JOURNAL OF BONE AND MINERAL RESEARCH
Volume 15, Number 11, 2000

Calcium Accretion in Girls and Boys During Puberty: A Longitudinal Analysis

DONALD A. BAILEY,[1,2] ALAN D. MARTIN,[3] HEATHER A. MCKAY,[3] SUSAN WHITING,[1] and ROBERT MIRWALD[1]

ABSTRACT

The primary purpose of this study was to estimate the magnitude and variability of peak calcium accretion rates in the skeletons of healthy white adolescents. Total-body bone mineral content (BMC) was measured annually on six occasions by dual-energy X-ray absorptiometry (DXA; Hologic 2000, array mode), a BMC velocity curve was generated for each child by a cubic spline fit, and peak accretion rates were determined. Anthropometric measures were collected every 6 months and a 24-h dietary recall was recorded two to three times per year. Of the 113 boys and 115 girls initially enrolled in the study, 60 boys and 53 girls who had peak height velocity (PHV) and peak BMC velocity values were used in this longitudinal analysis. When the individual BMC velocity curves were aligned on the age of peak bone mineral velocity, the resulting mean peak bone mineral accrual rate was 407 g/year for boys (SD, 92 g/year; range, 226–651 g/year) and 322 g/year for girls (SD, 66 g/year; range, 194–520 g/year). Using 32.2% as the fraction of calcium in bone mineral, as determined by neutron activation analysis (Ellis et al., J Bone Miner Res 1996;11:843–848), these corresponded to peak calcium accretion rates of 359 mg/day for boys (81 mg/day; 199–574 mg/day) and 284 mg/day for girls (58 mg/day; 171–459 mg/day). These longitudinal results are 27–34% higher than our previous cross-sectional analysis in which we reported mean values of 282 mg/day for boys and 212 mg/day for girls (Martin et al., Am J Clin Nutr 1997;66:611–615). Mean age of peak calcium accretion was 14.0 years for the boys (1.0 years; 12.0–15.9 years), and 12.5 years for the girls (0.9 years; 10.5–14.6 years). Dietary calcium intake, determined as the mean of all assessments up to the age of peak accretion was 1140 mg/day (SD, 392 mg/day) for boys and 1113 mg/day (SD, 378 mg/day) for girls. We estimate that 26% of adult calcium is laid down during the 2 adolescent years of peak skeletal growth. This period of rapid growth requires high accretion rates of calcium, achieved in part by increased retention efficiency of dietary calcium. (J Bone Miner Res 2000;15:2245–2250)

Key words: calcium, bone mineral content, longitudinal, children, dual-energy X-ray absorptiometry

INTRODUCTION

ADULT BONE mass, the strongest predictor of osteoporotic fracture risk[(1)] can be viewed as the peak bone mass (PBM) of early adulthood, less the subsequent bone loss. Most research has investigated the factors associated with bone loss, and, consequently, most fracture prevention strategies attempt to reduce or reverse the loss, primarily through drugs, exercise, and dietary supplementation. An alternative approach, the enhancement of PBM, has been hampered by a lack of data; there is still controversy as to the age of attainment of PBM, and there has been no

[1]Colleges of Kinesiology and Pharmacy and Nutrition, University of Saskatchewan, Saskatoon, Canada.
[2]School of Human Movement Studies, University of Queensland, Brisbane, Australia.
[3]School of Human Kinetics, University of British Columbia, Vancouver, Canada.

adequate longitudinal investigation of bone mass accumulation before PBM.

Because virtually all of the body's calcium resides in the skeleton, dietary calcium has the potential to be a limiting factor in skeletal growth. Despite this, international consensus has not been reached on calcium requirements of children. Balance studies, although difficult and expensive, can reveal calcium retention and accretion rates over the short term, but few studies have been done in children. An alternative approach is the use of dual-energy X-ray absorptiometry (DXA), which allows the precise and accurate determination of whole-body bone mineral content (BMC), with a minimal (about 1 mrem) radiation exposure. A series of such scans in one individual over the adolescent growth spurt reveals the change in BMC accrual rates. These can be converted into calcium accretion rates, since the calcium fraction of bone mineral has been determined.[2] Knowing skeletal calcium retention rates through adolescence thus can yield insight into calcium requirements during growth. We recently reported a cross-sectional analysis of bone mineral accrual rates from 978 whole-body BMC scans by DXA in 113 boys and 115 girls.[3] This analysis revealed peak calcium accretion rates of 212 mg/day in girls and 282 mg/day in boys, at ages 11.4 years and 13.3 years, respectively. However, cross-sectional analysis is known to underestimate true mean peak velocity values for growth variables.[4] We report here a longitudinal analysis of a multiyear study in which annual whole-body DXA scans were analyzed to yield peak calcium accretion rates in 60 boys and 53 girls.

Longitudinal versus cross-sectional analysis of growth

The peak value of any growth rate variable and the age at which it occurs can be estimated in two ways. When data following an adequate number of children longitudinally through the peak period are lacking, it is commonplace to pool data by chronological age. This cross-sectional approach results in a growth curve, each of whose points is calculated as the mean value for all subjects of that age. This can be seen in Fig. 1A, which shows a schematic view of whole-body BMC velocity values (g/year) for 5 boys. The dashed line shows the curve resulting from averaging the individual BMC velocity values at each age from 12 to 16 years. The peak value of the composite curve is similar to that of the smallest individual peak. The true mean peak value can only be determined after aligning the five subjects on peak BMC velocity (Fig. 1B). When this is done, it can be seen that the true peak is considerably greater than the cross-sectionally estimated peak, the true age at peak is earlier, and the phase of rapid growth is much shorter. These differences can be considerable. Thus our cross-sectionally estimated peak calcium accretion rates for boys (282 mg/day) and girls (212 mg/day) were reported with the caveat that they were almost certainly lower than the true values.[3] Since that study, enough of the children have passed through their age of peak calcium accretion that a longitudinal analysis is now feasible.

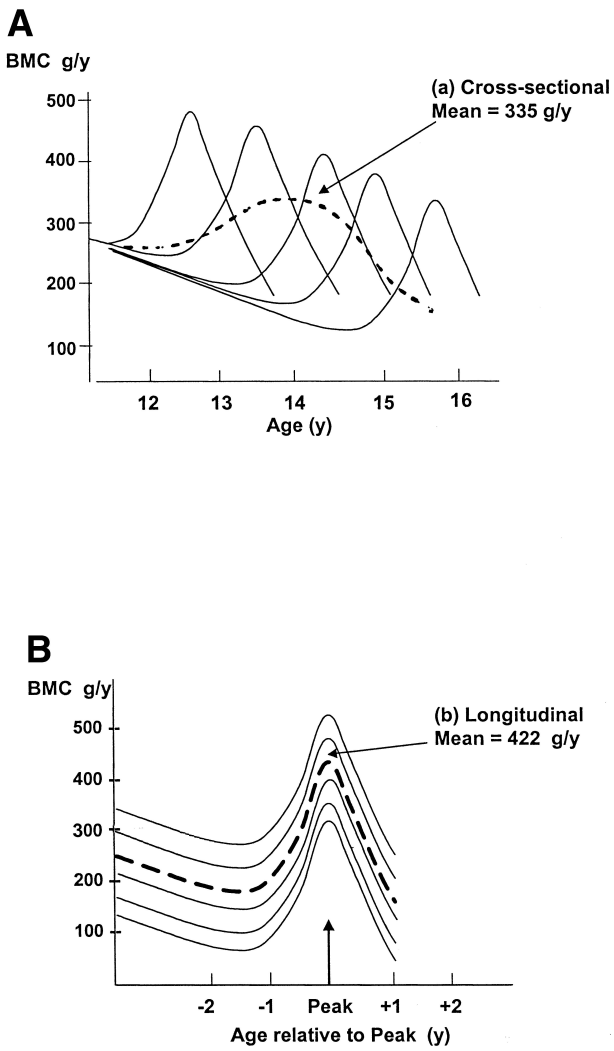

FIG. 1. Schematic representation of (A) cross-sectional and (B) longitudinal analysis of BMC velocity curves for 5 boys.

MATERIALS AND METHODS

Subjects

All subjects were participants in the University of Saskatchewan Pediatric Bone Mineral Study. Of 375 eligible students attending two elementary schools in Saskatoon, Canada, 113 boys and 115 girls, ranging in age from 8 to 14 years, were initially enrolled in this multiyear longitudinal study. Only those subjects who clearly showed a peak in their height and BMC velocity curves were selected for the longitudinal analysis, resulting in a final sample size of 60 boys and 53 girls. Subjects who were excluded were primarily individuals who were beyond their age of peak height velocity (PHV) when first measured. The previous cross-sectional analysis, used here for comparative purposes, was carried out on data from 471 scans from 113 boys and 507 scans from 115 girls. All study procedures were approved by appropriate university and hospital ethics

committees and have been described elsewhere.[5] All testing was done at the Royal University Hospital (Department of Nuclear Medicine) in Saskatoon.

Bone measurements

Annual DXA scans of the whole body, AP lumbar spine, and proximal femur were carried out by one of two experienced operators using DXA (Hologic QDR 2000; Hologic, Waltham, MA, U.S.A.) in the array mode using enhanced global software version 7.10. To minimize operator-related variability, the same qualified person analyzed all whole-body scans, using enhanced software version 5.67A. In our laboratory, in vivo short-term reproducibility for this procedure is 0.51%. A Victoreen ion chamber survey meter (model 450p; Victoreen, Inc., Cleveland, OH, U.S.A.) measured entrance radiation dose. When this surface dose was corrected for body attenuation, subject age, and type and volume of tissue being irradiated, the effective dose equivalent was less than 1 mrem.

Anthropometric and dietary assessments

Height and weight and a set of 35 other anthropometric measures were taken on all subjects every 6 months. Dietary assessments using a 24-h recall were carried out three times a year for the first 3 years of the study and twice a year thereafter. Initially, children were trained to identify food portion sizes and on subsequent assessment occasions were shown life-size representations of food portions to enhance the accuracy of their recall. Intakes from the 24-h recall were analyzed using the Nutritional Assessment System (NUTS) program, version 3.7 (Quilchena Consulting, Victoria, B.C., Canada). Recalls were coded, with the same individual checking all forms, and analyzed according to procedures described elsewhere.[6] On the basis of these recalls, average daily macro- and micronutrient intakes including calcium were determined for each subject.

Data analysis

Because subjects were not remeasured on exactly the same dates each year, whole-year velocity values were calculated for each subject by dividing the time between the quasi-annual BMC measurements by the age increment (mean value, 0.998 ± 0.048 years). A cubic spline fit was then applied to the whole-year height and BMC velocity values for each child. This allowed the determination of the peak bone mineral velocity value and the age at which it occurred. Mean values and SDs were then calculated for peak bone mineral accrual rate in boys and in girls. Corresponding rates of calcium accretion were calculated as 32.2% of the BMC velocity values and expressed in milligrams per day. Mean dietary calcium intake was determined as the mean of all reported intakes. Apparent calcium retention efficiency at peak accretion rate was defined as 100 times the peak calcium accretion rate divided by the mean daily dietary calcium intake for each child.

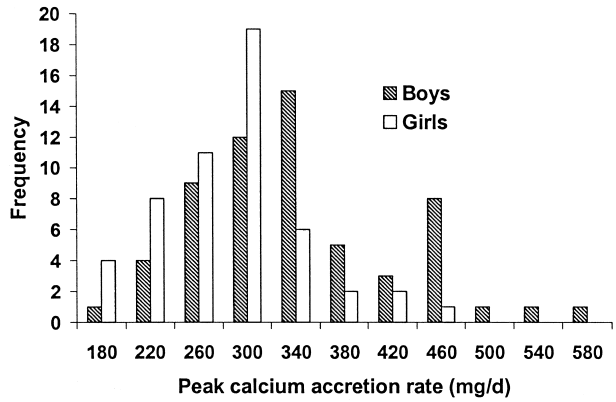

FIG. 2. Frequency distribution of peak calcium accretion rates in 60 boys and 53 girls.

TABLE 1. PEAK VALUES AND AGES AT WHICH THEY OCCURRED

Variable	*Boys*	*Girls*
Age at PHV (years)	13.4 (1.0)	11.8 (0.9)
Age at peak BMC velocity (years)	14.0 (1.0)	12.5 (0.9)
Peak BMC velocity (g/year)	407 (93)	322 (66)
Peak Ca accretion rate (mg/day)	359 (82)	284 (59)
Mean Ca intake (mg/day)	1140 (392)	1113 (378)
Apparent retention efficiency (%)	36.5 (12.3)	29.6 (8.5)

SD in parentheses.

RESULTS

The data reported here are based on a set of six whole-body DXA scans for each of 60 boys and 53 girls who were measured annually. The peak bone mineral accrual rate and the age at which it occurred were determined from a cubic spline curve fitted around the peak for each child. Boys had a 26% higher mean peak bone mineral accrual rate (407 g/year; SD = 93 g/year) than the girls (322 g/year; SD = 66 g/year). Assuming that calcium constitutes 32.2% of bone mineral, the bone mineral values in grams per year convert to peak calcium accretion rates of 359 mg/day (SD = 82) for the boys and 284 mg/day (SD = 59) for the girls. There was considerable individual variability in peak calcium accretion rates (Fig. 2). Values for boys ranged from 199 to 574 mg/day and for girls from 171 to 458 mg/day. The boys' peak occurred at 14.0 (SD = 1.0) years and the girls' peak at 12.5 years (SD = 0.9). The ages at PHV were 13.4 years (SD = 1.0) in boys and 11.8 years (SD = 0.9) in girls (Table 1).

Because dietary recall data show considerable variability, mean calcium intake was calculated as the mean of all assessments up to the age of peak accretion rate. The number of assessments that were averaged per child until the age of peak ranged from 6 to 13. The mean calcium intake determined in this way was 1140 mg/day (SD = 392) for the boys and 1113 mg/day (SD = 378) for the girls. The averaging of all intake values up until the age of peak accretion is a reasonable and appropriate strategy to attempt

to determine usual dietary intake of the children, as in our study the relationship between mean intake in the first year of measurement and 4 years later was small ($r = 0.23$ for boys and $r = 0.36$ for girls). The correlation coefficients for peak calcium accretion rate and calcium intake were 0.05 for the boys and 0.07 for the girls, explaining less than 1% of the variance. Apparent mean retention efficiencies (at peak accretion rate) were 36.5% (SD = 12.3) for boys and 29.6% (SD = 8.5) for girls.

DISCUSSION

Virtually all dietary calcium is either excreted (fecal, renal, and dermal) or retained as bone mineral. Balance studies estimate calcium in the body by difference: net absorption = ingested − fecal; retained = absorbed − (renal + dermal + endogenous secretion). Balance studies have shown that adolescents continue to increase calcium retention at dietary intakes above 1500 mg/day.[7] On the basis of this study and more recent data, dietary calcium recommendations for adolescents have increased to 1300 mg/day.[8] However, balance studies are expensive and difficult and give only a brief window through which to view calcium retention in the body. An alternative approach is to measure bone mineral radiologically and determine accretion rate as the difference between serial measures divided by the time between them. Early measurement of calcium accretion rate during growth used extrapolation from regional measures of bone mineral and yielded estimates of 300 mg/day for boys and 280 mg/day for girls, based on metacarpal,[9] and 200 mg/day for boys and 160 mg/day for girls, based on radial BMC.[10]

The use of whole-body DXA avoids the errors arising from extrapolation of bone changes at a single site to the whole body. Several studies have estimated calcium accretion rates in this way. Mean accretion rate over 10 years of growth from a cross-sectional study was found to be 160 mg/day with a suggested peak in the range of 300–400 mg/day.[11] In a 6-month longitudinal investigation of adolescent girls,[12] a calcium increment averaging 221 mg/day was found (based on a 32.2% calcium fraction of bone mineral, not the 39% reported by these authors[12]), with slightly higher values for those supplemented with dietary calcium. In a preliminary analysis of earlier data from this study,[3] we reported peak BMC velocity values and the corresponding calcium accretion rates after a cross-sectional analysis, because at that time there were too few children with complete growth peaks for a longitudinal analysis. Peak calcium accretion rates were 282 mg/day for the boys and 212 mg/day for the girls. The longitudinal analysis reported here revealed peak accretion rates that were, on average, 30% higher than we reported in our previous cross-sectional analysis (359 mg/day for boys and 284 mg/day for girls). It could be that the true peak accretion rates are even higher than these values because our bone mineral velocities are based on annual measurement occasions as opposed to our height measurements, which were taken every 6 months.

Individual variability in the magnitude of these peak rates can be examined for the first time (Fig. 2). The upper values are surprisingly large, with the highest individual value of 574 mg/day. In boys, 48% had peak values greater than 350 mg/day and 31% of the values were greater than 400 mg/day. The girls' values were lower than the boys but nonetheless represent a high skeletal accretion rate: 74% of the girls were above 250 mg/day and 30% were over 300 mg/day. The variability may reflect size differences because smaller children might be expected to have lower peak growth rates. Therefore the approximate 10-cm greater height for boys at PHV ($p < 0.001$) might partially explain the sex difference in peak calcium accretion rates. This possibility was supported by the positive association between peak calcium accretion and attained height at the age of PHV ($r = 0.40$; $p < 0.01$).

It is not known whether peak accretion rates are related to total accretion, that is, adult BMC values, because full skeletal maturity could not be confirmed for most of our subjects. However, we have confirmed that the bone mineral growth spurt continues after height velocity has peaked. The ages of peak calcium accretion rates were 14.0 years (1.0 years) in boys and 12.5 years (0.9 years) in girls, which lagged behind PHV by 0.6 years (boys) and 0.7 years (girls). This time lag could have important implications. If linear growth in stature may be taken to represent the growth of skeletal volume (i.e., bone breadths follow the same growth pattern as stature), the lag suggests that bone mineralization does not keep up with the rapidly expanding skeletal volume. It has been hypothesized that in some children, if the high demand for bone mineral cannot be met from dietary sources, the mineral could be "borrowed" from cortical bone and be "repaid" later when demand has declined.[13] The reported coincidence of the timing of PHV and the peak rate of forearm fractures in boys and girls from the same geographical area as the present sample strongly supports this hypothesis.[14] This raises the important question of whether dietary calcium might be, in some children, a limiting factor in bone mineralization. Three calcium supplementation studies have investigated this. Lloyd et al.[15] showed a 1.3% additional gain in skeletal bone mineral attributed to calcium supplementation of 354 mg/day in premenarcheal girls. Similarly, Johnston et al.[16] reported a significant, positive effect of calcium supplementation in a double-blind monozygotic twin study in prepubertal children, but not in those who were beyond this maturational stage. However, a more recent study showed a positive effect of calcium in pubertal children. Nowson et al. supplemented 1 child of each of 42 pairs of twins with 1000 mg of calcium a day.[17] After 6 months, hip and spine bone mineral density (BMD) had increased significantly in the supplemented twin (1.3% and 1.5%, respectively), but no further effect was seen in the subsequent year of supplementation. In a study of Hong Kong Chinese children on a habitually low-calcium diet (mean, 280 mg/day), those supplemented with 300 mg/day of calcium showed significantly greater increases in radial BMD than unsupplemented controls.[18] However, a follow-up study of these children 18 months later showed that the benefits had disappeared after supplementation was stopped.[19] On the other hand, in a

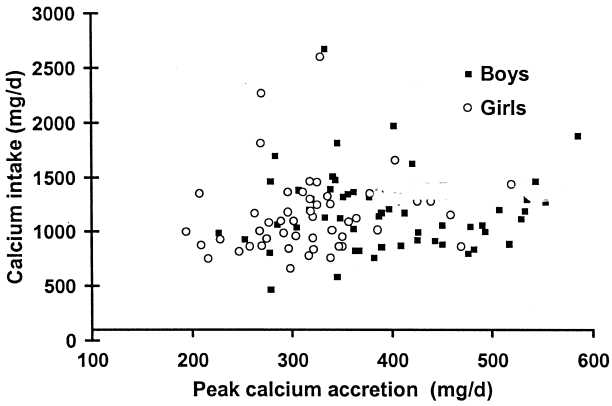

FIG. 3. The relationship between peak calcium accretion rate and dietary calcium intake in boys and girls.

study by Bonjour et al.[20] there was a statistically significant difference in the mean BMD between supplemented subjects and controls, which remained 1 year after the end of calcium supplementation. Thus, although it appears that calcium supplementation can enhance BMD in children and adolescents, more studies are needed to determine whether such increases are sustained and result in a higher adult PBM.

The high bone mineral accretion rates in puberty mean that a considerable fraction of adult BMC is gained in a few years of adolescence. In the 2-year period spanning the age of peak accretion rate, boys' BMC increased by 720 g (150 g), while girls gained 569 g (105 g). Converting these values to calcium equivalents gives a value of 231 g of calcium for boys and 183 g for girls laid down over the 2-year period. The young adult BMC values for these children are not yet known, but corresponding data, measured on the same bone densitometer, are available for several other samples of adults. The mothers and fathers of some of our subjects have been measured as part of a study of familial relationships.[21] The 76 mothers (mean age, 40 years) had a BMC of 2164 g and the 37 fathers (mean age, 45 years) had a BMC of 2884 g. A separate unpublished study of 59 men (mean age, 40 years) and 32 women (mean age, 36 years) revealed BMC values of 2880 g and 2181 g, respectively. Finally, a study of 57 younger women[22] (mean age, 21 years) revealed a BMC of 2180 g. Averaging these adult values and converting to calcium equivalents gives a mean young adult skeletal calcium of 928 g for men and 700 g for women. If we take these to be estimates of the young adult calcium values of the boys and girls in this study, approximately 26% of adult calcium is gained in the 2 years of peak skeletal growth.

The high calcium retention rates around puberty can be caused by both increased dietary intakes and greater efficiencies of absorption and retention. Our subjects consumed moderate amounts of calcium; intakes were slightly lower in the girls (1113 mg/day) than in the boys (1140 mg/day), but variability was large (Table 1). Dietary calcium intake at these levels showed virtually no association with peak calcium accretion rates (Fig. 3), explaining less than 1% of the variance in boys ($r = 0.05$) and girls ($r = 0.07$). Considering the vagaries involved in determining calcium intake by dietary recall in children, this may be an underestimate of the effect of calcium intake on peak accretion rates. Calcium absorption efficiencies have been reported at 20.3% in adolescent girls at calcium intake levels of about 1300 mg/day [23]; retention efficiency must be lower than absorption efficiency because of urinary calcium excretion. However, our mean apparent calcium retention efficiencies were 36.5% for the boys and 29.6% for the girls. Efficiencies would increase reasonably with skeletal demand; hence, our values, which are at peak accretion rates, are greater than those reported previously.[23] Alternatively, higher efficiencies could compensate for low dietary intake; in girls given a low calcium diet after a high calcium diet, absorption efficiencies more than doubled from 26.0% to 58.2%.[24] The graphical estimation of the relationship between calcium absorption efficiency and calcium intake in girls reported by these authors[24] showed that when intake drops from 600 to 400 mg/day, absorption efficiency rises from 40% to 50%. Recent evidence supports earlier suggestions that skeletally driven increases in absorption efficiency are mediated by increased circulating calcitriol.[25]

There are limitations to the interpretation of these data. It is possible that dietary intakes have been underreported (leading to overestimates of retention efficiency), as is known to occur especially in girls. However, this may be less of an error with calcium, because snack foods, the items most often omitted in recalls, are not typically rich in calcium. The calcium fraction of bone mineral is not known in children and we and others have used adult values. The Hologic 2000 DXA used in this investigation has been shown to yield bone mineral fractions consistent with neutron activation analysis.[26] Although hydroxyapatite is 39.9% calcium by weight, the calcium content of bone mineral has been estimated variously at 38%[11] and 34%.[24] We have used a lower value (32.2%) based on a direct comparison of the Hologic 2000 DXA and neutron activation analysis.[2] Our use of a lower value than others would have the effect of lowering all our calculated efficiencies.

We conclude that peak calcium accretion rates were high with mean values of 359 mg/day (82) for boys and 284 mg/day (59) for girls, and an upper limit of 575 mg/day for 1 boy and 459 mg/day for 1 girl. We confirm the underestimate arising from cross-sectional analysis of growth velocities; our previously reported peak accretion rates were 27–34% lower than those reported here. The high accretion rates were associated with high apparent calcium retention efficiencies: 36.5% for the boys and 29.6% for the girls. In addition, adolescence is clearly a critical time for bone mineralization because 26% of adult calcium was accumulated in the 2 years around the age of peak calcium accretion. Although there appears to be a compensatory mechanism that promotes an increase in calcium retention at low dietary intakes, diets that provide adequate calcium nutrition during the adolescent years should be encouraged.

ACKNOWLEDGEMENTS

This work was supported in part by a grant from the National Health Research and Development Program, Health Canada (D.A.B.)

REFERENCES

1. Melton LJ, Kan SH, Wahner HW, Riggs BL 1988 Lifetime fracture risk: An approach to hip fracture risk assessment based on bone mineral density and age. J Clin Epidemiol **41:**985–994.
2. Ellis KJ, Shypailo RJ, Hergenroeder A, Perez M, Abram S 1996 Total body calcium and bone mineral content: Comparison of dual-energy x-ray absorptiometry with neutron activation analysis. J Bone Miner Res **11:**843–848.
3. Martin AD, Bailey DA, McKay HA, Whiting S, Mirwald R 1997 Bone mineral and calcium accretion during puberty. Am J Clin Nutr **66:**611–615.
4. Tanner JM 1962 Growth at Adolescence, 2nd ed. Blackwell Scientific Publications, Oxford, U.K.
5. Bailey DA 1997 The Saskatchewan pediatric bone mineral accrual study: Bone mineral acquisition during the growing years. Int J Sports Med **18**(Suppl 3)**:**S191–S194.
6. Whiting S, Colleaux C, Bacchetto T 1995 Dietary intakes of children age 8 to 15 years living in Saskatoon. J Can Diet Assoc **56:**119–125.
7. Jackman LA, Millane SS, Martin BR, Wood OB, McCabe GP, Peacock M, Weaver CM 1997 Calcium retention in relation calcium intake and postmenarcheal age in adolescent females. Am J Clin Nutr **66:**327–333.
8. Standing Committee on the Scientific Evaluation of Dietary Reference Intakes, Food and Nutrition Board, Institute of Medicine 1997 Dietary Reference Intakes for Calcium, Phosphorus, Magnesium, Vitamin D, and Fluoride. National Academy Press, Washington D.C., pp. 4–28.
9. Peacock M 1991 Calcium absorption efficiency and calcium requirements in children and adolescents. Am J Clin Nutr **54**(Suppl)**:**261S–265S.
10. Hui SL, Johnston CC, Mazess RB 1985 Bone mass in normal children and young adults. Growth **49:**34–43.
11. Matkovic V, Jelic T, Wardlaw GM, Ilich JZ, Goel PK, Wright JK, Andon MB, Smith KT, Heaney RP 1994 Timing of peak bone mass in Caucasian females and its implication for the prevention of osteoporosis. J Clin Invest **93:**799–808.
12. Andon MB, Lloyd T, Matkovic V 1994 Supplementation trials with calcium citrate malate: Evidence in favor of increasing the calcium RDA during childhood and adolescence. J Nutr **124**(Suppl 8)**:**1412S–1417S.
13. Parfitt AM 1994 The two faces of growth: Benefits and risks to bone integrity. Osteoporos Int **4:**382–398.
14. Bailey DA, Wedge JH, McCullough RG, Martin AD, Bernhardson SC 1989 Epidemiology of fractures of the distal end of the radius in children as associated with growth. J Bone Joint Surg **71A:**1225–1231.
15. Lloyd T, Andon MB, Rollings N, Martel JK, Landis JR, Demers LM, Eggli DF, Kieselhorst K, Kulin HE 1993 Calcium supplementation and bone mineral density in adolescent girls. JAMA **270:**841–844.
16. Johnston CC Jr, Miller JZ, Slemenda CW, Reister TK, Hui S, Christian JC, Peacock M 1992 Calcium supplementation and increases in bone mineral density in children. N Engl J Med **327:**82–87.
17. Nowson CA, Green RM, Hopper JL, Sherwin AJ, Young D, Kaymakci B, Guest CS, Smid M, Larkins RG, Wark JD 1997 A co-twin study of the effect of calcium supplementation on bone density during adolescence. Osteoporos Int **7:**219–225.
18. Lee WT, Leung SS, Wang SH, Xu YC, Zeng WP, Lau J, Oppenheimer SJ, Cheng JC 1994 Double-blind, controlled calcium supplementation and bone mineral accretion in children accustomed to a low-calcium diet. Am J Clin Nutr **60:** 744–750.
19. Lee WT, Leung SS, Leung D, Cheng JC 1996 A follow-up study on the effects of calcium supplement withdrawal and puberty on bone acquisition of children. Am J Clin Nutr **64:**71–77.
20. Bonjour JP, Carrie AL, Ferrari S, Clavien H, Slosman D, Theintz G 1997 Calcium enriched foods and bone mass growth in prepubertal girls: A randomized, double-blind, placebo-controlled trial. J Clin Invest **99:**1287–1294.
21. McKay HA, Bailey DA, Wilkinson AA, Houston CS 1994 Familial comparison of bone mineral density at the proximal femur and lumbar spine. Bone Miner **24:**95–107.
22. Arnold CM, Bailey DA, Faulkner RA, McKay HA, McCulloch RG 1997 The effect of water fluoridation on the bone mineral density of young women. Can J Public Health **88:** 388–394.
23. Weaver CM, Martin BR, Plawecki KL, Peacock M, Wood OB, Smith DL, Wastney ME 1995 Differences in calcium metabolism between adolescent and adult females. Am J Clin Nutr **61:**577–581.
24. O'Brien K, Abrams SA, Kiang LK, Ellis KJ, Gagel RF 1996 Increased efficiency of calcium absorption during short periods of inadequate calcium intake in girls. Am J Clin Nutr **63:**579–583.
25. Illich JZ, Badenhop NE, Jelic T, Clairmont AC, Nagode LA, Matkovic V 1997 Calcitriol and bone mass accumulation in females during puberty. Calcif Tissue Int **61:**104–109.
26. Economos CD, Nelson ME, Fiatarone Singh MA, Kehayias JJ, Dallal GE, Heymsfield SB, Wang J, Yasumura S, Ma R, Pierson RN 1999 Bone mineral measurements: A comparison of delayed gamma neutron activation, dual-energy x-ray absorptiometry and direct chemical analysis. Osteoporos Int **10:** 200–206.

Address reprint requests to:
Dr. D.A. Bailey
College of Kinesiology
University of Saskatchewan
105 Gymnasium Place
Saskatoon, SK S7N 5C2, Canada

Received in original form December 3, 1999; in revised form April 3, 2000; accepted May 25, 2000.