Relationship between long-term calcium intake and bone mineral content of children aged from birth to 5 years

BY WARREN T. K. LEE,* SOPHIE S. F. LEUNG AND SUSAN S. H. LUI

Department of Paediatrics, The Chinese University of Hong Kong, Shatin, Hong Kong

AND JOSEPH LAU

Centre for Clinical Trials and Epidemiological Research, The Chinese University of Hong Kong, Shatin, Hong Kong

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This study evaluated Ca intake in Hong Kong Chinese children and examined the association between long-term Ca intake and bone mineral content (BMC) in children. Longitudinal dietary intake from birth to 5 years was obtained in 128 children (sixty-seven boys, sixty-one girls). Ca intakes were evaluated by dietary history and cross-checked with food frequency and 24 h recall. At age 5 years BMC was determined at the one-third distal radius of the right arm using single-photon absorptiometry. The mean Ca intake of 133 children at 5 years was 546 (SD 325) mg/d. Milk was the chief source of Ca (43·5%). From birth to 5 years, 90% of the children had been taking milk regularly. The mean BMC and bone width (BW) of these children were 0·317 (SD 0·042) g/cm and 0·756 (SD 0·074) cm respectively. BMC was not correlated with current intakes of Ca, energy and protein but was positively correlated with weight (r 0·57), height (r 0·47) and BW (r 0·66). However, cumulative Ca intake throughout the past 5 years showed significant correlation with BMC (r 0·235, $P = 0·0133$). The significant correlation remained even after weight, height, BW, sex, and cumulative intakes of energy and protein were adjusted in multiple regression analysis (r 0·248, $P = 0·0107$). Moreover, using principal component analysis, Ca intake during the 2nd year of life had the strongest correlation with BMC at 5 years (r 0·240, $P = 0·02$). Ca intake of Hong Kong Chinese children was higher than the RDA of the Food and Agriculture Organization/World Health Organization (1962) and achieved 66% of the current US recommendation (National Research Council, 1989). The increased regular milk consumption reflects a significant change in dietary habits of the younger generation. Children with a habitually higher Ca intake throughout the past 5 years, particularly in the 2nd year, were found to have higher BMC.

Calcium: Childhood: Bone mineral content: Single-photon absorptiometry

There is a rising incidence of osteoporosis all over the world (National Institute of Health, 1984) and Hong Kong is no exception. Lau (1988) reported that over the last 20 years the incidence of osteoporotic fractures in Hong Kong has increased 3-fold in the elderly to reach a rate of about 10 in 1000 in people at 70 years and above, and that the rate of osteoporosis is rising rapidly to levels observed in the Western world. It has been speculated that insufficient accumulation of bone mass before skeletal maturity might predispose to an increasing risk of fractures in old age (Riggs & Melton, 1986; Marcus, 1987; National Research Council, 1989), whereas peak bone mass attained at skeletal maturity is considered the best prevention against the disease (Mazess, 1982; Mazess *et al.* 1987). An often cited Yugoslavian study (Matkovic *et al.* 1979) demonstrated that a population with a habitual Ca intake of 1000 mg/d had a significantly higher bone mass than their counterparts receiving 500 mg/d, and that the incidence of hip fractures was lower in the

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high-Ca intake population than the low-intake population. Despite the fact that such a cross-sectional relationship has not been proved in any controlled longitudinal study, there has been a growing concern for achieving peak bone mass during the period of bone growth. Peak bone mass appears to relate to Ca intake during childhood right into early adulthood (Marcus, 1987; National Research Council, 1989). Bone mass declines gradually after reaching the peak; this effect results in diminishing bone strength, increasing the risk of fractures (Dequeker, 1988). Several retrospective population studies have suggested that an attainment of maximum bone mass in adulthood would probably reduce the risk of developing osteoporotic fractures later in life when age-related bone loss commences (Matkovic *et al.* 1979; Sandler *et al.* 1985; Picard *et al.* 1987, 1988). The attainment of peak adult bone mass seems to be related to adequate Ca intake throughout adolescence and early adulthood (Picard *et al.* 1987, 1988; Halioua & Anderson, 1989). Until recently, there has been limited longitudinal data in the literature demonstrating the association between habitual Ca intake and bone mineral content (BMC) in children.

This paper reports the longitudinal relationship between cumulative Ca intake in 128 Chinese children over the first 5 years of life and BMC achieved at 5 years of age.

METHODS

Subjects

From June to December in 1984, 174 full-term healthy Chinese infants (ninety-four boys and eighty girls) were recruited randomly from a Maternal and Child Health Centre (MCH) in Hong Kong for a longitudinal study of growth and nutrition. The mean age at recruitment was 7 d. All parents understood that the nature of this project was an objective assessment of growth and nutrient intake of infants. The infants were fed according to guidelines provided by the MCH and no additional dietary advice was received from the research workers. Of the parents, 94% were Cantonese and the rest originated from other parts of China. Of the infants, 82% were either first or second born to their parents. These children were followed-up regularly. At 5 years, 133 children (seventy boys and sixty-three girls) remained in the cohort. Table 1 shows the classification of fathers' occupations at recruitment and 5 years later. The data were comparable to the socio-economic profiles of the general population (Census and Statistics Department, 1981, 1990).

Dietary assessment

The practice of breast-feeding is uncommon in Hong Kong; only 8% and 2% were breast-fed at 2 and 6 months respectively (Leung & Davies, 1989). Therefore, in the present study only the nutrient intakes from bottle-fed infants were assessed. The daily intakes of Ca, energy and protein for each child were assessed every 2 months in the first year, 3 months in the second year, 6 months in the third year and annually in the 4th and 5th years. During infancy the formula brand, strength of reconstitution and volume of milk consumed were recalled from mothers or child-minders by a research dietitian and the nutrient intake was calculated according to the nutritional information provided by respective milk manufacturers. As weaning commenced, dietary intake was assessed using the dietary history method of Burke (1947) and cross-checked with a food frequency questionnaire and 24 h recall. The recall was assisted by displaying various sizes of common household measures and food models. The dietary history method has an advantage of assessing average habitual intakes of individuals over a specified period of time without interfering with subjects' usual dietary habits (Burke, 1947; Jain, 1989). The method also allows day-to-day as well as seasonal variations in food intake (Bingham, 1987). The validity of the method has been reviewed by Bingham (1987).

Table 1. *Distribution of fathers' occupations at recruitment in 1984 and 5 years later in comparison with general population statistics*

Occupation	Recruitment 1984		Census 1981*	Follow-up 1989		Survey 1990†
	n	%	%	*n*	%	%
Professional, administrative and managerial workers	19	11	8·7	22	16·5	11·3
Clerical and related workers	26	15	12·2	16	12·0	18·7
Sales workers	12	7	10·3	7	5·3	12·3
Service workers	19	11	15·6	21	15·8	16·9
Production and related workers, transport equipment operators and labourers	95	55	50·4	67	50·4	39·5
Others	2	1	2·8	0	0	0
Total	173	100	100	133	100	100

* Census and Statistics Department (1981).
† Census and Statistics Department (1990).

The habitual intakes of energy and nutrients for every child were assessed based on the dietary history method, which was modified to assess the quantity of food intake and the usual eating patterns of the previous 6 months. The information was cross-checked by the dietitian with a food frequency list to validate the quantity, variety and frequency of food consumption. The food frequency list comprised groups of food commonly consumed by Hong Kong children. Any discrepancy of intake between the two methods would be clarified to obtain a value closest to the actual intake. For example, if a discrepancy in the amount of milk consumed was three bottles per week as assessed by dietary history *v.* four bottles per week as assessed by food frequency, after clarification by the mother that the milk consumption would vary from three to four bottles per week, an average value of 3·5 bottles of milk would be taken. Most food items, if missed out, could be restored into the dietary history record by checking against the food frequency list. A 24 h recall from a previous day was followed to cross-check the consistency of food habits against the hours of the day. Any discrepancy that arose in the 24 h recall would be clarified in a similar approach to that already mentioned. Dietary intakes obtained by dietary history combined with cross-checking against a food frequency list and 24 h recall should provide a more valid estimation of habitual food intake.

The daily intakes of Ca, energy and protein were calculated by a computerized food table with food items compiled from appropriate food tables (Tung *et al.* 1961; US Department of Health, Education & Welfare, 1972; Church & Church, 1975; Paul & Southgate, 1978; Institute of Health, 1980; Watt & Merrill, 1983) and from the respective food manufacturers and food chemists.

The accuracy of the computerized food table in estimating Ca content in food has been validated by chemical analysis. Normal meals consisting of different varieties of meat, fish, cereal, milk, vegetables, fruit and snacks were collected over 7 d from a paediatric ward of a general hospital in Shatin. The meals were prepared in Chinese style by the hospital food service which was supervised by dietitians. At meal times, a tray of food with typical portion sizes for a 5-year-old child was set aside for the study. The weight of individual foods in each meal was recorded and the Ca content was determined from the computerized food table; the weighed food in each meal was then dry-ashed and the Ca content was determined by atomic absorption spectrometry (Nordin, 1976). A total of twenty-one meals

over 7 d was collected. The Ca content in each of the twenty-one meals as calculated from the computerized food table correlated well with the results determined by chemical analysis (r 0·8, $P < 0·05$). The coefficient of variation between calculated and analysed Ca contents was 11·7%, which was comparable to the data in a recent review (Bingham, 1987).

Anthropometric measurements

At 5 years, the weight and height of each subject were recorded on the day of bone mineral measurement. Nude weight was measured using a Seca electronic scale (Seca, Vogel & Halke GmbH & Co., Hamburg, Germany). Supine height was taken without shoes using a Harpenden stadiometer (Holtain Ltd, Crosswell, Dyfed). The standard errors of measurement were 0·007 kg for weight and 0·078 cm for height (Leung & Lui, 1990).

Bone mineral measurement

BMC and bone width (BW) were determined by the technique of single-photon absorptiometry (SPA) using Norland 2780 Densitometer (Norland Corporation, Fort Atkinson WI, USA). SPA is a non-invasive, accurate and highly reproducible technique in quantifying bone mass in peripheral bone (Sorenson & Cameron, 1967; Steichen *et al.* 1988). A beam of collimated monochromatic photons is emitted from a ^{125}I radionuclide beneath the measuring deck and a collimated scintillation detector which counts the attenuated photons is placed over the bone. The scintillation detector and the ^{125}I source traverse the bone simultaneously, the amount of photon attenuated by the bone mineral is greater than that by the surrounding soft tissue. An absorption curve is integrated from the attenuated photon counts and the integrated surface area under the absorption curve is proportional to the amount of BMC contained in the narrow strip of the bone being scanned. A full account of the principles involved in SPA has been described by Cameron & Sorenson (1963); Sorenson & Cameron (1967) and Christiansen *et al.* (1975).

BMC at the distal radius was measured at the distal one-third distance between the mid-point of the styloid process and the tip of the olecranon from the right forearm where the radius is uniformly cylindrical and mainly consists of cortical bone (Cameron & Sorenson, 1963; Cameron *et al.* 1968; Schlenker & Von Seggen, 1976). Furthermore, there is little problem of surrounding fat and soft tissue in this region to interfere with the measurement (Sorenson & Cameron, 1967). Christiansen & Rodbro (1975) and Cohn *et al.* (1975) have demonstrated that BMC measured in the distal forearm is well-correlated with total body Ca. The BMC and BW were measured in duplicate and mean values were taken. The ^{125}I source is a weak radioactive source with a maximum strength of 200 mCi. The irradiation does not involve the vulnerable areas such as the gonads. A narrow cross-section of the forearm is exposed to the photon beam collimated to about 4·5 mm wide, and the beam passing through the tissue is completely absorbed by the scintillation detector. The dosage of radiation to the forearm is very small, the maximum surface dose of radiation per scan is 20 uSv (i.e. 40 uSv for each set of duplicate scans). The integral dose actually received by the irradiated tissues is less than 10% of a conventional X-ray examination of the forearm (DePriester *et al.* 1991).

One hundred and twenty-eight of the children studied agreed to have their forearm BMC measured. The measurement was performed by the author (W.T.K.L.). The between-scans precision error without repositioning the subjects was 2·49 and 2·03% for BMC and BW respectively, whereas the intra-class correlations between scans with subject repositioning was 0·937 for BMC and 0·906 for BW. Such a degree of precision was achieved through excellent subject cooperation and comfortable subject positioning. The precision of measurement was comparable to those of other recent centres (Steichen *et al.* 1988). In addition, a randomly-selected subgroup of children was tested for intra-personal variation

in BMC between the dominant and non-dominant arms. Using the paired t test there was no significant difference in BMC between the dominant and non-dominant arms (t 1·596, df 26, $P < 0·05$).

The study was approved by the Ethical Committee of the Faculty of Medicine, The Chinese University of Hong Kong. Informed consents were obtained from parents.

Statistical analysis

Statistical analysis involved the use of Student's t test, correlation analysis and multiple regression analysis with BMC being a dependent variable. The influence of independent variables on BMC was examined. These variables included weight, height, BW, sex and dietary intakes of Ca, protein and energy at 5 years and cumulative intakes of Ca, protein and energy over the past 5 years.

Principal component analysis was employed to determine at what critical age the Ca intake would bear a strong association with BMC measured at age 5. Principal component analysis with varimax rotation was used to generate factors that group the fifteen Ca assessments throughout the past 5 years into several homogeneous periods. The factors which explained a substantial portion of the variance of the Ca intake were extracted (with eigenvalues larger than 1). Scores of such factors were computed for each individual and were then correlated with their BMC so that the effects of Ca intake at different stages of early life on BMC could be determined.

Throughout the study, statistical analysis was performed by using SPSS/PC+, Version 3.1 (SPSS Inc., Chicago, IL, USA).

RESULTS

Weight, height, and the current intakes of Ca, energy and protein of 133 children at age 5 are shown in Table 2. The mean daily Ca intake was 546 (SD 325) mg, which is above the Food and Agriculture Organization/World Health Organization (1962) RDA (400–500 mg/d) and is also two-thirds of the US recommended level (800 mg/d) (National Research Council, 1989).

The sources of Ca intake at 5 years are given in Fig. 1. The chief source of Ca for these children was milk (43·5%). Cheese and yoghurt were not popular foods. Cereals and vegetables were the next two important sources of Ca, contributing 16·6 and 12·5% respectively to the total Ca intake. Over 90% of the children continued to drink milk. The levels of Ca intake depended mainly on the frequency and quantity of milk consumed. The types of milk consumed by the children were powdered milk fortified with Vitamins A and D, fresh milk, and UHT milk. In addition, follow-on milk formulas were still being consumed by a few children.

Fig. 2 shows the distribution of Ca intake for the children at 5 years of age. Twenty-five children (20%) had a mean Ca intake less than 300 mg/d. The dietary sources of Ca in these children were mainly non-dairy foods, namely cereals, vegetables and fruit. Without regular consumption of milk very few children could ingest more than 300 mg Ca/d. Twelve cohort children who had stopped using milk by 5 years had Ca intakes below 250 mg/d.

Cross-sectional analysis of calcium intake and BMC at 5 years

The BMC, BW, and BMC/BW of the 128 children at 5 years are shown in Table 3. There was no sex difference in BMC and BMC/BW using a two-sample t test. However, there was a significant sex difference in BW (t 3·53, df 126, $P < 0·001$). The BMC at 5 years was positively correlated with weight (r 0·57, $P < 0·01$), height (r 0·47, $P < 0·01$), BMC/BW

Table 2. *Mean weight, height and current intakes of calcium, energy and protein of 133 5-year-old Hong Kong children**

		Wt (kg)			Height (cm)			Ca (mg/d)			Energy (kJ/d)			Protein (g/d)		
	n	Mean	SD	(Range)	Mean	SD	(Range)	Mean	SD	(Range)	Mean	SD	(Range)	Mean	SD	(Range)
Boys	70	17·6	2·3	(13·6–27·8)	108·2	4·0	(96·8–118·6)	574	352	(170–2689)	6254	1327	(3633–10273)	69	17	(34–99)
Girls	63	17·1	2·6	(13·0–27·9)	107·9	4·3	(99·3–117·3)	514	291	(167–1379)	5565	1067	(3326–8631)	65	16	(32–96)

* For details of procedures, see pp. 236–238.

Table 3. *Mean BMC, BW and the BMC/BW of 128 Hong Kong children at 5 years**

		BMC (g/cm)			BW (cm)			BMC/BW (g/cm^2)		
	n	Mean	SD	(Range)	Mean	SD	(Range)	Mean	SD	(Range)
Boys	67	0·324	0·040	(0·240–0·432)	0·777	0·073	(0·616–0·962)	0·418	0·041	(0·304–0·541)
Girls	61	0·310	0·046	(0·232–0·443)	0·733	0·068	(0·610–0·932)	0·422	0·040	(0·313–0·501)
Total	128	0·317	0·042	(0·232–0·443)	0·756	0·074	(0·610–0·962)	0·420	0·041	(0·304–0·541)

* For details of procedures, see pp. 236–239.

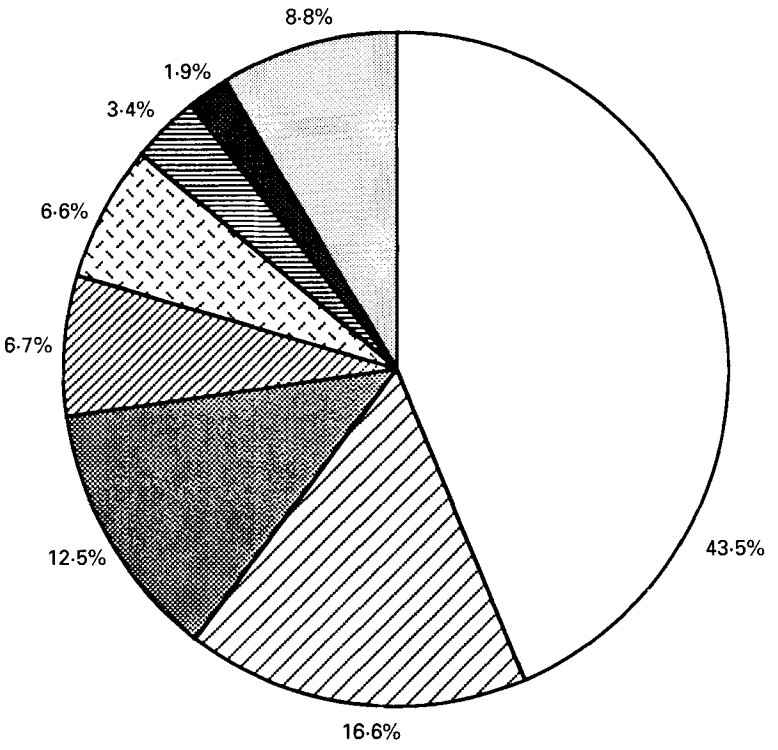

Fig. 1. Sources of dietary calcium in 128 Hong Kong children at 5 years of age. □, Milk and milk products; ▨, cereals; ▦, vegetables; ▨, fish and shell fish; ⬚, fruits; ▤, eggs; ▤, beans and bean products; ▨, others. For details of procedures, see pp. 236–238.

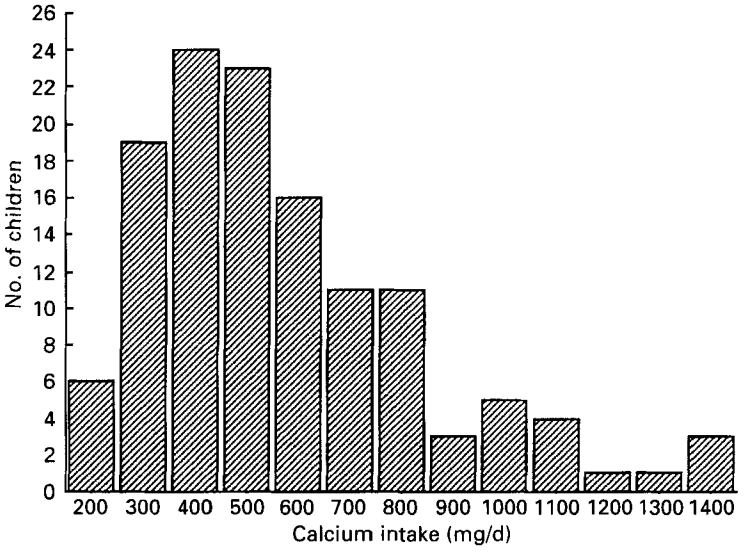

Fig. 2. Distribution of calcium intake in 128 Hong Kong children at 5 years of age. For details of procedures, see pp. 236–238.

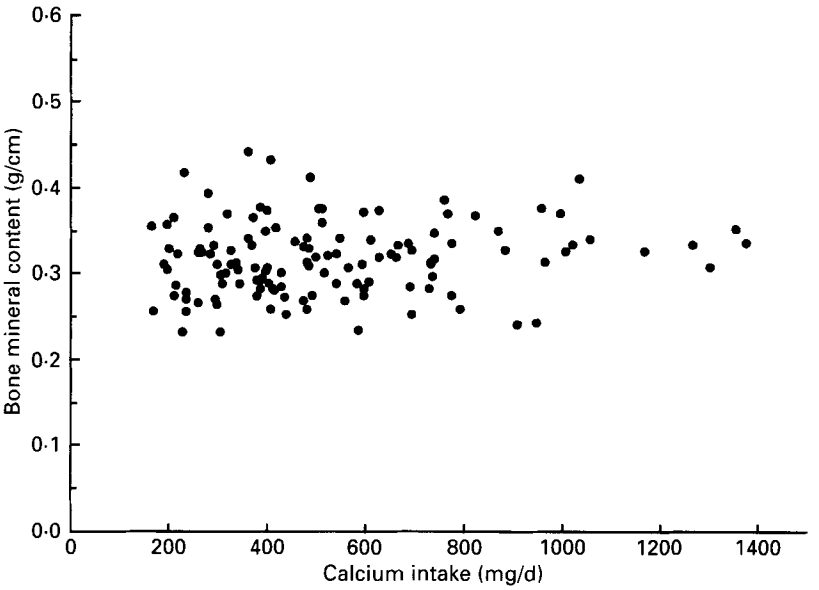

Fig. 3. Correlation of bone mineral content and calcium intake in 128 Hong Kong children at 5 years of age (r 0·13, $P = 0·14$). For details of procedures, see pp. 236–239.

(r 0·70, $P < 0·01$) and BW (r 0·66, $P < 0·01$). These findings indicated that weight, height and BW had profound effects on predicting BMC. However, BMC was not correlated with current intakes of energy (r 0·13, $P = 0·13$) and protein (r 0·04, $P = 0·66$).

It is interesting to note that there was no correlation between BMC and current Ca intake at 5 years (r 0·13, $P = 0·14$), as shown in Fig. 3. In other words, the BMC would lie within a narrow range from 0·23 to 0·44 g/cm at a wide range of Ca intakes at 5 years from about 170 to 1400 mg/d. Moreover, with children divided into low, medium and high Ca intake groups, BMC was regressed against two dummy variables representing the medium intake group (250–900 mg/d, BMC 0·3167 g/cm, n 103) and high intake group (> 900 mg/d, BMC 0·3297 g/cm, n 15) using the low intake group (< 250 mg/d, BMC 0·3083 g/cm, n 15) as reference; the regression coefficients suggested that BMC in the medium intake group and the high intake group was not significantly different from that of the low intake group ($P = 0·27$ and $P = 0·16$ respectively). The results also demonstrated that Ca intake at 5 years was not associated with BMC (R^2 0·015). Such differences remained non-significant after adjusting for sex, weight, height and BW. Therefore, the results consistently indicated that the current level of Ca intake was not associated with BMC in the 5-year-old children.

Longitudinal analysis of calcium intake throughout the past 5 years and BMC

It would be more appropriate to consider the bone mineral mass that children achieved at 5 years to reflect Ca deposited over the last 5 years. Therefore, the cumulative Ca intakes of the children from birth to 5 years were analysed. Dietary Ca intakes from birth to 5 years, i.e. every two months in the first year, three months in the second, six months in the third and annually in the 4th and 5th years, were used to estimate the total Ca intake and average daily Ca intake in each individual. The total Ca intake from birth to 5 years could be estimated by the area under a polygon formed by joining the points of mean daily Ca intakes obtained from the respective dietary assessments, with the x-axis representing total number of days. In this way the average daily Ca intake in the 5-year period was estimated by dividing the total Ca intake throughout the past 5 years by the total number of days.

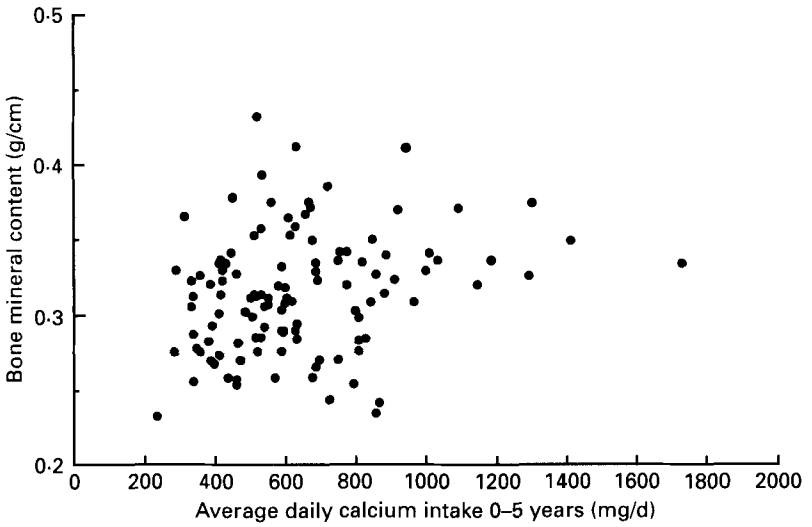

Fig. 4. Correlation of bone mineral content and average calcium intake from birth to 5 years in 128 Hong Kong children (r 0·235, $P = 0·0133$). For details of procedures, see pp. 236–239.

Both variables gave exactly the same P values and partial correlation coefficients, as the total intake is a constant multiple of the average daily intake. The latter was used in the following analysis because we are more familiar with the magnitude of daily intake.

The correlation of average daily Ca intake over the first 5 years was found to be significantly correlated with BMC at age 5 (r 0·235, $P = 0·0133$) (Fig. 4). In other words, children with higher Ca intakes from birth to 5 years attained higher BMC values at 5 years. An attempt was made to divide the average daily Ca intake in the first 5 years into three groups: higher intake, > 750 mg Ca/d (BMC 0·32 g/cm, n 28); medium intake, 400–750 mg Ca/d (BMC 0·31 g/cm, n 64); low intake, < 400 mg Ca/d (BMC 0·30 g/cm, n 21). Both the high and medium Ca intake groups had significantly higher BMC values than the low intake group ($P < 0·05$). In order to determine at which period Ca intake was more significantly associated with BMC, principal component analysis was applied. The previous fifteen dietary assessments for Ca intake from birth to 5 years were reduced to four factors which were orthogonal, i.e. not correlated with each other. Such four sets of factor scores could be interpreted as Ca intake from the 2nd to 4th month, 6th to 10th month, 15th to 24th month and 27th to 60th month. The fifteen variables loaded distinctively onto the four factors mentioned, which took up 71·8 % of the variance. When the four sets of factor scores were used to predict BMC by the linear regression method, Ca intake from the 15th to the 24th month was significantly associated with BMC (partial r 0·240, $P = 0·02$), while Ca intakes in the other months were non-significant. The significant association remained (partial r 0·237, $P = 0·02$) even after adjusting for weight, height, BW and sex. The results suggested that Ca intake in the 2nd year of life had a remarkable effect on predicting BMC at age 5 years.

Confounding factors on the correlation between long-term calcium intake and BMC

Further analysis was undertaken to examine whether the positive correlation between the average daily Ca intake over the first 5 years and BMC might be explained by other factors such as weight, height, sex and BW. After controlling for the variables mentioned, the average daily Ca intake over the first 5 years remained significant in predicting BMC (partial r 0·248, $P = 0·0107$). Moreover, weight and BW were independent variables to

Table 4. *Multiple regression analysis incorporating average calcium intake over 5 years (AvCa), height, weight, BW and sex to predict BMC in 128 Hong Kong children**

	Partial correlation coefficient	*P*
AvCa (mg/d)	0·248	0·0107
Height (cm)	0·025	0·7193 (NS)
Wt (kg)	0·406	< 0·0001
BW (cm)	0·481	< 0·0001
Sex	0·035	0·719 (NS)

NS, not significant.
* For details of procedures, see pp. 238–239.

Table 5. *Multiple regression analysis incorporating weight, height, BW, sex, average intakes of protein (AvProt), energy (AvkJ) and calcium (AvCa) to predict BMC in 128 Hong Kong children**

	Partial correlation coefficient	*P*
Wt (kg)	0·393	< 0·0001
Height (cm)	0·018	0·8568 (NS)
BW (cm)	0·467	< 0·0001
Sex	0·058	0·5620 (NS)
AvProt (g/d)	0·014	0·8867 (NS)
AvkJ (kJ/d)	0·061	0·5368 (NS)
AvCa (mg/d)	0·222	0·0237

NS, not significant.
* For details of procedures, see pp. 238–239.

predict BMC (Table 4). The overall multiple regression model was highly significant and explained 55% of the variance of BMC.

Intakes of energy and protein over a prolonged period of time might have important effects on bone development. Using a similar approach, the average daily intakes of energy and protein over the first 5 years were estimated to examine their effects on BMC. Table 5 presents the results of multiple regression analysis. After controlling for body size and dietary intakes, BMC was not correlated with cumulative intakes of protein (partial r 0·014, $P = 0·8867$) and energy (partial r 0·061, $P = 0·5368$) over the past 5 years.

To conclude, in children the average daily Ca intake over the first 5 years of life was significantly correlated with BMC attained at 5 years. Ca intake, particularly in the second year of life, was the most significant predictor of BMC at 5 years. Body weight, height and BW were significant and independent variables in predicting BMC in children.

DISCUSSION

The present study is a unique investigation to demonstrate that cumulative Ca intake over the first 5 years of life, particularly during the second year, was positively correlated with BMC achieved at 5 years. The higher the habitual Ca intake in the past the higher the bone mineral mass attained. This observation reflected the phenomenon that the mechanism of bone mineralization in childhood is a cumulative process. The bone mineral mass is a function of Ca retained in the developing skeleton during the period of bone development.

Our finding of a positive association between lifelong Ca intake and bone mineral mass agrees with recent studies in adults. Halioua & Anderson (1989) studied lifetime Ca intakes of premenopausal women aged between 20 and 50 years by recalling their Ca intakes during their high-school, college and adult years. The authors observed that lifetime Ca intake spreading over a long period of time was significantly correlated with BMC measured at the radial bone. When lifetime Ca intake was divided into three groups, low (< 500 mg/d), medium (500–800 mg/d) and high (> 800 mg/d), the medium and high Ca intake groups had significantly greater radial bone mass than the low intake group. Kelly *et al.* (1990) found that a diet persistently higher in Ca content was associated with greater radial bone mass in adult men. Picard *et al.* (1987) conducted a retrospective study on the effect of Ca intake throughout adulthood in 197 premenopausal women (aged 40–50 years) and found that the BMC of the lumbar spine and distal forearm was related to Ca intake in early adulthood. The BMC of the lumbar spine was significantly greater in the higher Ca intake (> 1000 mg/d) compared with the medium intake group (500–1000 mg/d). The adult studies indicate that lifetime Ca intake spreading over a long period of time, particularly during adolescence and early adulthood, is significantly correlated with adult bone mass. In addition, the appropriateness of using long-term Ca intake data to correlate with current bone mineral mass has also been implicated. Walker (1972) concluded that low Ca intake in different populations does not prejudice bone dimensions in various age groups including children. However, this conclusion was not supported by any longitudinal data. In the present investigation, a significant correlation between long-term Ca intake and BMC in children was observed while the cross-sectional association between current Ca intake and BMC in children was not established. Hence, our results suggest that the relationship between Ca intake and bone mineral mass in growing children would be valid during longitudinal study.

A recent study (Pun *et al.* 1989) reported that Ca intake in adult Hong Kong Chinese was low, a fact attributed to low consumption of milk and milk products. Ca intake dropped from around 500 mg/d in young adults to 300 mg/d in people aged above 60 years. The major sources of Ca were cereals, green leafy vegetables, legumes and tofu. In contrast, the present investigation reveals a remarkable increase in Ca intake among the younger generation in Hong Kong; 90% of children continued to consume milk regularly from birth to 5 years. The mean daily Ca intake was comparable to the RDA. The change in dietary habits was attributable to parents' growing awareness of milk as a good source of Ca and other nutrients for their children. At 5 years, most children would take an average of one glass of milk during breakfast every day. Such a trend reflects a significant change in dietary habits of the younger generation in a traditionally non-milk-drinking nation. The dietary habits developed in early life tend to influence food choices in adult life. The persistent habit of drinking milk for higher Ca intake right into adulthood would possibly enhance the average peak bone mass of the Hong Kong population in the future. However, the significance of having a higher BMC in children at age 5 years for peak bone mass at skeletal maturity is not known and warrants further investigation.

There were twenty-one cohort children in the present study with lower average Ca intakes in the first 5 years (< 400 mg/d). They all consumed milk regularly until 2 years of age when the frequency and quantity of milk consumption was gradually reduced. However, their individual records of growth pattern and health condition have been normal since birth and none of them has had any major illnesses (Leung & Lui 1989, 1990). Therefore, it does not appear that a habitually low Ca diet together with lower BMC was deleterious to the current state of health in this sub-group of children. Whether these children with lower BMC will predispose to lower peak bone mass in adulthood remains to be investigated.

Although we have demonstrated a positive effect of long-term Ca intake on BMC in children, Ca intake only accounted for approximately 6·2% of the variance in BMC as shown in Table 4, while current weight and BW contributed 16·5 and 23% respectively to the variations in BMC. This implies that body size and bone size had greater influence than Ca intake on predicting BMC in children. The finding of a moderate effect of Ca intake in determining bone mass of children was in general agreement with several recent studies in children and adolescents (Matkovic *et al.* 1990; Sentipal *et al.* 1991; Johnston *et al.* 1992). Very recent studies in children and adolescents have already indicated that the acquisition of bone mineral mass in children is multifactorial in that it is significantly related to age (Prentice *et al.* 1990; Katzman *et al.* 1991; Sentipal *et al.* 1991), weight, height and BW (Prentice *et al.* 1990; DePriester *et al.* 1991), genetic inheritance (Pollitzer & Anderson, 1989; Matkovic *et al.* 1990), pubertal status (Katzman *et al.* 1991; Sentipal *et al.* 1991) and physical activity (Kroger *et al.* 1992). Sentipal *et al.* (1991), using backward elimination regression analysis, found that the bone mineral density of children and adolescents was significantly correlated to the variables in the order of sexual maturity rating ($P < 0{\cdot}0001$), chronological age ($P < 0{\cdot}005$) and Ca intake ($P < 0{\cdot}04$). Nonetheless, the interactions between long-term Ca intake and other genetic and environmental factors have not been investigated adequately. Longitudinal studies are necessary in which these factors are considered concomitantly to confirm the extent of genetic–environmental influences on the development of bone mineral mass in children and adolescents.

Furthermore, the observation that Ca intake in the second year was the most influential period of early life on predicting BMC attained at 5 years remains to be confirmed by prospective study before one could advise infants to continue on Ca-rich infant foods until at least 2 years of age in order to provide sufficient Ca for bone mineralization.

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REFERENCES

Bingham, S. A. (1987). The dietary assessment of individuals; methods, accuracy, new techniques and recommendations. *Nutrition Abstracts and Reviews* **57**, 705–742.

Burke, B. S. (1947). The dietary history as a tool in research. *Journal of the American Dietetic Association* **23**, 1041–1046.

Cameron, J. R., Mazess, R. B. & Sorenson, J. A. (1968). Precision and accuracy of bone mineral determination by direct photon absorptiometry. *Investigative Radiology* **3**, 141–150.

Cameron, J. R. & Sorenson, J. A. (1963). Measurement of bone mineral in vivo: an improved method. *Science* **142**, 230–232.

Census and Statistics Department (1981). *Hong Kong Census Tables, 1981*. Hong Kong: Hong Kong Government Press.

Census and Statistics Department (1990). General Household Survey, Labour Force Characteristics (Quarterly report, April to June 1989). Hong Kong: Hong Kong Government Press.

Christiansen, C. & Rodbro, P. (1975). Estimation of total body calcium from the bone mineral content of the forearm. *Scandinavian Journal of Clinical Laboratory Investigation* **35**, 425–431.

Christiansen, C., Rodbro, P. & Jensen, H. (1975). Bone mineral content in the forearm measured by photon absorptiometry. *Scandinavian Journal of Clinical Laboratory Investigation* **35**, 323–330.

Church, C. F. & Church, H. N. (1975). *Food Values of Portions Commonly Used*. Philadelphia: J. B. Lippincott Co.

Cohn, S. H., Ellis, K. J., Caselnova, R. C., Asad, S. N. & Letteri, J. M. (1975). Correlation of radial bone mineral content with total body calcium in chronic renal failure. *Journal of Laboratory and Clinical Medicine* **86**, 910–919.

DePriester, J. A., Cole, T. J. & Bishop, N. J. (1991). Bone growth and mineralisation in children aged 4 to 10 years. *Bone and Mineral* **12**, 57–65.
Dequeker, J. (1988). Calcified tissues: structure–function relationships. In *Calcium in Human Biology*, pp. 209–340 [B. E. C. Nordin, editor]. London: Springer–Verlag.
Food and Agriculture Organization/World Health Organization Expert Group (1962). Calcium requirements. In *FAO Nutrition Meetings Report Series* No. 230. Rome: FAO.
Halioua, L. & Anderson, J. J. B. (1989). Lifetime calcium intake and physical activity habits: independent and combined effects on the radial bone of healthy premenopausal Caucasian women. *American Journal of Clinical Nutrition* **49**, 534–541.
Institute of Health (1980). *Food Composition Table*. Chinese Academy of Medical Sciences, Beijing: Chinese People's Health Publishing Co.
Jain, M. G. (1989). Diet history: questionnaire and interview techniques used in some retrospective studies of cancer. *Journal of the American Dietetic Association* **89**, 1647–1652.
Johnston, C. C., Miller, J. Z., Slemenda, C. W., Reister, T. K., Hui, S., Christian, J. C. & Peacock, M. (1992). Calcium supplementation and increases in bone mineral density in children. *New England Journal of Medicine* **327**, 82–87.
Katzman, D. K., Bachrach, L. K., Carter, D. R. & Marcus, R. (1991). Clinical and anthropometric correlates of bone mineral acquisition in healthy adolescent girls. *Journal of Clinical Endocrinology and Metabolism* **73**, 1332–1339.
Kelly, P. J., Pocock, N. A., Sambrook, P. N. & Eisman, J. A. (1990). Dietary calcium, sex hormone, and bone mineral density in men. *British Medical Journal* **300**, 1361–1364.
Kroger, H., Kotaniemi, A., Vainio, P. & Alhava, E. (1992). Bone densitometry of the spine and femur in children by dual-energy x-ray absorptiometry. *Bone and Mineral* **17**, 75–85.
Lau, E. M. C. (1988). Osteoporosis in elderly Chinese (letter). *British Medical Journal* **296**, 1263.
Leung, S. S. F. & Davies, D. P. (1989). Anthropometric assessment of nutritional status: a need for caution. In *Auxology 88, Perspectives in the Science of Growth and Development*, pp. 133–137 [J. M. Tanner, editor]. London: Smith-Gordon.
Leung, S. S. F. & Lui, S. (1989). Chinese infants are smaller than Caucasian: nutritional or genetic? *Pediatric Reviews and Communications* **3**, 309–316.
Leung, S. S. F. & Lui, S. H. (1990). Nutritive value of Hong Kong Chinese weaning diet. *Nutrition Research* **10**, 707–715.
Marcus, R. (1987). Calcium intake and skeletal integrity: is there a critical relationship? *Journal of Nutrition* **117**, 631–635.
Matkovic, V., Fontana, D., Tominac, C., Goel, P. & Chesnut, C. H. III (1990). Factors that influence peak bone mass formation: a study of calcium balance and the inheritance of bone mass in adolescent females. *American Journal of Clinical Nutrition* **52**, 878–888.
Matkovic, V., Kostial, K., Simonovic, I., Buzina, R., Brodarec, A. & Nordin, B. E. C. (1979). Bone status and fracture rates in two regions of Yugoslavia. *American Journal of Clinical Nutrition* **32**, 540–549.
Mazess, R. B. (1982). On aging bone loss. *Clinical Orthopedics* **165**, 239–252.
Mazess, R. B., Barden, H. S. & Ettinger, M. (1987). Spine and femur density using dual-photon absorptiometry in US white women. *Bone and Mineral* **2**, 211–219.
National Institute of Health (1984). Osteoporosis: Consensus Conference. *Journal of the American Medical Association* **252**, 799–802.
National Research Council (1989). *Food and Nutrition Board: Recommended Dietary Allowances*, 10th edn. Washington, D.C.: National Academy Press.
Nordin, B. E. C. (1976). Plasma calcium and plasma magnesium homeostasis. In *Calcium, Phosphate and Magnesium Metabolism*, pp. 186–216 [B. E. C. Nordin, editor]. Edinburgh: Churchill Livingstone.
Paul, A. A. & Southgate, D. A. T. (1978). *McCance and Widdowson's the Composition of Foods. 4th revised edn.* London: H.M. Stationery Office.
Picard, D., Ste-Marie, L. G., Carrier, L., Chartrand, R., Lepage, R. & A'Amour, P. (1987). Influence of calcium intake during early adulthood on bone mineral content in premenopausal women. In *Calcium Regulation and Bone Metabolism: Basic and Clinical Aspects*, vol. 9, pp. 128–131 [D. V. Cohn, T. J. Martin and P. J. Meunier, editors]. Amsterdam: Elsevier.
Picard, D., Ste-Marie, L. G., Coutu, D., Carrier, L., Chartrand, R., Lepage, R., Fugère, P. & A'Amour, P. (1988). Premenopausal bone mineral content relates to height, weight, and calcium intake during early adulthood. *Bone and Mineral* **4**, 299–309.
Pollitzer, W. S. & Anderson, J. B. (1989). Ethnic and genetic differences in bone mass: a review with a hereditary vs environment perspective. *American Journal of Clinical Nutrition* **50**, 1244–1259.
Prentice, A., Laskey, M. N., Shaw, J., Cole. T. J. & Fraser, D. R. (1990). Bone mineral content of Gambian and British children aged 0–36 months. *Bone and Mineral* **10**, 211–224.
Pun, K. K., Chan, L. W. T. & Chung, V. (1989). The problem of calcium deficiency in Hong Kong. *The Hong Kong Practitioner* **11**, 287–294.
Riggs, B. L. & Melton, L. J. (1986). Involutional osteoporosis. *The New England Journal of Medicine* **314**, 1676–1686.

Sandler, R. B., Slemenda, C. W., LaPorte, R. E., Cauley, J. A., Schramm, M. M., Barresi, M. L. & Kriska, A. M. (1985). Postmenopausal bone density and milk consumption in children and adolescence. *American Journal of Clinical Nutrition* **42**, 270–274.

Schlenker, R. A. & Von Seggen, W. W. (1976). The distribution of cortical and trabecular bone mass along the lengths of the radius and the ulna and the implications for in vivo bone mass measurements. *Calcified Tissue International* **20**, 41–52.

Sentipal, J. M., Wardlaw, G. M., Mahan, J. & Matkovic, V. (1991). Influence of calcium intake and growth indexes on vertebral bone mineral density in young females. *American Journal of Clinical Nutrition* **54**, 425–428.

Sorenson, J. A. & Cameron, J. R. (1967). A reliable in vivo measurement of bone mineral content. *Journal of Bone and Joint Surgery* **49A**, 481–497.

Steichen, J. J., Steichen Asch, P. A. & Tsang, R. C. (1988). Bone mineral content measurement in small infants by single-photon absorptiometry; current methodologic issues. *Journal of Pediatrics* **113**, 181–187.

Tung, T. C., Huang, P. C. & Li, H. C. (1961). Composition of foods used in Taiwan. *Journal of the Formosan Medical Association* **60**, 973–1005.

US Department of Health, Education and Welfare (1972). *Food Composition Table for Use in South East Asia.* Department of Health, Education and Welfare. Bethseda, Maryland, USA.

Walker, A. R. P. (1972). The human requirement of calcium: should low intakes be supplemented? *American Journal of Clinical Nutrition* **25**, 518–530.

Watt, B. K. & Merrill, H. L. (1983). *Composition of Foods. Agriculture Handbook* no. 8. U.S. Department of Agriculture, Washington, DC.

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