXA measurements were completed for the whole body (WB), the lumbar spine (L2-L4), the 1/3 radius, the ultra distal radius (UD), the total hip (TH) and the femoral neck (FN) using the instrument previously described (Hologic QDR-4500W; Waltham, MA).

The Hologic APEX software, version 2 (1986-2007, Hologic Inc.) was used to analyze the DXA scans on the Hologic machine. For WB, the formula of BMAD is: BMC /(BMA^2/body height) [19]. The expressions WB BMC/height and WB BMD/height were calculated to adjust for WB bone size [20]. In our laboratory, the coefficients of variation were < 1% for BMC and BMD [18].

The same certified technician performed all analyses using the same technique for all measurements.

Pubertal status assessment

Tanner pubertal status was determined by self-evaluation, a method of recognized validity and reliability [21]. Children were provided with line drawings of the five Tanner stages and were instructed by a research assistant to choose the drawing that best represented their current stage of development. Children completed the form in a private setting away from the other children.

Daily calcium intake

The estimation of the daily calcium intake was based on a frequency questionnaire [22]. Selection of items was based on the food composition diet, frequency of use, and relative importance of food items as a calcium source. The total number of foods was 30 items. The questionnaire included the following food items: milk and dairy products, including calcium-enriched items such as yoghurt, cheese and chocolate. Items such as eggs, meat, fish, cereals, bread, vegetables and fruits were also included. Adequacy of calcium in the subjects was assessed using the adequate intake guidelines of 1300 mg of calcium.

Physical activity

Exercise frequency was assessed from a questionnaire inquiring about the number of hours spent on sports per week (organized sports plus leisure-time activity). This questionnaire included questions on physical education classes, formal and informal activities, activities done at school, activities done out of school in sports clubs or gyms, as well as activities done at home.

Statistical analysis

The means and standard deviations were calculated for all clinical data and for the bone measurements. Chi^2 tests were used to test the Tanner stage distribution between the three groups. Comparisons between the three groups were made after checking for Gaussian distribution. If Gaussian distribution was found, one-way analyze of variance (ANOVA) tests were used. In other cases, ANOVA on-Ranks tests were used. Associations between clinical characteristics and bone data were given as Pearson correlation coefficients (for normally distributed variables) or Spearman correlation coefficients (for non-normally distributed variables). Multiple linear regression models were used to test the relationships between DXA variables

TABLE I
CLINICAL CHARACTERISTICS in the OBESE, OVERWEIGHT and NORMAL WEIGHT BOYS

	Obese (n = 23)	Overweight (n = 19)	Normal weight (n = 25)
Age (years)	17.1 ± 1.9	16.8 ± 2.2	16.8 ± 2.1
Tanner (3/4/5)	3/9/11	2/11/6	6/8/11
Tanner (mean)	4.3 ± 0.7	4.2 ± 0.6	4.2 ± 0.8
Weight (kg)	105.4 ± 13.6***	75.9 ± 7.1♦♦♦	61.6 ± 7.6▾▾▾
Height (cm)	176.4 ± 6.7	172.5 ± 5.0	173.2 ± 5.6
BMI (kg/m^2)	33.8 ± 3.3***	25.4 ± 1.6♦♦♦	20.4 ± 2.1▾▾▾
Lean mass (kg)	66.0 ± 6.9***	56.0 ± 4.4♦♦	43.7 ±16.0▾▾▾
Lean mass/height (kg/cm)	0.374 ± 0.030***	0.324 ± 0.020♦♦	0.280 ± 0.034▾▾▾
Fat mass (kg)	31.7 ± 6.4***	15.7 ± 4.7♦♦♦	8.3 ± 1.9▾▾▾
Fat mass (%)	31.4 ± 4.0***	20.9 ± 5.1♦♦♦	14.0 ± 2.4▾▾▾
Physical activity (h/week)	3.5 ± 2.5	3.9 ± 2.2	4.0 ± 2.4
Daily Ca intake (mg/d)	1303 ± 457**	934 ± 220♦♦	920 ± 229

BMI: body mass index **Ca**: calcium
***Obese significantly different than normal weight $p < 0.001$
**Obese significantly different than normal weight $p < 0.01$
♦♦♦Overweight significantly different than obese $p < 0.001$
♦♦Overweight significantly different than obese $p < 0.01$
▾▾▾Normal weight significantly different than overweight $p < 0.001$

TABLE II
BONE DATA in the OBESE, OVERWEIGHT and NORMAL WEIGHT BOYS

	Obese (n = 23)	Overweight (n = 19)	Normal weight (n = 25)
WB BMC (g)	2543 ± 295***	2395 ± 291	2088 ± 443▾
WB BMC/height (g/cm)	14.4 ± 1.4***	13.8 ± 1.5	12.0 ± 2.4▾▾
WB BMD (g/cm^2)	1.09 ± 0.08	1.11 ± 0.10	1.03 ± 0.01▾
WB BMD/height (g/cm^3)	0.006 ± 0.001	0.006 ± 0.001	0.006 ± 0.001
WB BMAD (g/cm^3)	0.084 ± 0.007*	0.089 ± 0.008♦	0.089 ± 0.007
L2-L4 BMD(g/cm^2)	0.982 ± 0.135*	0.962 ± 0.119	0.888 ± 0.126
TH BMD (g/cm^2)	1.03 ± 0.12**	1.02 ± 0.13	0.916 ± 0.140▾▾
FN BMD (g/cm^2)	0.972 ± 0.138**	0.941 ± 0.125	0.843 ± 0.144▾
1/3 radius BMD (g/cm^2)	0.690 ± 0.067	0.695 ± 0.059	0.662 ± 0.081
UD radius BMD (g/cm^2)	0.443 ± 0.058**	0.438 ± 0.046	0.391 ± 0.065▾

WB: whole body **BMC**: bone mineral content **BMD**: bone mineral density **TH**: total hip
BMAD: bone mineral apparent density **FN**: femoral neck **UD**: ultra distal
*** Obese significantly different than normal weight $p < 0.001$
** Obese significantly different than normal weight $p < 0.01$
* Obese significantly different than normal weight $p < 0.05$
♦ Overweight significantly different than obese $p < 0.05$
▾▾ Normal weight significantly different than overweight $p < 0.01$
▾ Normal weight significantly different than overweight $p < 0.05$

with lean mass and fat mass, and r^2 were reported. DXA variables were compared after adjustment for age, Tanner stage, total body weight, lean mass, fat mass, and BMI using a one-way analysis of covariance (ANCOVA). Data were analyzed with Number Cruncher Statistical System (NCSS, 2001). A level of significance of $p < 0.05$ was used.

RESULTS

Clinical characteristics of the subjects

Clinical characteristics of the obese, overweight and normal weight boys are displayed in Table I. Age, Tanner stage, height and physical activity (h/week) were not different among the three groups. However, weight, body mass index, lean mass, lean mass/height, fat mass and fat mass percentage were significantly different between the three groups ($p < 0.001$). Finally, daily calcium intake was higher in obese boys compared to overweight and normal weight boys ($p < 0.01$).

Crude bone measurements

Crude bone measurements of the obese, overweight and normal weight boys are listed in Table II. WB BMC, WB BMC/height, TH BMD, FN BMD and UD BMD were higher in obese and overweight boys compared to normal weight boys ($p < 0.05$). WB BMD was higher in overweight boys compared to normal weight boys ($p < 0.05$), while obese boys had higher L2-L4 BMD compared to normal weight boys ($p < 0.05$). WB BMD/height and 1/3 radius BMD were not significantly different among the three groups. Finally, obese boys had lower WB BMAD values in comparison with overweight and normal weight boys ($p < 0.05$).

Correlations between clinical characteristics and bone data (Table III)

Age was positively correlated to WB BMC, WB BMC/height, WB BMD, WB BMD/height, WB BMAD, L2-L4 BMD, TH BMD, 1/3 radius BMD and UD radius BMD. Tanner stage was positively correlated to WB BMC, WB BMC/height, WB BMD, L2-L4 BMD, 1/3 Radius BMD and UD Radius BMD. Weight, lean mass and lean mass/height were positively associated with WB BMC, WB BMC/height, WB BMD, L2-L4 BMD, TH BMD, FN BMD, 1/3 radius BMD and UD radius BMD. Daily calcium intake and physical activity (h/week) were not significantly correlated to bone data. Weight, body mass index, fat mass and fat mass percentage were negatively correlated to WB BMAD.

Multiple linear regression models

Fat mass was negatively associated with WB BMC, WB BMC/height, WB BMD, L2-L4 BMD and UD radius BMD after controlling for lean mass (Table IV).

TABLE III
CORRELATIONS BETWEEN CLINICAL CHARACTERISTICS and BONE DATA in the WHOLE POPULATION

	WB BMC (g)	WB BMC/height (g/cm)	WB BMD (g/cm^2)	WB BMD/height (g/cm^3)	WB BMAD (g/cm^3)	L2-L4 BMD (g/cm^2)	TH BMD (g/cm^2)	FN BMD (g/cm^2)	1/3 radius BMD (g/cm^2)	UD radius BMD (g/cm^2)
Age (years)	0.41***	0.44***	0.49***	0.46***	0.35**	0.50***	0.25*	0.13	0.60***	0.56***
Tanner (mean)	0.30*	0.29*	0.31*	0.24	0.18	0.43***	0.15	0.10	0.52***	0.42***
Weight (kg)	0.65***	0.59***	0.35**	0.21	−0.27*	0.39**	0.41***	0.39***	0.27*	0.45***
Height (cm)	0.46***	0.27*	0.21	−0.11	0.01	0.23	0.14	0.15	0.26*	0.18
BMI (kg/m^2)	0.57***	0.57***	0.34*	0.29*	−0.28*	0.37**	0.41***	0.40***	0.24*	0.44***
Lean mass (kg)	0.79***	0.74***	0.53***	0.36**	−0.12	0.45***	0.44***	0.39**	0.39**	0.46***
Lean mass/height (kg/cm)	0.78***	0.76***	0.55***	0.45***	−0.12	0.46***	0.50***	0.48***	0.43***	0.54***
Fat mass (kg)	0.47***	0.42**	0.16	0.05	−0.40***	0.13	0.21	0.22	0.01	0.24
Fat mass (%)	0.34*	0.31*	0.07	0.01	−0.43***	0.07	0.15	0.17	−0.05	0.19
PA (h/week)	0.01	−0.04	−0.09	−0.18	−0.12	0.06	0.09	0.20	−0.06	0.00
DCI (mg/d)	0.09	0.12	0.04	0.05	−0.12	0.02	0.06	0.13	0.01	0.04

WB: whole body **BMC**: bone mineral content **BMD**: bone mineral density **BMAD**: bone mineral apparent density **TH**: total hip
FN: femoral neck **UD**: ultra distal **PA**: physical activity **DCI**: daily calcium intake ***$p < 0.001$ **$p < 0.01$ *$p < 0.05$

TABLE IV
MULTIPLE LINEAR REGRESSION ANALYSIS MODELS

	Coefficient	SE	*p*
Dependent variable: WB BMC ($r^2 = 0.68$)			
Constant	−9.49	237.0	0.96
Lean mass (kg)	45.5	5.1	*< 0.001*
Fat mass (kg)	−12.8	4.3	*0.004*
Dependent variable: WB BMC/height ($r^2 = 0.58$)			
Constant	1.63	1.43	*0.25*
Lean mass (kg)	0.22	0.03	*< 0.001*
Fat mass (kg)	−0.06	0.02	*0.01*
Dependent variable: WB BMD ($r^2 = 0.46$)			
Constant	0.495	0.092	*< 0.001*
Lean mass (kg)	0.012	0.001	*< 0.001*
Fat mass (kg)	−0.004	0.001	*0.01*
Dependent variable: L2-L4 BMD ($r^2 = 0.27$)			
Constant	0.400	0.119	*0.001*
Lean mass (kg)	0.011	0.002	*< 0.001*
Fat mass (kg)	−0.005	0.002	*0.009*
Dependent variable: UD radius BMD ($r^2 = 0.30$)			
Constant	0.155	0.055	*0.007*
Lean mass (kg)	0.005	0.001	*< 0.001*
Fat mass (kg)	−0.002	0.001	*0.03*

r: correlation coefficient **SE**: standard error **WB**: whole body
UD: ultra distal **BMC**: bone mineral content **BMD**: bone mineral density.

Adjusted bone data

After adjustment for weight, obese boys displayed lower WB BMC, WB BMC/height, WB BMD and UD radius BMD in comparison to overweight and normal weight boys ($p < 0.05$) (Table V). After adjustment for lean mass, obese boys displayed lower WB BMC, WB BMC/height, WB BMD, WB BMD/height and WB BMAD in comparison to overweight and normal weight boys ($p < 0.05$). After adjustment for BMI, obese boys displayed lower WB BMC/height, WB BMD/height and UD radius BMD values in comparison to normal-weight and overweight boys ($p < 0.05$). After adjustment for fat mass, obese and overweight boys displayed higher femoral neck BMD and WB BMD/height values in comparison to normal weight boys ($p < 0.05$). After adjustment for either age or Tanner stage, obese and overweight boys displayed higher WB BMC, WB BMC/height, WB BMD, WB BMD/height, L2-L4 BMD, TH BMD, FN BMD and UD radius BMD values in comparison to normal weight boys ($p < 0.05$).

DISCUSSION

The main finding of this study was that obese adolescent boys displayed lower WB BMC, WB BMC/height, WB BMD and UD radius BMD values in comparison to overweight and normal weight boys after adjusting for body weight. Hence, this study suggests that, in obese adolescent boys, the BMD is not adapted to the increased weight at the whole body and at the UD radius.

Concerning the morphological characteristics, the ratio lean mass/height was higher in obese and overweight boys

TABLE V
BONE DATA ADJUSTED for BODY WEIGHT and AGE in the THREE GROUPS

	Adjusted for body weight			Adjusted for age		
	Obese (n = 23)	**Overweight** (n = 19)	**Normal weight** (n = 25)	**Obese** (n = 23)	**Overweight** (n = 19)	**Normal weight** (n = 25)
WB BMC (g)	1964 ± 64**	2493 ± 64◆◆	2570 ± 64	2559 ± 70***	2400 ± 70◆	2068 ± 70▼
WB BMC/height (g/cm)	11.8 ± 0.3*	14.2 ± 0.3◆	14.1 ± 0.3	14.4 ± 0.3***	13.8 ± 0.3	11.9 ± 0.3▼▼
WB BMD (g/cm^2)	0.991 ± 0.023*	1.12 ± 0.02◆	1.12 ± 0.02	1.10 ± 0.02*	1.11 ± 0.02	1.02 ± 0.02▼
WB BMD/height (g/cm^3)	0.005 ± 0.0001	0.006 ± 0.0001	0.006 ± 0.0001	0.006 ± 0.0001*	0.006 ± 0.0001	0.005 ± 0.0001▼
WB BMAD (g/cm^3)	0.083 ± 0.001	0.089 ± 0.001	0.089 ± 0.001	0.084 ± 0.001	0.089 ± 0.001	0.089 ± 0.001
L2-L4 BMD (g/cm^2)	0.871 ± 0.025	0.979 ± 0.027	0.971 ± 0.024	0.978 ± 0.023*	0.962 ± 0.025	0.890 ± 0.021▼
TH BMD (g/cm^2)	0.920 ± 0.027	1.04 ± 0.02	1.00 ± 0.02	1.03 ± 0.02**	1.02 ± 0.03	0.917 ± 0.026▼▼
FN BMD (g/cm^2)	0.829 ± 0.028	0.952 ± 0.031	0.898 ± 0.027	0.971 ± 0.029**	0.940 ± 0.031	0.843 ± 0.027▼
1/3 radius BMD (g/cm^2)	0.630 ± 0.013	0.705 ± 0.015	0.708 ± 0.013	0.685 ± 0.011	0.695 ± 0.012	0.665 ± 0.013
UD radius BMD (g/cm^2)	0.385 ± 0.011*	0.448 ± 0.012◆	0.435 ± 0.010	0.439 ± 0.009*	0.438 ± 0.010	0.393 ± 0.009▼

Values are means ± standard error. **WB**: whole body **BMC**: bone mineral content **BMD**: bone mineral density **BMAD**: bone mineral apparent density **TH**: total hip **FN**: femoral neck **UD**: ultra distal

** Obese significantly different than normal weight $p < 0.01$ *Obese significantly different than normal weight $p < 0.05$

◆◆Overweight significantly different than obese $p < 0.01$ ◆Overweight significantly different than obese $p < 0.05$

▼▼Normal weight significantly different than overweight $p < 0.01$ ▼Normal weight significantly different than overweight $p < 0.05$

compared to normal weight boys. This result is in accordance with those of several previous studies [5-7]. In fact, being obese or overweight is usually associated with increased lean mass, fat mass and bone mass [5-7].

In our study, overweight and obese boys had higher crude WB BMC and WB BMC/height values in comparison to normal weight boys. Overweight and obesity during adolescence are associated with increased bone mass and bone area [5-7]. Moreover, total hip BMD and femoral neck BMD were also higher in obese and overweight boys compared to normal weight boys while the ratio WB BMD/height and the 1/3 radius BMD were not significantly different between the three groups. These results reinforce the hypothesis which states that obesity and overweight have a site-specific effect on BMD [4]. Actually, the influence of obesity and overweight on weight-bearing bones is the result of load, this effect being comparable to the influence of physical activity [4]. On the whole, this study suggests a positive effect of overweight and obesity on BMD of the weight-bearing bones (especially the total hip and the femoral neck) in adolescent boys. Overweight and obesity may influence bone mass by another mechanism [2, 23]. Free sex hormones, insulin, insulin-like growth-factor-I, leptin, amylin and preptin concentrations increase with obesity; these hormones can stimulate the osteoblastic activity and decrease the osteoclastic activity and may positively influence the BMD of the weight-bearing and the non-weight bearing bones [2, 23]. It is important to note that the BMD of the lumbar spine was not significantly different between overweight and normal weight boys even though it is a weight-bearing site. This may be explained by the fact that the genetic effect appears to be greater in the lumbar spine compared to the femoral neck [24-25]. It is possible that mechanical loading exerts a greater effect on the cortical component of the bony structure of the femur [24-25].

Because BMD is dependent on bone thickness, there is a risk of an overestimated value in tall people and an underestimated value in short people. Katzman *et al.* [19] suggested an equation to minimize the contributions of bone dimensions. Therefore, we included in our study an estimation of BMAD, which is BMC normalized to a derived bone reference volume. We found that bone mineral apparent density was lower in obese boys compared with overweight and normal-weighted boys. These results are in line with those reported by Rocher *et al.* [4]. In fact, the bone mineral area/height and bone mineral area^2/height ratios were higher in obese compared with overweight and normal-weighted boys in this study.

Age, Tanner stage, weight, lean mass and BMI were positively related to BMC and BMD values. These results are in line with those of several previous studies conducted on adolescents [26-31]. In addition, fat mass was negatively correlated to WB BMC, WB BMC/height, L2-L4 BMD and UD radius BMD after controlling for lean mass. In actual fact, BMD adapts primarily to dynamic (lean mass) rather than static loads (fat mass) [4, 6, 12, 31]. After adjustment for weight or lean mass, there were no differences in bone data between overweight and normal weight boys. Thus, BMC and BMD of the overweight boys adapt to the increased weight and lean mass. In contrast, obese boys displayed lower WB BMC, WB BMC/height, WB BMD and UD radius BMD values in comparison to overweight and normal-weighted boys after adjusting for weight and lower WB BMC, WB BMC/height, WB BMD, WB BMD/height and WB BMAD in comparison

to overweight and normal-weighted boys after adjusting for lean mass. Up to our knowledge, it's the first study that shows different effects of obesity and overweight on bone status in adolescent boys. Thus, this study suggests that there is a mismatch between body weight and BMD accrual in obese adolescent boys but not in overweight adolescent boys. This may explain the conflicting results previously reported by several studies comparing only obese to non-obese boys or overweight to normal-weighted boys.

Furthermore, after adjustment for age or Tanner stage, overweight and obese boys displayed higher WB BMC, WB BMC/height, WB BMD, WB BMD/height, L2-L4 BMD, total hip BMD, femoral neck BMD and ultra distal Radius BMD values in comparison to controls. Therefore, this study suggests that in adolescent boys, being overweight or obese is associated with higher BMC and BMD.

In our study, mean daily calcium intake in overweight and normal-weighted boys was below the daily requirements for this age group (1300 mg) [32]. These results are in line with those of several reports which measured daily calcium intake in Lebanese adolescents [33-34]. In addition, daily calcium intake was not significantly related to bone data. These results are in accordance with those of several cross-sectional studies conducted on children and adolescents [5, 12, 18]. The lack of correlation between daily calcium intake and bone data may be due to the cross-sectional nature of this study. Furthermore, genetic factors are the strongest predictors of bone mass accounting for 50-80% of its variance while other lifestyle factors such as nutrition, exercise, and smoking explain an additional 20-30% of bone mass variance [1, 35].

The present study has several strengths. First, it is one of few studies which explored the effects of being obese and overweight on BMC and BMD in pubertal boys. Second, this study aimed at studying the effects of being obese and overweight on BMC and BMD of weight-bearing and non-weight-bearing bones. Last, this study was conducted on Lebanese adolescents; it is well known that Lebanese adolescents have mean BMD values which are lower than Western normative values [36].

We acknowledge several limitations of the study. Firstly, the cross-sectional nature of the study is a limitation since it cannot evaluate the confounding variables. Secondly, the small number of subjects is a limitation. Thirdly, there are well-known difficulties in assessing diet, sexual maturation and physical activity using self-reported questionnaires [37-38]. For instance, Tanner self-assessment does not provide a high degree of accuracy of sexual maturation in obese children [37]. Moreover, food-frequency questionnaires provide a limited list of foods and do not allow specific ingredients to be entered for analysis [38]. Fourthly, BMD measured with DXA is a surrogate for bone strength but not a measurement of it [39]. In fact, bone strength is not only determined by the amount of bone mineral, but also by its partial distribution with respect to the loading forces that may be encountered [39]. Therefore, further investigations on bone geometry and microarchitecture are necessary to better understand the effects of being overweight on the growing skeleton. Finally, according to Bolotin and Sievänen [40], DXA-measured in vivo BMD inaccuracies are patient specific, because the magnitude of the BMD value extracted from a given DXA measurement depends on the exact specifications of the bone marrow composition, the detailed composition of the extra-osseous soft tissue, and the true (not measured) value of BMD (i.e., proportional to the average thickness of bone material along all X-ray paths traversing the given bone-site) actually pertaining within the specific scan region of interest (ROI) of each given patient [40].

In conclusion, this study shows that obese and overweight boys have higher WB BMC, WB BMC/height, total hip BMD, femoral neck BMD and ultra distal radius BMD values in comparison to normal weight boys. However, after adjustment for weight, obese boys displayed lower WB BMC, WB BMC/height, WB BMD and UD radius BMD in comparison to overweight and normal weight boys. Thus, this study suggests that in obese adolescent boys, the bone mineral content and the bone mineral density of the whole body and the bone mineral density of the ultra distal radius do not adapt to the increased body weight. Implementing strategies to increase lean mass and to reduce excess fat mass may be necessary in boys to prevent fractures later in life.

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CONFLICTS OF INTEREST

The authors state that they have no conflicts of interest.

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