

Original Article

Bone mineral content has stronger association with lean mass than fat mass among Indian urban adolescents

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ABSTRACT

Introduction: There are conflicting reports on the relationship of lean mass (LM) and fat mass (FM) with bone mineral content (BMC). Given the high prevalence of Vitamin D deficiency in India, we planned the study to evaluate the relationship between LM and FM with BMC in Indian children and adolescents. The objective of the study was to evaluate the relationship of BMC with LM and FM. **Materials and Methods:** Total and regional BMC, LM, and FM using dual energy X-ray absorptiometry and pubertal staging were assessed in 1403 children and adolescents (boys [B]: 826; girls [G]: 577). BMC index, BMC/LM and BMC/FM ratio, were calculated. **Results:** The age ranged from 5 to 18 years, with a mean age of 13.2 ± 2.7 years. BMC adjusted for height (BMC index and BMC/height ratio) was comparable in both genders. There was no difference in total BMC between genders in the prepubertal group but were higher in more advanced stages of pubertal maturation. The correlation of total as well as regional BMC was stronger for LM (B: Total BMC - 0.880, trunk - 0.715, leg - 0.894, arm - 0.891; G: Total BMC - 0.827, leg - 0.846, arm - 0.815 (all value indicate r^2 , $P < 0.0001$ for all) when compared with FM (B: Total BMC - 0.776, trunk - 0.676, leg - 0.772, arm - 0.728; G: Total BMC - 0.781, leg - 0.741, arm - 0.689; all $P < 0.0001$) except at trunk BMC (LM - 0.682 vs. FM - 0.721; all $P < 0.0001$), even after controlling for age, height, pubertal stage, and biochemical parameters. **Conclusions:** BMC had a stronger positive correlation with LM than FM.

Key words: Bone mineral content, children and adolescents, fat mass, lean mass

INTRODUCTION

Bone mineral accrual during childhood and adolescence depends on genetic factors, hormonal status, growth, sexual maturation, nutritional status including body composition^[1,2] and ethnicity.^[3-5] Several body composition studies have shown the bone mass to vary significantly among ethnic groups.^[4,5] Height has been correlated with bone mineral content (BMC).^[1,6] Since, Asians are shorter

than Caucasians;^[4] it was easy to explain the racial difference in BMC by the height difference. However, height adjusted BMC was reported to be lower in Asians.^[4] The differences in BMC and bone mineral density (BMD) have been noted among genders,^[7-12] particularly during pubertal progression.^[1,2,13-15]

There is growing evidence which suggests that tissues such as fat, muscle, and bone are intimately involved in regulation of each other.^[16] The bone mass is affected by lean mass (LM) and fat mass (FM). Effect of FM is probably mediated through its weight-bearing effect

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and other pathways including adipokines,^[3,6] and lean body mass (LM) positively affect the bone accrual by the mechanical strains.^[2] Though, bone mass has been found to be positively associated with FM^[13-16] and LM^[10,17-22] in children and adolescents, but controversy exists in the relative contribution of each on bone mass.^[23-25]

Among pediatric population for analysis of body composition, dual energy X-ray absorptiometry is most widely used as in addition to bone health, it gives precise information about the total and regional distribution of FM and LM.^[26] There are few Indian studies which have assessed BMD^[27] and BMC^[8] but none have assessed the effect of FM and LM on bone health. In the present study, we have assessed the total and regional BMC among children and adolescents, evaluated the gender differences and its relation with pubertal status, and assessed relative contribution of FM and LM on bone health.

MATERIALS AND METHODS

This study was an extension of the analysis from our earlier study.^[27,28] Adolescents were recruited from different schools in the city of Delhi as a part of a project to generate normative data for BMD. There were 1829 apparently healthy children and adolescents who underwent health examination (clinical, biochemical, and densitometric) on a voluntary basis. The data on BMC, LM, and FM, and its distribution were available from 1403 children and adolescents, for the present study. Children and adolescents with clinically overt hepatic, renal, neoplastic, gastrointestinal, dermatological and endocrine and systemic infective disorders, steroid intake or alcoholism were excluded. Demographic, anthropometric and clinical data were ascertained, and a detailed physical examination conducted. The study was approved by the ethics committee of the Institute of Nuclear Medicine and Allied Sciences and all subjects gave written informed consent.

Pubertal staging was carried out by trained professionals of the same sex based on Tanner criteria.^[29] Testicular volume was determined by comparative palpation with Prader orchidometer (Pharmacia and Upjohn, Uppsala, Sweden). Based on testicular volume, subjects were divided into four stages. Stage 1 (prepubertal) included subjects with testicular volume < 4 ml, Stage 2 (early puberty) - volume \geq 4 ml but \leq 8 ml, Stage 3 - volume > 8 ml but \leq 10 ml, Stage 4 - volume > 10 ml but \leq 15 and Stage 5 (fully mature) - testicular volume > 15 ml. A testicular volume of 4 ml or greater was considered as the onset of puberty. If there was a discrepancy in the testicular volumes of two sides, the larger one was taken as the final volume.

Fasting blood samples were drawn for the estimation of serum 25-hydroxy Vitamin D (25(OH) D), intact parathyroid hormone (iPTH), total and ionized calcium, inorganic phosphorus, and alkaline phosphatase (ALP). The normal range for different biochemical parameters are as follows: Serum total calcium - 2.2–2.55 mmol/L, ionized calcium 1.12–1.32 mmol/L, inorganic phosphorus 0.9–1.5 mmol/L, and ALP < 240 U/L. The serum concentrations of 25(OH) D (reference range: 22.5–94 nmol/L) and PTH (reference range: 10–65 ng/L) were measured by RIA (Diasorin, Stillwater, MN) and electrochemiluminescence assay (Roche Diagnostics, GmdH-Manheim, Germany), respectively.

BMC and regional distribution, FM and LM were measured using the Prodigy Oracle (GE Lunar Corp., Madison, WI) according to standard protocol. Quality control procedures were carried out in accordance with the manufacturer's recommendations. Instrument variation was determined regularly using a phantom supplied by the manufacturer and mean coefficient of variation was < 0.5%. For *in vivo* measurements, mean coefficients of variation for all sites were < 1%. BMC index was calculated by total bone weight in kg divided by square of height in meters. Total and regional BMC were adjusted for height, FM and LM by calculating BMC/Ht, BMC/fat, and BMC/lean ratio.

Statistical analysis was carried out using SPSS version 20.0 (Chicago, IL, USA). Data were presented as mean \pm standard deviation or number (%) unless specified. Independent two variables (gender) were tested by Student's *t*-test. A one-way analysis of variance was used to test differences between pubertal staging using *P* value for trend. *Post-hoc* analysis was used to compare the significance level between two groups within each parameter. Pearson's correlation coefficient was calculated to assess the strength of the relationship between total BMC and its distribution and various anthropometric, biochemical, and densitometric parameters. Multiple regression analysis was done to ascertain association between total and regional BMC as dependable variable and LM or FM, age, SMS, serum calcium, phosphates, serum alkaline phosphatase (SAP), 25(OH) D, and iPTH levels as independent variables.

RESULTS

Basic characteristics of 1403 children and adolescents (B - 826; G - 577) ranging from 5 to 18 years and a mean age of 13.2 ± 2.7 years (B - 13.0 ± 2.7 ; G - 13.4 ± 2.8 years) are as shown in Table 1. Boys were younger, taller and heavier than girls, but their BMI was lower than that of girls. Boys had higher serum 25(OH) D, calcium, phosphates, and ALP levels [Table 1].

BMC at all sites except trunk was higher in boys when compared with girls. When BMC was adjusted for height (BMC index, total BMC/Ht ratio), there was no difference between boys and girls. Similarly, total BMC adjusted for weight was also similar between the genders. BMC/FM was higher while BMC/LM was lower in boys than girls, probably reflecting the higher LM in boys compared to girls [Table 1].

Total and regional BMC were higher in more advanced stages of pubertal maturation, and the difference between early and late puberty persisted even after adjustment for age, except the comparison between pubertal Stages 4 and 5 in girls. Similarly, BMC index only increased significantly between pubertal Stage 3 and 4 in girls and

Stage 4 and 5 in boys after controlling for age [Table 2]. The percentage increase in total BMC from pubertal Stage 1–5 was comparable between genders (B: 125% vs. G: 134%). A similar pattern of increase in BMC was observed at other regions [Supplementary Table 1]. Girls accumulated more BMC per unit of LM during pubertal maturation when compared to boys. However, BMC accumulation per unit of fat remained constant among girls during pubertal progression as compared to boys.

Total and regional BMC were found to be positively correlated with age, height, BMI, total LM and FM, and 25(OH) D levels and negatively correlated with iPTH, ALP, calcium, and phosphorus in the study population and both genders independently [Table 3]. Importantly, correlation of BMC with height was stronger than that with BMI, and LM stronger than FM [Figure 1]. On multiple regression analysis, with adjustment for age, height, serum calcium, phosphates, ALP, 25(OH) D, iPTH, and SMS, the BMC was positively correlated with LM and FM at all sites. The relationship was stronger for total LM except at trunk in girls, where it was stronger for total FM [Table 4].

Table 1: Comparison of anthropometric, hormonal, and densitometric (bone and total body) parameters between boys and girls

Parameters	Boys (n=826)	Girls (n=577)	P
Age (years)	13.0±2.7	13.4±2.8	0.002
Weight (kg)	47.62±15.71	45.89±13.15	0.026
Height (m)	1.56±0.15	1.51±0.11	<0.0001
BMI (kg/m ²)	19.07±4.11	19.76±4.19	0.002
Serum 25(OH)D (ng/ml)	8.21±5.48	7.56±5.25	0.027
Serum PTH (pg/ml)	60.40±46.01	65.83±61.11	0.074
Calcium (mg/dl)	10.12±0.41	9.98±0.42	<0.0001
Phosphorus (mg/dl)	4.36±0.49	4.23±0.52	<0.0001
Serum ALP (IU/L)	471±182	372±179	<0.0001
Ionic calcium (mg/dl)	1.14±0.03	1.14±0.02	0.016
Total BMC (Kg)	1.85±0.64	1.74±0.50	0.001
Arm BMC (kg)	0.220±0.093	0.189±0.060	<0.0001
Leg BMC (kg)	0.729±0.275	0.633±0.191	<0.0001
Trunk BMC (kg)	0.547±0.246	0.550±0.210	0.788
BMC index (kg/m ²)	0.734±0.145	0.746±0.148	0.129
Total LM (kg)	34.18±9.69	27.84±5.38	<0.0001
Total FM (kg)	11.57±8.35	15.78±8.15	<0.0001
Total BMC/height ratio	11.60±3.12	11.38±2.76	0.169
Total BMC/weight ratio	0.039±0.006	0.038±0.005	0.005
Total BMC/FM ratio	0.229±0.140	0.132±0.056	<0.0001
Total BMC/LM ratio	0.053±0.006	0.062±0.010	<0.0001

BMI: Body mass index, 25(OH)D: 25 hydroxy Vitamin D, PTH: Parathormone, FMI: Fat mass index, BMC: Bone mineral content, FM: Fat mass, LM: Lean mass, ALP: Alkaline phosphatase

DISCUSSION

In the present study, we report higher total and regional BMC at all ages in boys when compared to girls except at trunk. Similar observations have been reported among UK,^[10,13] Polish,^[14] Lebanese,^[23] and Thai children and adolescents.^[7] However, there was no significant difference in BMC index, which takes into account differences in height, between genders except in the prepubertal age group. This suggests that BMC is comparable in both genders, when adjusted for height. This was further supported by comparable BMC/Ht ratio and increment in BMC during puberty in both genders. In the present study, the difference in total BMC between genders became significant only after the age of 11 years. A similar observation was made in another Indian study^[8] and in healthy Thai children and

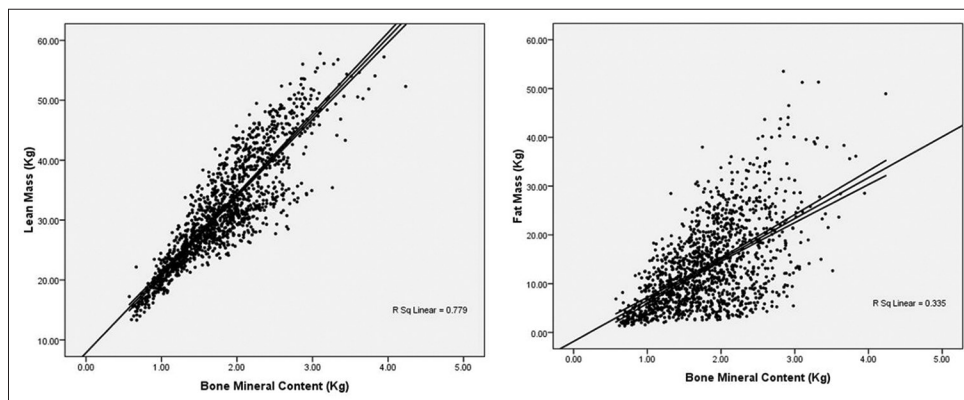


Figure 1: Correlation of total bone mineral content with lean and fat mass in study population

Table 2: BMC according to pubertal staging after adjusting for age

Pubertal staging*	1 (boys=103; girls=39)	2 (boys=194; girls=49)	3 (boys=183; girls=80)	4 (boys=148; girls=117)	5 (boys=198; girls=292)
Total BMC (kg)					
Boys	1.694±0.056 (1.583–1.805)	1.616±0.032 (1.554–1.678)	1.789±0.027 (1.735–1.843)	1.972±0.033 (1.906–2.037)	2.118±0.039 (2.041–2.195)
P**	0.134	<0.0001	<0.0001	<0.0001	0.001
Girls	1.364±0.080 (1.207–1.520)	1.419±0.060 (1.302–1.536)	1.596±0.041 (1.516–1.678)	1.800±0.030 (1.742–1.858)	1.863±0.028 (1.808–1.918)
P	0.443	0.003	0.003	<0.0001	0.137
Arm BMC (kg)					
Boys	0.190±0.008 (0.174–0.205)	0.181±0.004 (0.172–0.189)	0.208±0.004 (0.200–0.215)	0.243±0.005 (0.234–0.252)	0.269±0.006 (0.258–0.280)
P	0.219	<0.0001	<0.0001	<0.0001	<0.0001
Girls	0.140±0.009 (0.122–0.159)	0.149±0.007 (0.135–0.162)	0.169±0.005 (0.159–0.177)	0.198±0.003 (0.191–0.204)	0.206±0.003 (0.199–0.212)
P	0.323	0.004	0.004	<0.0001	0.092
Leg BMC (kg)					
Boys	0.639±0.024 (0.591–0.687)	0.633±0.014 (0.607–0.660)	0.721±0.012 (0.698–0.744)	0.791±0.014 (0.763–0.819)	0.834±0.017 (0.801–0.868)
P	0.810	<0.0001	<0.0001	<0.0001	0.021
Girls	0.444±0.032 (0.381–0.506)	0.499±0.024 (0.452–0.545)	0.604±0.016 (0.572–0.636)	0.671±0.012 (0.648–0.694)	0.675±0.011 (0.652–0.697)
P	0.056	0.001	<0.0001	0.001	0.841
Trunk BMC (kg)					
Boys	0.515±0.026 (0.497–0.599)	0.471±0.013 (0.443–0.500)	0.548±0.015 (0.491–0.541)	0.583±0.015 (0.553–0.613)	0.623±0.018 (0.588–0.658)
P	0.304	0.020	0.020	0.001	0.042
Girls	0.432±0.038 (0.358–0.506)	0.418±0.028 (0.363–0.473)	0.475±0.019 (0.437–0.513)	0.579±0.014 (0.552–0.607)	0.598±0.013 (0.571–0.624)
P	0.678	0.044	0.044	<0.0001	0.358
BMC index (kg/m ²)					
Boys	0.726±0.017 (0.693–0.759)	0.693±0.009 (0.675–0.712)	0.721±0.008 (0.705–0.737)	0.742±0.010 (0.723–0.762)	0.785±0.012 (0.762–0.807)
P**	0.037	0.024	0.024	0.101	0.001
Girls	0.672±0.027 (0.619–0.726)	0.678±0.020 (0.638–0.718)	0.697±0.014 (0.670–0.725)	0.756±0.010 (0.736–0.775)	0.777±0.010 (0.758–0.796)
P**	0.828	0.349	0.349	0.001	0.133

Values are expressed as mean±SE. SE: Standard error, BMC: Bone mineral content

Table 3: Correlation of BMC with anthropometric, hormonal, and densitometric (bone and total body composition) parameters

Parameters	Total BMC	Trunk BMC	Leg BMC	Arm BMC
Boys				
Age (years)	0.793 (<0.0001)	0.707 (<0.0001)	0.797 (<0.0001)	0.804 (<0.0001)
Height (cm)	0.872 (<0.0001)	0.771 (<0.0001)	0.900 (<0.0001)	0.876 (<0.0001)
BMI (kg/m ²)	0.620 (<0.0001)	0.634 (<0.0001)	0.609 (<0.0001)	0.513 (<0.0001)
SMS	0.767 (<0.0001)	0.672 (<0.0001)	0.767 (<0.0001)	0.795 (<0.0001)
Serum 25(OH)D (ng/ml)	0.114 (0.001)	0.099 (0.005)	0.119 (0.001)	0.121 (0.001)
Serum PTH (pg/ml)	-0.183 (<0.0001)	-0.167 (<0.0001)	-0.172 (<0.0001)	-0.173 (<0.0001)
Calcium (mg/dl)	-0.053 (0.131)	-0.033 (0.352)	-0.059 (0.092)	-0.068 (0.050)
Phosphorus (mg/dl)	-0.487 (<0.0001)	-0.427 (<0.0001)	-0.480 (<0.0001)	-0.500 (<0.0001)
ALP	-0.460 (<0.0001)	-0.415 (<0.0001)	-0.449 (<0.0001)	-0.481 (<0.0001)
Total LM (kg)	0.937 (<0.0001)	0.845 (<0.0001)	0.944 (<0.0001)	0.942 (<0.0001)
Total FM (kg)	0.550 (<0.0001)	0.580 (<0.0001)	0.541 (<0.0001)	0.411 (<0.0001)
Girls				
Age (years)	0.760 (<0.0001)	0.685 (<0.0001)	0.721 (<0.0001)	0.775 (<0.0001)
Height (cm)	0.832 (<0.0001)	0.745 (<0.0001)	0.853 (<0.0001)	0.832 (<0.0001)
BMI (kg/m ²)	0.673 (<0.0001)	0.675 (<0.0001)	0.673 (<0.0001)	0.545 (<0.0001)
SMS	0.749 (<0.0001)	0.676 (<0.0001)	0.720 (<0.0001)	0.769 (<0.0001)
Serum 25(OH)D (ng/ml)	0.210 (<0.0001)	0.174 (<0.0001)	0.222 (<0.0001)	0.215 (<0.0001)
Serum PTH (pg/ml)	-0.215 (<0.0001)	-0.186 (<0.0001)	-0.195 (<0.0001)	-0.211 (<0.0001)
Calcium (mg/dl)	-0.283 (<0.0001)	-0.289 (<0.0001)	-0.250 (<0.0001)	-0.281 (<0.0001)
Phosphorus (mg/dl)	-0.499 (<0.0001)	-0.459 (<0.0001)	-0.452 (<0.0001)	-0.494 (<0.0001)
ALP	-0.562 (<0.0001)	-0.520 (<0.0001)	-0.499 (<0.0001)	0.591 (<0.0001)
Total LM (kg)	0.883 (<0.0001)	0.801 (<0.0001)	0.911 (<0.0001)	0.867 (<0.0001)
Total FM	0.761 (<0.0001)	0.773 (<0.0001)	0.757 (<0.0001)	0.607 (<0.0001)

Results are expressed as r value and (P value). 25(OH)D: 25 hydroxy Vitamin D, BMC: Bone mineral content, FM: Fat mass, LM: Lean mass, PTH: Parathormone, ALP: Alkaline phosphatase, SMS: Sexual maturity score

Table 4: Correlation of BMC with lean and fat mass after adjusting for age, height, SMS, serum calcium, phosphates, ALP, 25(OH)D, and iPTH

Parameters	Total BMC	Trunk BMC	Leg BMC	Arm BMC	BMC index
Boys					
Total lean	r ² =0.880 Beta=0.892 P<0.0001	r ² =0.715 Beta=0.839 P<0.0001	r ² =0.894 Beta=0.903 P<0.0001	r ² =0.891 Beta=0.870 P<0.0001	r ² =0.619 Beta=0.845 P<0.0001
Total fat	r ² =0.776 Beta=0.361 P<0.0001	r ² =0.676 Beta=0.420 P<0.0001	r ² =0.772 Beta=0.348 P<0.0001	r ² =0.728 Beta=0.207 P<0.0001	r ² =0.667 Beta=0.523 P<0.0001
Girls					
Total lean	r ² =0.827 Beta=0.693 P<0.0001	r ² =0.682 Beta=0.638 P<0.0001	r ² =0.846 Beta=0.804 P<0.0001	r ² =0.815 Beta=0.615 P<0.0001	r ² =0.642 Beta=0.589 P<0.0001
Total fat	r ² =0.781 Beta=-0.490 P<0.0001	r ² =0.721 Beta=-0.562 P<0.0001	r ² =0.741 Beta=0.516 P<0.0001	r ² =0.689 Beta=0.269 P<0.0001	r ² =0.709 Beta=-0.568 P<0.0001

Results are expressed as r², beta-coefficient and P value. BMC: Bone mineral content, 25(OH)D: 25 hydroxy Vitamin D, ALP: Alkaline phosphatase, iPTH: Intact parathyroid hormone, SMS: Sexual maturity score

adolescents.^{17]} However, a study from Poland reported no difference in total BMC till the age of 16 years between genders.^{130]} Since BMC index is adjusted for height and does differ between genders, it can become a useful tool for assessing musculoskeletal health in children and adolescents.

As reported earlier,^{18,28]} we also found that puberty is associated with an increase in total and regional BMC. The overall increase in total BMC during pubertal progression in present study was lower than that reported in another

study from India (B: 125% vs. 184%; G: 134% vs. 177%),^{18]} but was similar to that reported in young Asian and Caucasian Americans (B: 119%; G: 140%).^{14]} Studies among Caucasians, Polish, and adolescents from Thailand reported higher bone mass accrual among boys compared to girls.^{14,7,14]} Total and regional BMC increases with age, which may also contribute to the increment in BMC observed during the evolution of puberty. After adjusting for age, there was no difference in total and regional BMC between pubertal Stages 1 and 2, suggesting that this is age related, whereas, the contribution of puberty to increase

in BMC predominantly begins from pubertal Stage 3. A similar observation was made by Ashby *et al.*, who reported no difference between genders in total BMC till pubertal Stage 3.^[13] This may be due to the fact that bone accrual follows the peak height velocity.

Our results showed that total and regional BMC was positively related to total LM and FM, which persisted after adjusting for anthropometric and biochemical parameters. Previous studies have also reported a positive association between BMC and LM after controlling for various factors.^[3,5,9-11,17,18,20-22] As reported previously,^[9,11] BMC had a higher Pearson's correlation coefficient for LM in boys when compared to girls. The relation between BMC and FM has been inconsistent, with reports showing a positive,^[3,9,17-21] negative correlation^[18,31] and absent correlation.^[23] Similar to earlier literature,^[3,13,32] we also report that the relation between LM and total and regional BMC was stronger than FM in both genders, except trunk BMC in girls. Other studies, including a longitudinal birth cohort study, showed a stronger correlation between total FM and BMC in girls as compared to boys.^[6,9,23,25,33] On the contrary, a study from Italy found that the association between BMC and FM in boys and girls was comparable.^[3] This heterogeneity in observations can be due to differential sensitivity of trabecular and cortical bone to mechanical loading and response to adipokines.^[34] It has been reported that FM is a stronger stimulus for the accrual of cortical bone mass in girls with a greater tendency to stimulate periosteal growth and suppress endosteal expansion.^[25]

The main limitation was the cross-sectional design of our study, which makes it difficult to assess the sequential changes in BMC with the progression of puberty. Correlation between various factors may differ between cross-sectional and longitudinal study.^[5,18,22] In the present study, there is no information available on genetics, plasma hormones, nutritional status, physical activity, or growth and development in our subjects, which have been shown to have an impact on BMC.^[1,2,35]

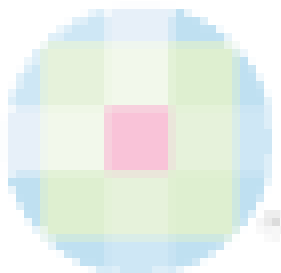
CONCLUSION

Boys had higher BMC than girls, but height adjusted BMC was comparable in both genders. We demonstrated that LM was more strongly associated with BMC than FM.

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Supplementary Table 1: BMC according to pubertal staging

Pubertal staging*	1 (boys=103; girls=39)	2 (boys=194; girls=49)	3 (boys=183; girls=80)	4 (boys=148; girls=117)	5 (boys=198; girls=292)
Total BMC (kg)					
Boys	1.114±0.286 (1.058–1.170)	1.385±0.294 (1.344–1.427)	1.792±0.429 (1.729–1.854)	2.153±0.465 (2.077–2.229)	2.507±0.488 (2.438–2.575)
Percentage increase [§]		24.3	29.4	20.1	16.4
P**	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Girls	0.869±0.240 (0.791–0.947)	1.108±0.194 (1.052–1.163)	1.431±0.325 (1.359–1.503)	1.780±0.355 (1.715–1.845)	2.035±0.488 (1.994–2.076)
Percentage increase		27.5	29.2	24.4	14.3
P	0.005	0.001	<0.0001	<0.0001	0.001
P***	<0.0001	0.107	0.393	<0.0001	<0.0001
Arm BMC (kg)					
Boys	0.111±0.033 (0.105–0.117)	0.150±0.040 (0.144–0.155)	0.208±0.060 (0.199–0.277)	0.267±0.086 (0.256–0.278)	0.322±0.069 (0.312–0.331)
Percentage increase [§]		35.1	38.7	28.4	20.6
P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Girls	0.083±0.033 (0.072–0.094)	0.112±0.027 (0.105–0.120)	0.149±0.038 (0.141–0.157)	0.195±0.042 (0.187–0.203)	0.222±0.040 (0.221–0.230)
Percentage increase [§]		34.9	33.0	30.9	15.9
P	<0.0001	<0.0001	0.002	0.002	<0.0001
P***	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Leg BMC (kg)					
Boys	0.359±0.146 (0.361–0.418)	0.534±0.143 (0.514–0.554)	0.723±0.190 (0.695–0.750)	0.869±0.183 (0.840–0.899)	1.002±0.201 (0.973–1.030)
Percentage increase [§]		32.5	35.4	20.2	15.3
P	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Girls	0.279±0.102 (0.246–0.312)	0.395±0.085 (0.371–0.420)	0.549±0.140 (0.518–0.580)	0.664±0.143 (0.638–0.690)	0.732±0.134 (0.716–0.747)
Percentage increase [§]		37.3	39.0	20.9	10.2
P	<0.0001	<0.0001	<0.0001	<0.0001	0.021
P***	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Trunk BMC (kg)					
Boys	0.320±0.241 (0.273–0.367)	0.381±0.123 (0.363–0.398)	0.517±0.163 (0.493–0.540)	0.654±0.200 (0.622–0.687)	0.776±0.197 (0.748–0.803)
Percentage increase [§]		19.1	35.7	26.5	18.7
P	0.246±0.090 (0.217–0.275)	0.007	<0.0001	<0.0001	<0.0001
Girls	0.246±0.090 (0.217–0.275)	0.301±0.074 (0.280–0.322)	0.413±0.134 (0.383–0.443)	0.572±0.182 (0.538–0.605)	0.662±0.164 (0.643–0.681)
Percentage increase [§]		22.4	37.2	38.5	15.7
P	0.064	<0.0001	0.001	<0.0001	0.005
P***	<0.0001	<0.0001	<0.0001	0.001	<0.0001
BMC index (kg/m ²)					
Boys	0.611±0.081 (0.595–0.627)	0.648±0.086 (0.635–0.660)	0.722±0.118 (0.705–0.739)	0.778±0.123 (0.758–0.798)	0.861±0.144 (0.841–0.881)
Percentage increase [§]		6.1	11.4	7.8	10.7
P**	0.010	<0.0001	<0.0001	<0.0001	<0.0001
Girls	0.536±0.078 (0.511–0.562)	0.592±0.063 (0.574–0.610)	0.652±0.108 (0.628–0.676)	0.750±0.119 (0.728–0.772)	0.825±0.120 (0.811–0.838)
Percentage increase [§]		10.5	10.1	15.0	10.0
P**	<0.0001	0.021	0.004	<0.0001	<0.0001
P***	<0.0001	<0.0001	<0.0001	0.061	0.002

* P value trends <0.0001 for all; [§]Percentage increase of mean lean mass between successive pubertal stage; ** P value between successive pubertal staging within each gender; *** P value between gender at each pubertal staging. BMC: Bone mineral content