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The Relationship Between Childhood Growth, Bone Mass, and Muscle Strength in Male and Female Adolescents

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Abstract. In this population-based study, the relationship between childhood weight and height, and adolescent bone mass and muscle strength have been studied in 39 girls and 48 boys. Total body and femoral neck bone mass measurements (bone mineral content, BMC and bone mineral density, BMD) were made by dual X-ray absorptiometry. Quadriceps muscle strength was measured. Mean age at the time of measurement was 15.1 years for girls and boys. Results were individually linked to data on childhood (birth to 6 years of age) weight and height, taken from community health records. Childhood weight was found to be predictive of adolescent total body BMC (TBMC). However, this was not the case when correlating childhood weight and total body BMD (TBMD), suggesting that growth determines the size of the skeleton, whereas the density within that bone envelope is to a greater extent governed by other factors. Further, in a multiple regression model we found that the combined effect of childhood weight and height was significantly correlated with adolescent quadriceps muscle strength.

Key words: Bone mineral density — Bone mineral content — Childhood growth — Dual X-ray absorptiometry — Muscle strength.

The peak bone mass attained during childhood and adolescence is known to influence the later risk of osteoporotic fracture. However, the determinants of the increase in bone size and mineral density during this period of life remain uncertain. In children, there seems to be a close relationship between bone mass and body size [1–4], suggesting that the skeletal growth trajectory might be programmed early in life. Indirect evidence for such programming comes from epidemiological studies which have suggested a relationship between body weight in infancy and adult bone mineral content (BMC) [5, 6]. These observations, if reproducible, would suggest that an adverse environment during intrauterine and early postnatal life might permanently alter the rate of bone mineral density (BMD) in the skeleton and thereby influence peak bone mass. To explore this hypothesis, we examined the relationship between weight and height at various times in childhood, and between adolescent bone mass and muscle strength, in a population-based cohort study.

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Table 1. Current age, anthropometric and bone mineral data, and menarcheal age for girls and boys included in study

	Girls (n = 39)		Boys (n = 48)	
	Mean	± SD	Mean	± SD
Age	15.1	0.4	15.1	0.3
Weight (kg)	56.3	7.4	60.4	8.6
Height (cm)	167.3	5.9	173.9	8.9
Total body BMC (g)	2420.2	299.4	2633.9	448.7
Total body BMD (g/cm^2)	1.11	0.07	1.09	0.09
Femoral neck BMC (g)	5.10	0.80	5.70	1.00
Femoral neck BMD (g/cm^2)	1.04	0.13	1.06	0.14
Menarcheal age	12.4	1.1	—	—

Subjects and Methods

All ninth grade students (120) in the school of the suburban community of Kirseberg, Malmö (population 11,000) were recruited. A total of 101 (84%) responded. The demographic structure of this population has been well characterized by the Department of Community Health Sciences, Lunds University and found to be similar to that of the entire city of Malmö (population 240,000) [7].

Anthropometric data included weight and height. Bone mineral was measured in each subject by dual X-ray absorptiometry (DXA) at the femoral neck and total body using a Lunar instrument (Model DPX; Lunar Radiation Corp, Madison, WI). The technical details for DXA have been reported by Mazess et al. [8]. Two parameters were utilized: bone mineral content (BMC) and bone mineral density (BMD). BMD is an area density and is expressed as BMC (grams) of a cross-sectional area (cm^2) of the bone measured. Strength in the leg extensors (quadriceps muscle) was measured utilizing a isokinetic muscle force meter (Biodex®, Smith & Nephew). PT 60 (peak torque 60°/second) was assessed and used as a determinant for muscle strength.

By reviewing birth and community health records, kept by the public health service, we were able to find individual information on weight and height during infancy and childhood on 49 boys and 38 girls. All participants were born at 37 weeks or more of gestation. Subjects with chronic illness or medication known to affect growth or bone mass development were excluded. Items of information available included weight and height at birth, 2, 4, and 6 months, and 1, 2, 3, 4, and 6 years. Statistical Analysis System® software was used for data analysis. Associations between variables were examined using linear and multiple linear regression models. The significant level was set at less than 0.05.

This study was approved by the Ethics Committee of Lund/Malmö University. Informed written consent was obtained from all subjects and their parents.

Results

Table 1 displays the age distribution and anthropometric

Table 2. Correlations between weight in infancy and childhood and adolescent bone mass

	Weight									
Girls	Birth	1 month	2 month	4 month	6 month	1 year	2 years	3 years	4 years	6 years
Measure										
Total body BMC	−0.31	−0.14	0.00	−0.07	−0.14	0.02	0.24	0.26	0.44[b]	0.37[a]
Total body BMD	−0.38	−0.28	−0.19	−0.27	−0.31	−0.37	−0.17	−0.04	0.01	0.02
Femoral neck BMC	−0.22	−0.25	−0.19	−0.37	−0.36	0.02	0.15	−0.02	0.07	0.02
Femoral neck BMD	−0.3	−0.34	−0.43	−0.44	−0.41	−0.13	−0.08	0.03	0.01	−0.07

	Weight									
Boys	Birth	1 month	2 months	4 months	6 months	1 year	2 years	3 years	4 years	6 years
Measure										
Total body BMC	−0.19	0.07	0.15	0.23	0.21	0.20	0.12	0.25	0.41[a]	0.44[b]
Total body BMD	−0.19	−0.19	−0.13	0.00	−0.02	−0.08	−0.13	−0.04	0.08	0.15
Femoral neck BMC	−0.25	0.15	0.17	0.14	0.16	0.26	0.20	0.23	0.18	0.27
Femoral neck BMD	−0.21	−0.11	−0.09	−0.05	−0.03	−0.04	−0.10	−0.10	−0.08	0.01

For numbers measured at each age see Table 2.
Figures are correlation coefficients.
[a] $P < 0.05$, [b] $P < 0.01$, [c] $P < 0.001$.

and bone mineral data of the study objects. Boys and girls had the same mean age: 15.1 years. Mean weight and height were higher for boys (60.4 kg/173.9 cm) than for girls (56.3 kg/167.3 cm). Mean age of menarche among the girls was 12.4 years. The relationships between body weight at various times during infancy and childhood and skeletal status (BMD, BMC) at age 15 years are shown in Table 2. Statistically significant positive correlations were found between weight and total body BMC (TBMC) but not total body BMD (TBMD) at ages 4 and 6 years for boys and girls. Figure 1 illustrates the differences in correlation coefficients between weight and TBMC, and weight and TBMD at different ages. In Figures 2 (boys) and 3 (girls) subjects have been divided into three weight groups (tertiles) according to their weight at 6 years, with a presentation of corresponding adolescent bone mass values (TBMC and TBMD) in a box and whisker plot. Differences in the relationship between childhood weight and TBMC/TBMD are evident.

In order to more accurately reflect the body build of participants, the relationship between the combined effects of weight and height at various ages, and adolescent weight, height, muscle strength, and bone mass measurements were explored (Table 3). The matrix shows that weight and height at 1 year are strongly predictive of adolescent weight and height by the age of 1 year. Similar associations are seen for early childhood growth and TBMC and muscle strength. A statistically significant correlation between childhood weight and height, and TBMD or femoral neck BMC and BMD could not be established.

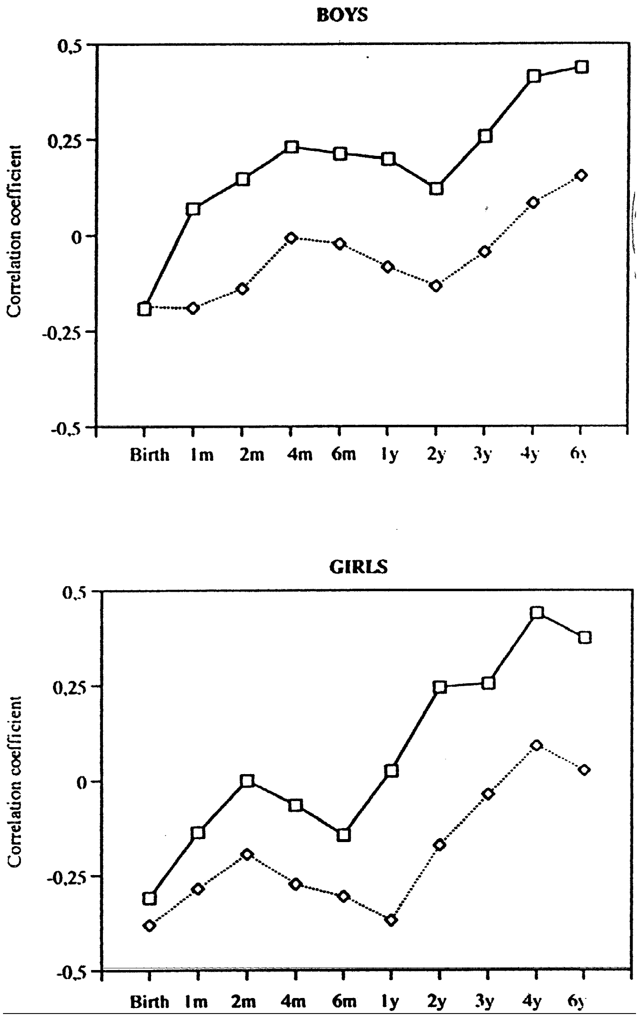

Fig. 1. Correlation coefficients in the relationship between body weight at different ages and adolescent TBMC and TBMD, for boys and girls. (□) BMC-total body; (◇) BMD-total body.

Discussion

In this population-based study, childhood anthropometric data have been used to examine the relationship between childhood weight and height, and adolescent weight, height, muscle strength, and bone mass. Birth weight does not correlate well with adolescent bone mass or any of the other variables we have measured. Similar observations have been made by others [9]. They probably reflect the main

Table 3. Multiple linear regression showing the relationship between the combined effect of weight and height in infancy and childhood (independent variables) and adolescent height, weight, muscle strength, and bone mass (dependent variables)

	Weight, height				
Girls	Birth	6m	1y	4y	6y
Measure (adolescents)					
Height	0.39	0.41	0.66[a]	0.82[c]	0.77[c]
Weight	0.16	0.16	0.56[a]	0.68[c]	0.74[c]
Total body BMC	0.12	0.32	0.36	0.53[b]	0.60[c]
Total body BMD	0.33	0.33	0.40	<0.1	0.22
Femoral neck BMC	<0.1	0.55	0.33	0.37	0.38
Femoral neck BMD	0.25	0.45	0.36	0.15	0.30
Muscle strength (PT 60)	0.31	0.55[a]	0.30	0.51[a]	0.43[a]

	Weight, height				
Boys	Birth	6 months	1 year	4 years	6 years
Measure (adolescents)					
Height	0.41	0.78[c]	0.79[c]	0.87[c]	0.83[c]
Weight	0.35	0.41	0.78[c]	0.58[c]	0.68[c]
Total body BMC	0.14	0.19	0.59[a]	0.56[b]	0.47[a]
Total body BMD	0.24	<0.1	0.34	0.23	0.16
Femoral neck BMC	0.13	0.32	0.49	0.29	0.33
Femoral neck BMD	0.26	<0.1	0.16	<0.1	<0.1
Muscle strength (PT 60)	0.27	0.41	0.61[a]	0.57[b]	0.56[b]

Figures are correlation coefficients
[a] $P < 0.05$; [b] $P < 0.01$; [c] $P < 0.001$

determinants of birth weight, i.e., maternal age and height, maternal smoking, parity [10]. Statistically significant positive correlations were found in boys and girls between weight at 4 and 6 years and TBMC but not for TBMD. This relationship was strengthened when height was included in the calculations in a multiple regression model. A plausible explanation for this is that BMD is a partially size-corrected measure whereas BMC is relatively more size dependent, although this distinction is by no means clear [11].

These findings support those of previous workers [5] in suggesting that the size of the envelope (BMC) and the mineral density within that envelope are determined by different factors. The size of the envelope appears to be closely related to the general growth trajectory of the child, which seems to be ‘determined’ early in life since we also see a very strong relationship between childhood and adolescent body build. As shown in Figure 1, it seems as if there is no close relationship between childhood weight and the development of mineral density—in this case TBMD—within the given envelope. However, it is suggested that BMD in children can be modified by factors such as physical activity and calcium intake [12, 13]. No statistically significant relationship of the kind discussed above was found in the femoral neck, although the change of correlation coefficients at different ages in males shows a similar pattern to that of total body measurements, and the lack of statistical significance may be due to the relatively small sample size (weight age 6 years—adolescent femoral neck BMC; $n = 37$, $r = 0.27$, $P = 0.10$). The different pattern in the female hip contradicts the findings of previous studies [5]. However, by dividing subjects in our study into three groups according to their weight at 6 years and looking at the corresponding adolescent bone mass values (Fig. 3), suggests that the conclusions drawn above with regard to childhood weight to adolescent TBMC/TBMD relationships also have some validity in the female hip.

It is likely that physical activity has an influence on muscle strength. We know from previous research that there are differences in levels of physical activity in this group not related to body size. In spite of this we found statistically significant associations between childhood body size (weight, height) and adolescent muscle strength (quadriceps). This leads us to believe that there is a significant genetic contribution to adult muscle mass as well as there is for adult weight and length [14], and as we have seen, for the size of the skeletal envelope. Further, recent studies suggest that the development of bone mass towards its peak is also mainly governed by hereditary factors [15–17], which may explain why we sometimes find it hard to detect signs of environmental modulation in our studies of bone mass development.

Subjects participating in our study were approximately 15 years old when bone mass was measured. By reviewing data from population-based studies in the same community we have information about average height and a prediction of peak bone mass bone mass levels for men and women that we know have completed their longitudinal growth (age 20–40 years). This information tells us that girls in our study seem to have completed their longitudinal growth since they had the same length as the older group, whereas boys were 6.5 cm shorter. Further, peak bone mass has probably not been reached in the group studied here. Girls in the present study have reached 94.1% and boys 89.3% of predicted peak TBMD. However, in spite of this, we believe that the observations we have made regarding the relationship between childhood body size and adolescent bone mass would be similar for a population that has reached peak bone mass.

In summary, this longitudinal study has shown that

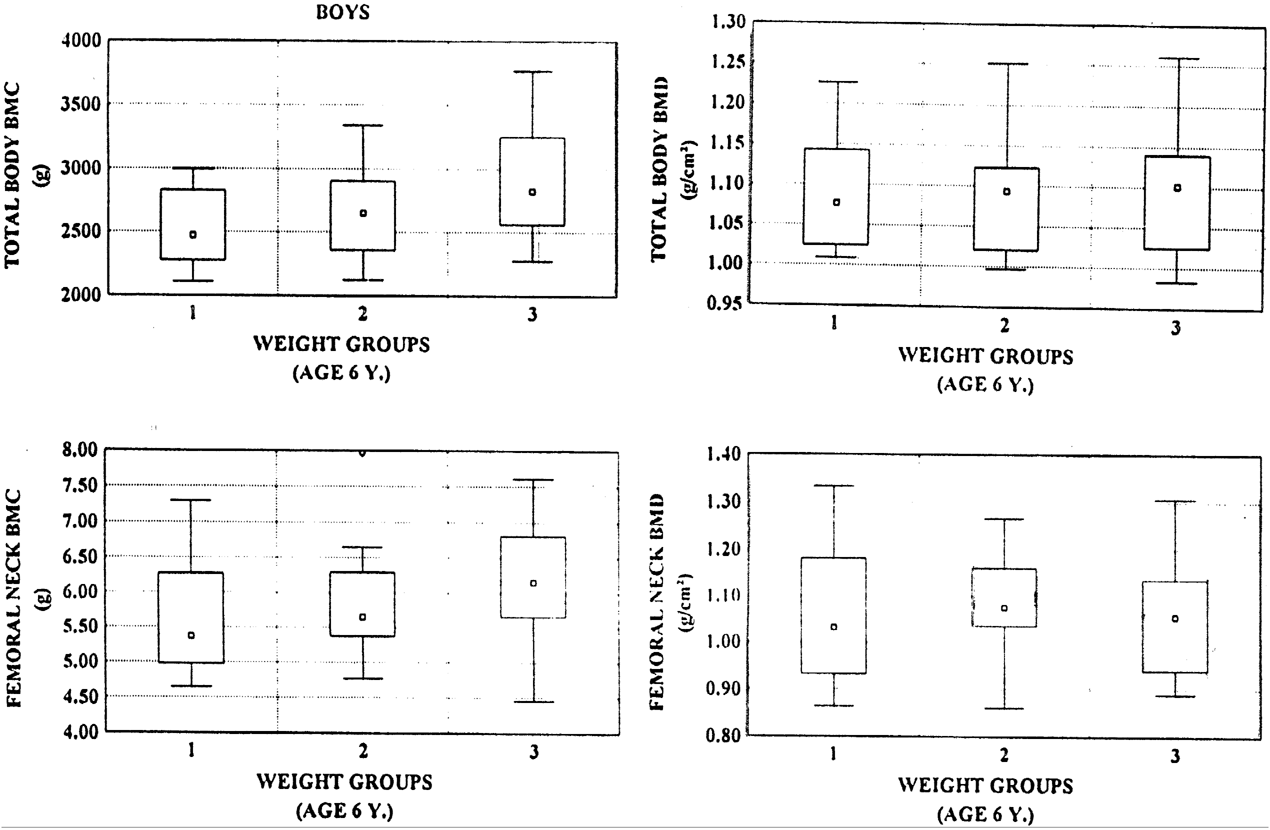

Fig. 2. Boys in three weight groups (tertiles) according to their weight at 6 years, and the corresponding adolescent total body and hip bone mass (BMC and BMD). The outer box indicates the lower and upper quartiles, small squares the median, 'whiskers' the extremes, and small circles the outliers.

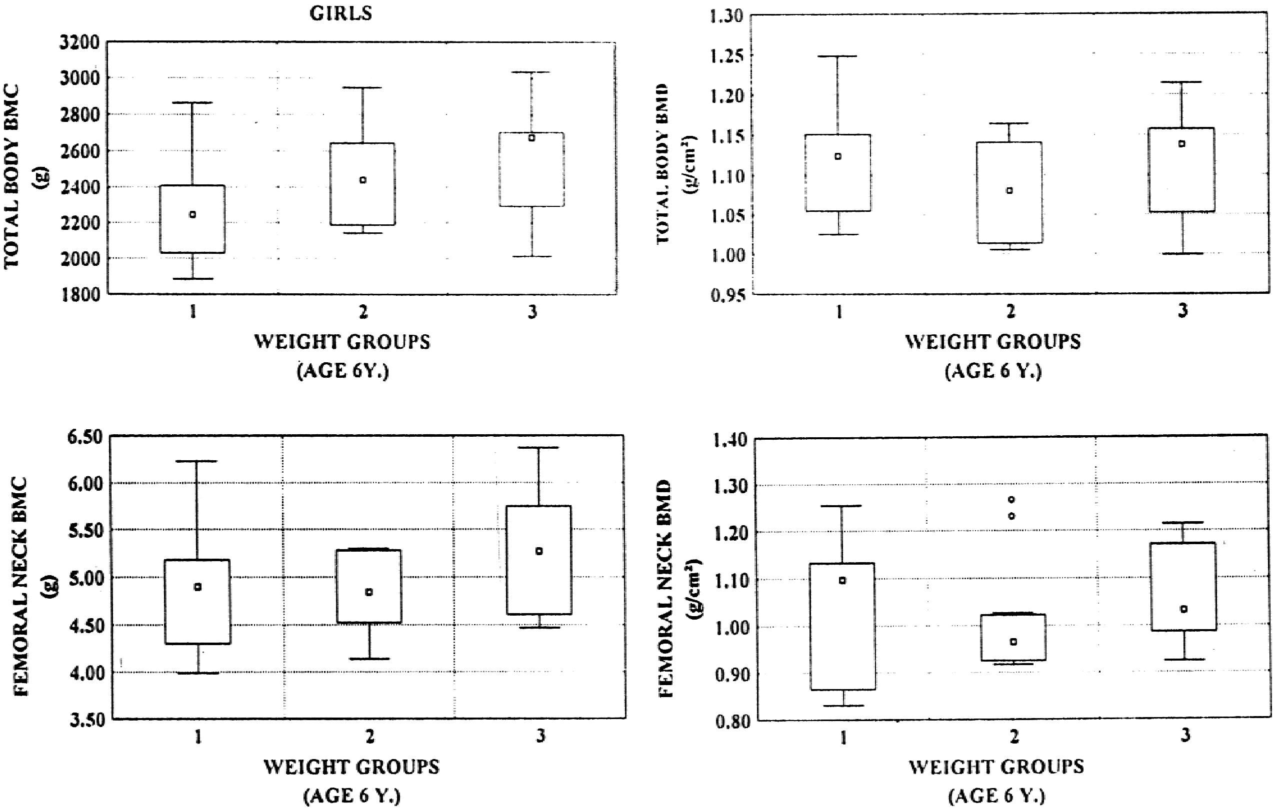

Fig. 3. Girls in three weight groups (tertiles) according to their weight at 6 years, and the corresponding adolescent total body and hip bone mass (BMC and BMD). Box indicates the lower and upper quartiles, small squares the median, 'whiskers' the extremes, and small circles the outliers.

childhood weight is a predictor of adolescent total body BMC, but not for total body BMD, in girls and boys. These data add to previous observations and suggest that growth determines the size of the skeletal envelope, whereas the density within that envelope is governed by other factors. Further, the combined effect of childhood weight and height in a multiple regression model was predictive of adolescent muscle strength.

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