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Changing Femoral Geometry in Growing Girls: A Cross-Sectional DEXA Study

A. GOULDING,[1] E. GOLD,[1] R. CANNAN,[2] S. WILLIAMS,[3] and N. J. LEWIS-BARNED[1]

[1] *Departments of Medicine,* [2]*Human Nutrition, and* [3]*Preventive and Social Medicine, University of Otago, Dunedin, New Zealand*

In elderly women, a long hip axis length has been shown to increase the risk of hip fracture. However, to date, few measurements of hip geometry have been reported in children and adolescents. The present cross-sectional dual-energy X-ray absorptiometry (DEXA) study of 200 girls aged 3–16 years was undertaken to determine at what age adult hip geometry is achieved and to examine possible influences of anthropometry and body composition on the development of femur axis length (FAL) and femur width (FW) during growth. Adult values for FAL and FW were achieved by age 15 years. Age, height, lean tissue mass, total body bone mineral content (BMC), weight, FW, neck of femur bone mineral density (BMD), and fat were each strongly associated with FAL ($p < 0.001$), the highest correlations being with age ($r = 0.917$) and height ($r = 0.906$). However, after adjusting for age and height, only lean tissue mass, weight, and fat mass remained significantly associated with FAL, suggesting that bone mineral accrual does not influence variance in FAL. Our results also suggested that fat mass and weight per se tended to have greater influence on FW than on FAL in age- and height-adjusted data. Twin studies indicate that 20% of adult hip axis length is associated with environmental factors. We therefore conclude that any environmental effects of physical activity or nutrition on hip geometry must occur before early teen-age years. (*Bone 19:645–649; 1996*) © *1996 by Elsevier Science Inc.*

Key Words: Femur geometry; Hip fracture risk, Dual-energy X-ray absorptiometry; Children; Adolescents.

Introduction

Recent evidence suggests that hip geometry influences hip fracture in women. Low bone mineral density and length of the femur neck are independent predictors of hip fracture.[7] Thus, elderly women with a long hip axis length have a greater risk of hip fracture than those with a shorter axis length.[1,7,19,26] Moreover, ethnic differences in hip axis length may play an important role in explaining differences in the rate of fracture in women of different race.[3,18,25] Elongation of the hip may also help to explain rising rates of hip fracture over the last 40 years.[21] In recent years, considerable attention has been paid to the acquisition of bone mineral density to the femur in childhood and the influence of this to the pathogenesis of osteoporosis in later life.[5] By contrast, few measurements of hip geometry have been made in childhood and adolescence. We and others have shown that girls attain a high proportion of adult hip geometry by their early teenage years.[10,11] The present cross-sectional dual-energy X-ray absorptiometry (DEXA) study of 200 girls aged 3–16 years was undertaken to determine at what age adult hip geometry is achieved and to examine possible influences of anthropometry and body composition on the development of femur axis length (FAL) and femur width (FW) during growth.

Methods

Study Sample

Two hundred healthy Caucasian girls aged 3–16 years, enrolled consecutively from more than 40 local schools for an investigation of bone mineral density, anthropometry, and nutrition, were studied between April 1994 and July 1995.[24] They came from different socioeconomic backgrounds and represent a good cross-section of Dunedin children. No child was receiving medication affecting bone health, calcium metabolism or body composition. The mean age of menarche was 12.5 years (n = 27). Informed written consent for the participation of each child was obtained from a parent/guardian. The investigation was approved by the Dunedin Ethics Committee of the Southern Regional Health Authority.

Protocol

A short medical history was taken by questionnaire, which assessed calcium intake and hours of vigorous physical activity. Tanner staging of pubertal development was done by self-assessment from comparisons with standard photographs and descriptions[4] and each child was weighed and measured in light clothing without shoes. A wall-mounted stadiometer was used to determine height. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared. After removing metal objects (belts, buckles, watches, zips, and jewelry) DEXA was performed with a DPX-L scanner and Software version 1.3z (Lunar Corp., Madison, WI). Faulkner et al. have established that measurement of a single proximal femur provides an adequate estimation of hip geometry in healthy individuals of normal gait.[8] We scanned the left hip to measure areal bone mineral density (grams per square centimeter) and hip geometry and the whole body to measure body composition [lean tissue mass, fat mass, and bone mineral content (BMC)]. Rice bags were used to standardize soft tissue depth for hip scans, as recommended by Lunar.

We measured hip geometry using the ruler on the DPX-L

Address for correspondence and reprints: Dr. Ailsa Goulding, Department of Medicine, Otago University, P.O. Box 913, Dunedin, New Zealand. E-mail: ailsa.goulding@stonebow.otago.ac.nz

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scanner. Femur axis length (FAL), the distance from the apex of the femoral head through the midline of the bone to the outer border of the trochanter,[19] and femur neck width (FW) shortest cross-sectional width,[9] were determined. In each hip scan, the FAL and FW measurements were taken twice by one observer and the results were averaged. Coefficients of variation for measurements taken on five repeat hip scans of the left hip in six adults were: FAL, 0.38 ± 0.18%, and FW, 0.99 ± 0.45%. Our precision for routine DEXA measurements of areal bone mineral density (BMD) and body composition matches that reported by others,[16] being (CV): femoral neck BMD, 1.42%; total BMC, 1.52%; lean tissue mass, 1.11%, and fat mass, 2.52%.

Normal reference adult values for hip geometry were determined on 50 healthy premenopausal Caucasian women scanned consecutively in our unit who did not have a history of osteoporotic fractures and were not taking bone-modifying therapy. Their results (means ± SD) were: age, 42.4 ± 7.4 years; height, 164.4 ± 5.7 cm; weight, 66.4 ± 10.3 kg; FAL, 96.61 ± 5.35 mm; and FW 28.61 ± 2.25 mm. The normal values for adult bone composition in premenopausal women we used were: neck of femur BMD, 0.994 g/cm^2; and total body BMC, 2537 g (Lunar Corp. database).

In addition, to determine whether or not local cross-sectional data suggested any cohort effects were influencing femur geometry in our Caucasian population, we measured hip dimensions in two additional groups at Tanner Stages IV or V (girls aged 16–19 years and women aged 20–29 years). These subjects were scanned consecutively as healthy controls for another study in our unit.

Statistical Analysis

Results are displayed as means ± standard deviations. The SPSS statistical package (SPSS Inc., Chicago, IL) was used to assess statistical significance of the results. Pearson correlations and partial correlations, adjusting for age and age and height (variables associated most closely with FAL) were calculated. Statistical comparisons of correlations were made by standard methods.[14] Significance was set at $p < 0.05$ for all tests.

Results

Table 1 shows the mean data for height, weight, BMI, body composition, hip geometry, and femur BMD in different age groups. All values increased as the children grew so that results were significantly higher in the older age groups than in the younger groups ($P < 0.001$ for trend).

Figure 1 demonstrates that adult values for FAL are achieved at a young age. At menarche (12.5 years) approximately 90% of adult geometry and mineral deposition is present. By age 15 girls have achieved their full adult FAL, since values are similar to our adult norms. Furthermore, we found that the hip dimensions of the groups of women in their late teens and early twenties were similar to those found in the reference population. The results from older teenagers aged 16–19 years (n = 20) were: age, 17.75 ± 1.1 years; height, 165.4 ± 6.5 cm; weight, 59.7 ± 6.9 kg; FAL, 93.92 ± 5.12 mm; and FW, 28.53 ± 2.78 mm. The results from women aged 20–29 (n = 14) were: age, 23.6 ± 2.4 years; height, 166.9 ± 6.7 cm; weight, 61.5 ± 6.3 kg; FAL, 94.64 ± 5.50 mm; and FW, 28.87 ± 2.30 mm.

Figure 2 shows that the increase in FAL is closely correlated with gain in height, longer FAL values being seen in girls with more advanced pubertal stage. **Figure 3** shows that FAL is strongly associated with change in lean tissue mass.

Table 2 shows simple linear correlations between measures of hip geometry, anthropometric measures, and bone mineralization and the effects of adjusting for age, and for age plus height on these associations. The association between FAL and FW was strong and persisted after adjustment for age and age and height. In unadjusted data, both FAL and FW were positively correlated with measures of linear growth (height and lean tissue mass), adiposity/weight-bearing (weight and fat mass), and bone mineral accrual (total body BMC and femoral neck BMD). Adjustment for age weakened these associations, although all remained significant for FAL. Age adjustment eliminated significant associations between FW and femur neck BMD. Adjustment for both age and height eliminated all associations between bone mineral accrual and hip geometry, and weight and fat mass each remained more strongly associated with FW than with FAL, although the differences were not significant. Furthermore, lean tissue mass was no longer significantly associated with FW after adjustment for age and height.

Discussion

Our cross-sectional results confirm that girls attain a high proportion of adult hip dimensions and density by their early teenage years. Our 3-year-old girls had approximately 51% of FAL, 72% of FW, and 58% of femoral BMD, but only 27% of the total body BMC of adults. By 12.5 years of age (mean age of menarche) they have achieved approximately 91% of FAL, 92% of FW, and

Table 1. Population characteristics (mean ± SD)

Group (n)	<4 yr (4)	4 and 5 yr (27)	6 and 7 yr (22)	8 and 9 yr (46)	10 and 11 yr (52)	12 and 13 yr (35)	14 and 15 yr (14)
Age (y)	3.4 ± 0.3	5.3 ± 0.6	7.1 ± 0.6	9.2 ± 0.6	11.0 ± 0.6	12.7 ± 0.5	14.7 ± 0.6
Height (cm)	105.3 ± 1.7	116.1 ± 7.5	123.2 ± 6.4	134.5 ± 6.1	145.8 ± 7.7	152.2 ± 9.0	162.1 ± 5.5
Weight (kg)	16.5 ± 1.3	21.4 ± 4.8	23.4 ± 3.5	32.8 ± 6.6	41.8 ± 10.1	47.3 ± 9.0	55.1 ± 12.5
BMI (kg/m^2)	14.9 ± 0.7	15.7 ± 2.0	15.4 ± 1.4	18.0 ± 2.6	19.6 ± 4.1	20.5 ± 4.0	20.8 ± 3.6
Lean tissue mass (kg)	12.67 ± 0.66	15.65 ± 2.38	17.84 ± 2.05	22.26 ± 2.91	27.80 ± 4.05	31.62 ± 4.10	36.27 ± 4.18
Fat mass (kg)	2.33 ± 0.60	4.25 ± 2.80	3.98 ± 1.55	8.53 ± 4.44	11.63 ± 7.40	13.24 ± 6.91	15.91 ± 9.20
Total body BMC (kg)	0.698 ± 0.048	0.653 ± 0.136	0.791 ± 0.111	1.093 ± 0.194	1.439 ± 0.290	1.677 ± 0.333	2.162 ± 0.391
Femur axis length (mm)	49.3 ± 4.1	58.0 ± 6.3	63.3 ± 5.7	75.0 ± 5.5	82.8 ± 5.6	86.8 ± 5.9	94.9 ± 6.1
Femur width (mm)	20.5 ± 1.1	20.1 ± 1.9	20.8 ± 1.7	23.9 ± 2.1	25.1 ± 2.1	26.0 ± 2.3	27.4 ± 1.4
Femur neck BMD (g/cm^2)	0.574 ± 0.181	0.580 ± 0.116	0.654 ± 0.088	0.747 ± 0.079	0.822 ± 0.097	0.868 ± 0.110	0.994 ± 0.121
Ward's triangle BMD (g/cm^2)	0.679 ± 0.202	0.620 ± 0.111	0.680 ± 0.137	0.737 ± 0.096	0.817 ± 0.135	0.850 ± 0.138	0.983 ± 0.136
Trochanteric BMD (g/cm^2)	0.492 ± 0.063	0.559 ± 0.083	0.604 ± 0.098	0.641 ± 0.078	0.709 ± 0.111	0.750 ± 0.108	0.854 ± 0.093

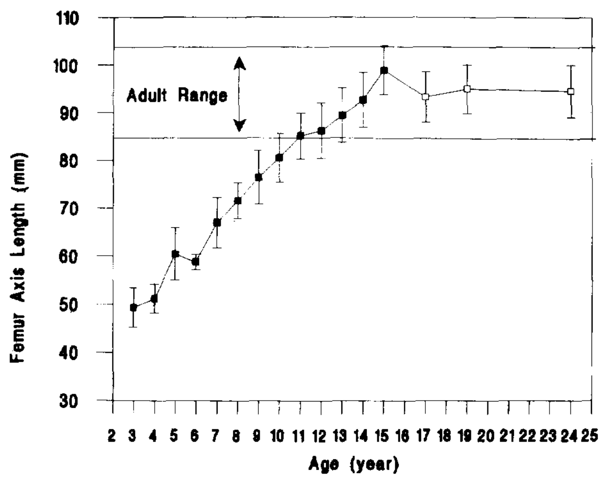

Figure 1. Change in femur axis length with age (results are means ± standard deviations). Closed circles show results for study population, open circles show results for additional older groups. Adult reference range is mean ± 2 SD for 50 consecutive healthy premenopausal adult women.

93% of femoral BMD, but only 72% of the total body BMC of adults. Our results suggest that, by 15 years of age, girls have achieved full adult hip dimensions and BMD, although they have only 85% of their final adult total body BMC. Thus, we consider that adult FAL and FW geometry is reached early in adolescence.

We chose to measure femur axis length (FAL), rather than hip axis length (HAL), in our study because femur morphology in young children differs from that of adults. The size, shape, and density of the human femur changes considerably as children grow into adults.[23] At about 6 years of age the simple curved shape of the femur neck alters. The femur neck elongates and there is upward enlargement of the trochanteric region from its growth plate. In young children there is a wide gap between the apex of the femoral head and the acetabulum, which renders HAL measurements less precise than FAL measurements. This gap subsequently decreases with femoral growth and development. Peacock et al.[19] have shown that FAL, like HAL, is an independent predictor of fracture risk in adults.

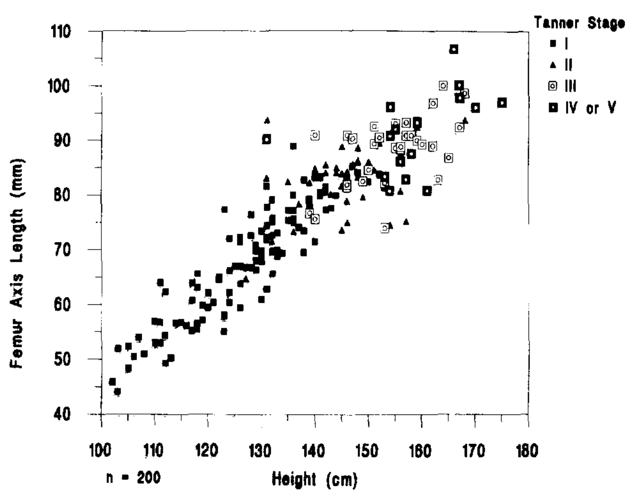

Figure 2. Femur axis length in relation to height. FAL = −24.908 + 0.727 (height); r = 0.906, p < 0.001. Tanner Stages of pubertal development are shown by different symbols.

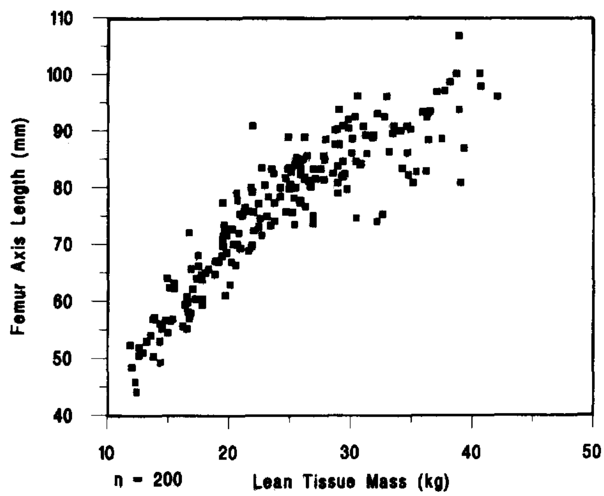

Figure 3. Femur axis length in relation to lean tissue mass. FAL = −36.821 + 1.598 (lean); r = 0.897, p < 0.001.

Only one previous group has measured femur geometry in childhood by DEXA. Flicker et al. reported HAL measurements in 678 female twins aged 10–89 years.[10] Because the large gap between femoral head apex and acetabulum closes by approximately age 10, these workers would not have encountered problems in measurement of HAL in their children. They concluded that full adult hip geometry is achieved by age 15 years and our results support this view. Comparisons of HAL in adult monozygotic and dizygotic twins suggested that 80% of the variation in HAL was due to genetic influence and 20% to environmental factors, both before and after adjusting for height, which was the variable they found exerted the greatest influence on HAL. However, these workers restricted examination of correlations between body composition and hip geometry to women who had already achieved their adult hip dimensions (15–80 years). By contrast, our study looked for associations between FAL and body composition during the phase of attaining adult hip geometry. We extend the findings of Flicker et al.[10] by demonstrating that height is strongly associated with FAL during growth. Our results further indicate that FW may be influenced more strongly by weight-bearing, than FAL. Animal studies suggest periosteal bone formation in the femur is stimulated by weight-bearing exercise.[20] Interestingly, mineral accrual had no influence on FAL or FW after adjusting for age and height, suggesting that variations in calcium uptake by bone do not alter hip geometry greatly. This view is supported by our failure to detect any significant correlation between current dietary calcium intakes recorded by questionnaire and hip dimensions. Thus, correlations between dietary calcium and FAL (r = 0.07) and between dietary calcium and FW (r = 0.03) were not statistically significant, nor did we find any evidence of a significant correlation between the hours per week of active sporting activity our subjects reported by questionnaire and either FAL (r = 0.04) or FW (r = 0.04). On the other hand, our results support that view that linear growth, particularly height, exerts a strong influence on FAL. High growth hormone levels can elongate bone[22] and fluctuating growth hormone levels, possibly associated with puberty or high physical activity, may speculatively be important here.

One limitation of our study is its cross-sectional design. We cannot rule out the possibility that cohort effects may be present. Although we have established that 15 year olds have FAL values as great as older teenagers, young women in their twenties and current 40-year-old adults, prospective measurements will be

Table 2. Associations between variables (correlations and partial correlations adjusted for age and age and height, n = 200)

	FAL			FW		
	Simple	Age-adjusted	Age-and height-adjusted	Simple	Age-adjusted	Age-and height-adjusted
FAL	1.0	1.0	1.0	0.816[a]	0.459[a]	0.399[a]
Height	0.906[a]	0.399[a]	—	0.768[a]	0.268[a]	—
Lean tissue mass	0.897[a]	0.384[a]	0.163[c]	0.756[a]	0.239[a]	0.078 NS
Weight	0.819[a]	0.321[a]	0.164[c]	0.734[a]	0.307[a]	0.213[a]
Fat mass	0.583[a]	0.221[a]	0.138[d]	0.575[a]	0.282[a]	0.231[a]
Total body BMC	0.854[a]	0.265[a]	0.059 NS	0.727[a]	0.195[b]	0.059 NS
Femur neck BMD	0.764[a]	0.184[b]	0.047 NS	0.618[a]	0.079 NS	−0.019 NS

[a]$p < 0.001$; [b]$p < 0.005$; [c]$p < 0.01$; [d]$p < 0.05$; NS = $p > 0.05$.

needed to show beyond doubt that FAL and FW of girls of 15 years of age do not continue to grow. Reid et al. recently suggested that the doubling in rate of age-adjusted hip fracture, which has occurred over the last 35–40 years in white New Zealand women, may be due in part to lengthening of the femoral neck.[21] They showed that lengthening had taken place in the FAL region of the hip and there was no accompanying increase in FW. They postulated that improved nutrition before puberty might have increased height and accounted for this hip lengthening. However, Flicker et al. found no evidence of cohort changes in adult HAL in their cross-sectional study of 488 women aged 15–89 years.[10]

Flicker et al calculated that 79% of height-adjusted population variance in HAL was due to genetic influences and 21% to environmental factors. These findings support our contention that any environmental influences affecting FAL must occur at an early phase of life. Their results also support our findings that factors associated with linear growth (height, lean mass) influence FAL more than weight and adiposity. In our study, there was a stronger association between FAL and height than between FAL and fat mass ($p < 0.001$). Thus, taller individuals tended to show longer FAL values than shorter individuals, even in childhood. The findings of Faulkner et al. suggest that individuals with long HAL will have a higher risk of hip fracture late in life.[7] There is growing evidence that taller individuals are more prone to hip fractures than are shorter individuals.[2,12,13,17] This may be due at least in part to longer HAL and FAL values in tall individuals. The reasons for strong associations of long hip axis and high fracture risk are unclear; elongation of the moment arm, poor shock absorption of a fall, or altered stress on the femoral neck have been postulated as possible reasons.[6] It is possible that, later in life, a greater load is carried at the base of the femoral neck in individuals with a long hip axis.[15]

Comparisons between the correlations for FAL and lean tissue mass and FAL and fat mass showed that, in data unadjusted for age, the correlation of FAL with lean tissue mass was significantly stronger than that between FAL and fat mass ($p < 0.001$), as was the correlation of FW with lean tissue vs that between FW and fat mass ($p < 0.001$), suggesting that lean tissue has greater influence than fat tissue on FAL and on FW. However, the difference between correlations for FAL and lean tissue mass and FAL and fat mass was not quite significant when adjusted for age ($p < 0.07$). Similarly, the correlations for FW and lean tissue mass and FW and fat mass were not statistically different in age-adjusted data.

In summary our results suggest that adult hip geometry is achieved by age 15. Because adult length is achieved at a young age any nutritional/environmental variables influencing attainment of FAL and FW must exert their effects before midadolescence.

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