Correlation of Body Growth and Bone Mineral Density Measured by Ultrasound Densitometry of the Calcaneus in Children and Adolescents

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The assessment of growth, including the developmental change in bone mass, is crucial for child health care. We herein report normative values of bone mineral density (BMD) for calcaneus obtained from a large cross-section sample in Japanese school children. To investigate yearly physical growth from pre-school age to adulthood, we measured height, weight, body mass index (BMI), and BMD in 3,835 school children aged 3 to 18 (1,886 boys and 1,949 girls). Participating institutions included kindergarten, junior high schools, high schools, and a college of technology. The growth pattern (or velocity) of BMD (the ratio of trabecular bone area of the calcaneum) shows 3 phases according to the age range: 3-10, 11-15, and 16-18 years for boys, and 3-7, 8-15, and 16-18 years for girls, both peaking at age 16 years. Likewise, that of weight shows 3 phases: 3-4, 5-15 and 16-18 years for boys, and 3-4, 5-14 and 15-18 years for girls, while the growth pattern of height shows 2 phases: 3-15 and 16-18 years for boys, and 3-13 and 14-18 years for girls, both sexes peaking at approximately 16 years. Therefore, the physical growth pattern of the school children shows progressive growth until 16 years, at which time growth is generally completed. In children under 16 years old, BMD of the calcaneus is higher in girls than in boys. Boys and girls show a similar growth pattern in body height and weight before peak development; however, the physical growth of boys eventually exceeds that of girls. BMD: ultrasound bone densitometry; calcaneus; body growth; school of children.


There have been a few reports investigating the relationship between both male and female normative children’s physical development and bone density in specific ranges (Glastre et al. 1990; Soejima et al. 2002; Rocher et al. 2008); however, no standard values have been established in each age group. Ministry of Education, Culture, Sports, Science and Technology (2009) has reported a steady reduction in physical strength and motor skills among Japanese schoolchildren between the ages of 10 and 18. Moreover, lifestyle-related diseases, such as obesity and dyslipidemia, are reportedly increasing in children (Yoneyama and Negoro 2006). These tendencies are considered related to changes in school children’s lifestyles, particularly inappropriate diet and insufficient physical exercise. Such lifestyle changes are thought to affect bone mineral density (BMD) (Yoneyama and Negoro 2006), and we therefore believe that, as well as investigating obesity, it is important to research BMD in order to evaluate physical development in schoolchildren. However, as BMD measurement has not been included in general health screening in schools, there has been no data reported in the national growth curves. This is probably because BMD measurement is difficult to perform in schools.

For adults, quantitative measurement of BMD has generally been performed for diagnosis, evaluation of progression and prevention of osteoporosis (Mazess 1987; Orimo et al. 2001). However, osteoporosis is extremely rare in childhood, except for unusual conditions, such as anorexia nervosa (Misra and Klibanski 2006). Therefore, only comparative group studies have been performed regarding the effects of physical exercise and nutritional intake on bone density in children, such as between groups with or without physical exercise (Vincente-Rodriguesz et al. 2008) and those with or without sufficient intake of calcium (Martin et al. 1997).

An ultrasound bone densitometry is a portable and practical machine, similar to a height-weight meter that involves no x-ray exposure (Langton and Langton 1997).
We therefore used this instrument to perform screening measurements of BMD. Herein, we report age-related changes in bone density of calcaneus in Japanese children, along with changes in height, weight, and degree of obesity.

Materials and Methods
For investigation of physical development, height, weight, body fat percentage, and BMD of the calcaneus were measured. Our subjects were a total of 3,835 children, consisting of 3,103 schoolchildren aged 6 to 18 (1,491 boys and 1,612 girls) in Shimane Prefecture, from elementary schools, junior high schools, high schools, and a college of technology in Izumo City and neighboring towns, and 732 kindergarten children aged 3 to 6 (395 boys and 337 girls) in Kanazawa City, Ishikawa Prefecture. We selected these institutions at random, and consent for inclusion in our collaborative study was obtained from each school. The measurements were performed as part of the health screening of all children at each school. To eliminate bias, we did not investigate the characteristics of each school or history of each child, and did not conduct a questionnaire survey.

Measurement of height, weight, fat percentage and bone density
Using a body stadiometer (TBF-202, Tanita Corporation, Tokyo, Japan), body height, weight, and body fat percentage were measured. Bone density was then measured using an ultrasound bone densitometer (Benus II, Ishikawa Seisakusyo, Ltd, Ishikawa, Japan). Those measurement devices were taken to each school and operated by the author. Informed consent was obtained from each child’s parents, or from the child (for high school students). The densitometer was used to measure BMD of the calcaneus, based on the ratio of trabecular bone area (RTBA) as an index for BMD at other sites. Densitometer was based on fractal dimension analysis for bone area ratio and characterized by coefficient of variation (CV) of 1.6% (Kagechika et al. 1996). The RTBA refers to the proportion of bone tissue in a cross section of the calcaneus bone, which is calculated from the ultrasound conduction velocity in the calcaneal bone.

Statistical Analysis
The data for 3,835 subjects (1,886 boys and 1,949 girls) were statistically analyzed. To investigate the relationship between age and 1) bone mineral density in the calcaneus (RTBA), 2) body height, 3) body weight, or 4) body fat percentage (based on body mass index in the present study), scatter diagrams were made with the X-axis as age, and the Y-axis as the RTBA, height, body weight, or body mass index (BMI).

Following this, we conducted a two-way ANOVA for age and sex as between-subject factors, followed by pair-wise comparisons, using the Student-Newman-Keuls procedure (Winer et al. 1991). We also analyzed linear regressions and correlations among age and RTBA, height, weight, and BMI. We used SPSS for Windows (Ver. 15.0.1J) for these analyses.

Results
Bone density (Rate of trabecula bone area in the calcaneus)
Fig. 1a shows changes in RTBA with age for boys and Fig. 2a shows these changes for girls. The interaction between age and sex is significant ($F = 4.423, df = 15,3803, p < 0.01$). RTBA changed significantly with age both for boys ($F = 82.193, df = 15,3803, p < 0.01$) and girls ($F = 108.516, df = 15,3803, p < 0.01$).

For boys, we could divide age into three phases (cf. Fig. 1b): 3-10 (Phase 1), 11-15 (Phase 2) and 16-18 (Phase 3). The linear regression equation applied to each phase was as follows (x: age, y: RTBA): $y = 0.161x + 26.105$ in Phase 1, $y = 1.202x + 15.747$ in Phase 2, $y = 0.138x + 32.722$ in Phase 3 (Fig. 1a). Coefficients of $x$ ($b$) differed significantly from zero in Phase 1 ($t = 3.385, df = 718, p < 0.01$) and in Phase 2 ($t = 13.515, df = 621, p < 0.01$), but did not differ significantly from zero in Phase 3 ($t = 0.694, df = 541, p > 0.05$). Pearson’s correlation coefficients between
RTBA and age were 0.125 ($p < 0.01$) in Phase 1, .477 ($p < 0.01$) in Phase 2 and 0.03 ($p > 0.05$) in Phase 3.

For girls, we could also divide age into three phases (cf. Fig. 2b): 3-7 (Phase 1), 8-15 (Phase 2) and 16-18 (Phase 3). The linear regression equation applied to each phase was as follows: $y = 0.152x + 26.293$ in Phase 1, $y = 1.058x + 19.683$ in Phase 2, and $y = 0.113x + 34.316$ in Phase 3 (Fig. 2a). Coefficients of $x$ ($b$) did not differ significantly from zero in Phase 1 ($t = 1.457$, $df = 448$, $p > 0.05$) and in Phase 3 ($t = 0.571$, $df = 656$, $p > 0.05$), but differed significantly from zero in Phase 2 ($t = 19.8$, $df = 839$, $p < 0.01$).

Pearson’s correlation coefficients between RTBA and age were 0.069 ($p > 0.05$) in Phase 1, .564 ($p < 0.01$) in Phase 2 and 0.022 ($p > 0.05$) in Phase 3.

Height

Fig. 3a shows changes in height with age for boys (blue lines) and girls (red lines). The interaction between age and sex was significant ($F = 67.745$, $df = 15,3803$, $p < 0.01$). Height changed significantly with age both for boys ($F = 3218.321$, $df = 15,3803$, $p < 0.01$) and girls ($F = 1186.429$, $df = 15,3803$, $p < 0.01$).

For boys, we could divide age into two phases (cf. Fig. 3b): 3-15 (Phase 1) and 16-18 (Phase 2). The linear regression equation applied to each phase was as follows: $y = 5.917x + 79.996$ in Phase 1, and $y = 0.589x + 159.644$ in Phase 2 (Fig. 3a, blue lines). Coefficients of $x$ ($b$) differed significantly from zero in Phase 1 ($t = 136.252$, $df = 1341$, $p < 0.01$) and in Phase 2 ($t = 2.015$, $df = 541$, $p < 0.005$). Pearson’s correlation coefficients between height and age were 0.966 ($p < 0.01$) in Phase 1 and 0.086 ($p < 0.05$) in Phase 2.

For girls, we could also divide age into two phases (cf. Fig. 3c): 3-13 (Phase 1) and 14-18 (Phase 2). The linear regression equation applied to each phase was as follows: $y = 5.749x + 80.527$ in Phase 1 and $y = 0.258x + 152.347$ in Phase 2 (Fig. 3a, red lines). Coefficients of $x$ ($b$) differed significantly from zero in Phase 1 ($t = 101.127$, $df = 966$, $p < 0.01$) and in Phase 2 ($t = 2.075$, $df = 979$, $p < 0.05$). Pearson’s correlation coefficients between height and age were 0.956 ($p < 0.01$) in Phase 1 and 0.066 ($p < 0.05$) in Phase 2.

Weight

Fig. 4a shows changes in weight with age for boys (blue lines) and girls (red lines). The interaction between age and sex was significant ($F = 19.3079$, $df = 15,3803$, $p < 0.01$). Weight changed significantly with age both for boys ($F = 876.5495$, $df = 15,3803$, $p < 0.01$) and girls ($F = 312.4213$, $df = 15,3803$, $p < 0.01$).

For boys, we could divide age into three phases (cf. Fig. 4b): 3-4 (Phase 1), 5-15 (Phase 2) and 16-18 years (Phase 3). The linear regression equation applied to each phase was as follows: $y = 1.294x + 11.767$ in Phase 1, $y = 3.9x - 2.369$ in Phase 2, $y = 1.532x + 35.117$ in Phase 3 (Fig. 4a, blue lines). Coefficients of $x$ ($b$) differed significantly from zero in Phase 1 ($t = 2.707$, $df = 136$, $p < 0.01$), in Phase 2 ($t = 62.433$, $df = 1203$, $p < 0.01$) and in Phase 3 ($t = 3.223$, $df = 541$, $p < 0.01$). Pearson’s correlation coefficients between weight and age were 0.226 ($p < 0.01$) in Phase 1, 0.874 ($p < 0.01$) in Phase 2 and 0.137 ($p < 0.01$) in Phase 3.

For girls, we could also divide age into three phases (cf. Fig. 4c): 3-4 (Phase 1), 5-14 (Phase 2) and 15-18 (Phase 3). The linear regression equation applied to each phase was as follows: $y = 0.445x + 14.661$ in Phase 1, $y = 3.6x - 0.933$ in Phase 2 and $y = 0.258x + 152.347$ in Phase 3. Coefficients of $x$ ($b$) differed significantly from zero in Phase 1 ($t = 101.127$, $df = 966$, $p < 0.01$) and in Phase 2 ($t = 2.075$, $df = 979$, $p < 0.05$). Pearson’s correlation coefficients between weight and age were 0.956 ($p < 0.01$) in Phase 1 and 0.066 ($p < 0.05$) in Phase 2.
in Phase 2, \( y = -0.075x + 53.045 \) in Phase 3 (Fig. 4a, red lines). Coefficients of \( x \) \( (b) \) did not differ significantly from zero in Phase 1 \( (t = 0.947, df = 124, p > 0.05) \) and in Phase 3 \( (t = -0.294, df = 820, p > 0.05) \), but differed significantly from zero in Phase 2 \( (t = 56.165, df = 999, p < 0.01) \). Pearson’s correlation coefficients between weight and age were 0.085 \( (p > 0.05) \) in Phase 1, 0.871 \( (p < 0.01) \) in Phase 2 and 0.01 \( (p > 0.05) \) in Phase 3.

Degree of obesity (body mass index)

The obesity index was evaluated based on BMI (data not shown). The interaction between age and sex was significant \( (F = 2.788, df = 15, 3803, p < 0.05) \). BMI changed significantly with age for both boys \( (F = 56.333, df = 15, 3803, p < 0.05) \) and girls \( (F = 62.383, df = 15, 3803, p < 0.05) \). Pearson’s correlation coefficients between BMI and age were 0.632 \( (p > 0.0001) \) for boys, and 0.649 \( (p > 0.0001) \) for girls. We could not classify age differences into clear groups. However, girls showed a continued increase in BMI until age 16, after which there was a mild decrease. The boys showed a continued increase in BMI between age 8 and 18.

Discussion

Osteoporosis in the adult is a well established clinical problem, and it is diagnosed with standard deviation of the mean value of peak bone mass, but what is the yardstick of “low bone mass” in pediatrics. Only a few reports (Glastre et al. 1990; Soejima et al. 2002; Rocher et al. 2008) have been published regarding bone density evaluation of children from 3 to 18 years of age (from pre-school age to adulthood). This is presumably because the initial purpose
of bone density measurements was the diagnosis or prevention of osteoporosis in the elderly. Subsequently, bone density studies have investigated the correlation between endocrine function and bone metabolism in women (Ongphiphadhanakul et al. 2000; Kim et al. 2002) and the correlation between physical exercise and bone metabolism (Akisaka et al. 1997; Vincente-Rodriguez et al. 2008). However, these were group comparison studies, and very few reports have described the relationship between physical development and BMD in specific age groups. When discussing the relationship between physical exercise and BMD, the bones in the foot are an important region for evaluation, as they bear the greatest effects of gravity during exercise; however, there have been even fewer reports on the BMD on the calcaneus. Although most published studies have reported BMD of the entire body or the lumbar spine, our preliminary study (in press) has shown that calcaneal bone density is the optimum indicator for evaluation of the effects of physical exercise on the body. However, standard for the use of bone density to evaluate bone growth that conforms with the physical development of children has yet to be defined, in contrast to the diagnostic criteria for osteoporosis in adults. Because bone density evaluation for children should better avoid X-ray exposure and should involve a measurement device that can be conveniently used in the school setting, we did not investigate bone or skeletal age. Thus, ultrasound bone density measurement was considered suitable, and its standard values for children
Table 1. Age and sample number for boys and girls.

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Overall, physical development of children (both boys and girls) showed gradual progression until the age of 16 years, at which age it can be considered to be completed. In children from 8 to 16 years, calcaneal RTBA for girls exceeded that for boys. Boys and girls show a similar growth pattern in body height and weight before peak development; however, the physical growth of boys eventually exceeds that of girls.

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