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Stature and age as factors in the growth of second metacarpal cortical bone in moderately malnourished children

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Summary. The association of stature and age with measures of second metacarpal cortical bone growth is investigated in a sample of 1586 radiographs taken from Guatemalan Ladino children aged 1–7 years in a setting of endemic mild-to-moderate malnutrition. For given stature, chronological age is positively associated with cortical thickness and cortical area and negatively associated with periosteal and medullary diameter. These different partial correlations are seen as evidence of different kinds of growth. Correlations of cortical bone variables with body size within a chronological age are shown to derive from the overall relationship between age, stature, and measures of cortical bone.

1. Introduction

Age-related changes in the development of cortical bone in children have been frequently described (Smithgall, Johnston, Malina and Galbraith, 1966; Takahashi and Frost, 1966; Wolanski, 1967; Bonnard, 1968; Virtama and Helela, 1969; Exton-Smith, Millard, Payne and Wheeler, 1969; Garn, 1970, 1972). During childhood bone diameters follow a growth curve similar to those of other measures of body size such as height. This is true both in well-fed populations (Tanner, 1962; Smithgall *et al.*, 1966; Gryfe, Exton-Smith, Payne and Wheeler, 1971) and in more poorly nourished ones (Himes, Martorell, Habicht, Yarbrough, Malina and Klein, 1975). However, none of the literature to date considers as such the nature of these age-related changes. Is growth of cortical bone a function of growth in body size, which is itself in turn related to age? Or is cortical bone growth a direct function of age, and as such only indirectly related to body size? These questions are important, since different kinds of growth suggest different mechanisms for this growth.

For a fixed age, cortical periosteal diameter is related to stature and weight, so that taller and heavier children tend to have greater diameters than smaller children of the same age and sex (Maresh, 1966). Our own unpublished observations show also that at least for mild-to-moderately malnourished pre-school children, stature and weight are related to medullary diameter, cortical area, cortical thickness and percentage cortical area, and that rate of growth in stature and weight is related to rate of growth in cortical diameter. This suggests an intrinsic connection between cortical bone growth and body size.

There are, however, animal studies which indicate that bone size of the normal animal is a function of both growth rate and chronological age. In growth of rats and dogs, if body weight is kept constant by underfeeding, bones still continue to grow in length, periosteal diameter, and cortical thickness (Dickerson and McCance, 1961; Pratt and McCance, 1960, 1964). The continued growth is, however, much slower than in normal animals indicating that cortical bone growth is also related to body size independently of chronological age.

Thus it seems reasonable to suppose there may be some part of human cortical bone growth which is purely age-related. The present report presents evidence to this effect in relation to second metacarpal cortical width.

2. Subjects and methods

The present investigation forms part of a longitudinal study of the effects of mild-to-moderate protein-calorie malnutrition on physical growth and mental development carried out by the Division of Human Development at the Institute of Nutrition of Central America and Panama (INCAP) (Klein, Habicht and Yarbrough, 1973). The study is being conducted in four rural Ladino villages in Guatemala where mild-to-moderate protein-calorie malnutrition is endemic (Habicht, Schwedes, Arroyave and Klein, 1973).

The study sample is mixed-longitudinal and the data consist of 1586 annual anthropometric examinations of 372 Ladino boys and 338 girls aged 1 to 7 (table 1). The present analyses use linear models, and treat the data cross-sectionally, so that each child may be represented in the total sample more than once. This presents no problem for the reported correlations, which are unbiased estimates of 'true' parameters regardless of whether the error terms are child-specific or, as we assume, observation-specific. There is, however, an issue to be raised over significance levels: if error variation is in fact child-specific, we overestimate the degrees of freedom and thus overstate the significance of our findings. However, even the reduced degrees of freedom in the worst case (approximately 308 for boys, 275 for girls) are so large that the only reported significance levels (table 3) would still be $<0\cdot05$ for 4 of the 5 values for boys and $<0\cdot01$ for girls.

Age	Boys (372)	Girls (338)
1	168	161
2	165	135
3	156	139
4	133	116
5	117	94
6	72	53
7	42	35
Total	853	733

Table 1. Number of annual examinations.

All examinations were made within 7 days of the child's birthday. At each examination standardized radiographs of the left hand and wrist were taken at a fixed tube–film distance of 76 cm. Stature was measured as recumbent length to the nearest millimetre (Yarbrough, Habicht, Malina, Lechtig and Klein, 1975).

The periosteal diameter (PD) and medullary diameter (MD) of the second metacarpal were measured at the midshaft point (excluding the epiphysis) by a single observer (Himes) with a graduated loupe (Bonnard, 1968) to the nearest 0·1 mm. Cortical thickness (CT) was obtained by subtraction of the medullary diameter from the periosteal diameter. An estimate of the cross-sectional cortical area (CA) was calculated assuming a cylindrical model: $CA = 0\cdot785\ (PD^2 - MD^2)$ (Garn, 1970). The relative amount of the periosteal area occupied cortex (percentage cortical area) was estimated as $PCA = 100\ [(PD^2 - MD^2)/PD^2]$ (Garn, 1970). The reliability of these measurements is given elsewhere (Himes *et al.*, 1975).

3. Results

Sex and age specific means for stature and the bone variables have been presented elsewhere (Himes *et al.*, 1975). The correlation coefficients between stature and age and the bone variables in the entire sample of 1–7 year old children are presented in table 2. There are no apparent differences by sex.

	Boys ($n=853$)		Girls ($n=733$)	
	Stature	Age	Stature	Age
Stature		0·95		0·95
Periosteal diameter	0·80	0·75	0·82	0·75
Medullary diameter	0·20	0·14	0·06	0·00
Cortical thickness	0·80	0·78	0·82	0·81
Cortical area	0·87	0·85	0·89	0·85
Percentage cortical area	0·63	0·63	0·66	0·67

Table 2. Correlations of stature and age with attained growth in metacarpal cortical bone.

Stature and age are highly correlated with cortical area, periosteal diameter, and cortical thickness, less so with percentage cortical area, and essentially uncorrelated with medullary diameter. This last is hardly surprising because there is little medullary expansion from 1 to 7 years in boys and none in girls (Himes *et al.*, 1975).

Table 3 presents the partial correlations of age with the bone variables, stature being held constant. There remains a small but statistically significant correlation with age. Importantly, the sign of this partial association varies from measure to measure. We return to this point in the discussion.

Table 4 presents the regression coefficients of stature with the bone variables (*a*) alone over all ages pooled ('stature' column), (*b*) holding age constant but over all ages pooled ('stature given age' column), and (*c*) averaged from separate regressions at each of the seven ages. The similarity of the regression coefficients between these last two columns of table 4 and the small variance of the averaged coefficients, lead us to conclude that stature and cortical bone are similarly related at each age even though ageing influences bone growth independently of stature.

Table 5 summarizes the linear quantitative relationships between age and stature for each of the various bone measures.

	Partial correlation with age given stature	Total variance accounted for by stature and age (%)
Boys (n=853)		
Periosteal diameter	−0·101**	64·59
Medullary diameter	−0·150***	5·00
Cortical thickness	0·120***	64·45
Cortical area	0·117***	76·61
Percentage cortical area	0·115***	40·35
Girls (n=733)		
Periosteal diameter	−0·166***	68·56
Medullary diameter	−0·209***	4·19
Cortical thickness	0·157***	67·49
Cortical area	0·062	78·55
Percentage cortical area	0·196***	44·92

**$P<0·01$; ***$P<0·001$.

Table 3. Metacarpal bone associations with stature and age.

Dimension	Stature (cm) All observations (Slope ± SE)	Stature (cm) given age, all observations (Slope ± SE)	Stature (cm) given age, slopes at each age averaged (Slope ± SE)
Boys (n=853)			
Periosteal diameter (mm)	0·0369 ± 0·001	0·0412 ± 0·003	0·0406 ± 0·003
Medullary diameter (mm)	0·0073 ± 0·001	0·0197 ± 0·004	0·0176 ± 0·004
Cortical thickness (mm)	0·0292 ± 0·001	0·0217 ± 0·002	0·0225 ± 0·003
Cortical area (mm²)	0·2262 ± 0·004	0·1887 ± 0·014	0·2045 ± 0·015
Percentage cortical area	0·5785 ± 0·024	0·3645 ± 0·080	0·3471 ± 0·085
Girls (n=733)			
Periosteal diameter (mm)	0·0347 ± 0·001	0·0460 ± 0·002	0·0498 ± 0·063
Medullary diameter (mm)	0·0021 ± 0·001	0·0219 ± 0·003	0·0220 ± 0·004
Cortical thickness (mm)	0·0319 ± 0·061	0·0239 ± 0·002	0·0245 ± 0·063
Cortical area (mm²)	0·2206 ± 0·004	0·2115 ± 0·013	0·2226 ± 0·016
Percentage cortical area	0·6450 ± 0·027	0·3015 ± 0·087	0·2602 ± 0·087

Table 4. Regression of metacarpal dimensions on stature.

Dimension	Constant	Stature (cm) Slope (± SE)	Age (months) Slope (± SE)	Residual Std. Dev.
Boys (n=853)				
Periosteal diameter (mm)	1·154	+0·0412 (±0·003)	−0·0044 (±0·0019)	0·363
Medullary diameter (mm)	1·1892	+0·0197 (±0·004)	−0·0083 (±0·0025)	0·480
Cortical thickness (mm)	−0·751	+0·0217 (±0·002)	+0·0049 (±0·0015)	0·293
Cortical area (mm²)	−9·0291	+0·1887 (±0·014)	+0·0252 (±0·0089)	1·689
Percentage cortical area	10·903	+0·3645 (±0·080)	+0·1406 (±0·503)	9·507
Girls (n=733)				
Periosteal diameter (mm)	0·692	+0·0460 (±0·002)	−0·0082 (±0·0018)	0·320
Medullary diameter (mm)	1·565	+0·0220 (±0·003)	−0·0135 (±0·0025)	0·446
Cortical thickness (mm)	−0·864	+0·0239 (±0·002)	+0·0054 (±0·0017)	0·306
Cortical area (mm²)	10·358	+0·2116 (±0·013)	+0·0139 (±0·0090)	1·592
Percentage cortical area	17·427	+0·3015 (±0·087)	+0·2369 (±0·0565)	10·046

Table 5. Regression of metacarpal cortical dimensions on stature and age.

4. Discussion

There are two basic models of bone growth which are best distinguished by the question: For a fixed stature, will younger children have more or less bone growth? In the case of linear models of growth, this general question reduces to one of the sign of a partial correlation. If the growth is related to chronological age and not to growth in stature *per se*, the partial correlation between age and attained bone growth at given stature will be positive. This is the case with cortical thickness and percentage cortical area (table 3).

On the other hand, if children who have been growing faster in stature have more bone growth, then for a given stature, age and attained bone growth measures will be negatively related. Periosteal and medullary diameter have this relationship (table 3).

Unlike age, stature is always positively associated with cortical bone growth at fixed age (table 4). That is, there is always a linear component of growth related to increasing size alone, independently of increasing age.

Finally, although both age and stature are separately related to cortical bone growth, resulting in the equations given in table 5, age and stature are so closely associated between one and seven years of age that equations using either age or stature have almost as good a prediction of cortical bone growth as do the equations in table 5.

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References

Bonnard, G. D. (1968). Cortical thickness and disphysial diameter of the metacarpal bones from the age of three months to eleven years. *Helvetica Paediatrica*, **23**, 445–463.

Dickerson, W. T., and McCance, R. A. (1961). Severe undernutrition in growing and adult animals. 8. The dimensions and chemistry of the long bones. *British Journal of Nutrition*, **15**, 567–576.

Exton-Smith, A. N., Millard, P. H., Payne, P. R., and Wheeler, E. F. (1969). Pattern of development and loss of bone with age. *Lancet*, **2**, 1154–1157.

Garn, S. M. (1970). *The Earlier Gain and the Later Loss of Cortical Bone*. Springfield, Illinois: C. C. Thomas.

Garn, S. M. (1972). The course of bone gain and the phases of bone loss. *Orthopaedic Clinics of North America*, **3**, 503–520.

Gryfe, C. I., Exton-Smith, A. N., Payne, P. R., and Wheeler, E. F. (1971). Pattern of development of bone in childhood and adolescence. *Lancet*, **1**, 523–526.

Habicht, J-P., Schwedes, J. A., Arroyave, G., and Klein, R. E. (1973). Biochemical indices of nutrition reflecting ingestion of a high protein supplement in rural Guatemalan children. *American Journal of Clinical Nutrition*, **26**, 1046–1052.

Himes, J. H., Martorell, R., Habicht, J-P., Yarbrough, C., Malina, R. M., and Klein, R. E. (1975). Patterns of cortical bone growth in moderately malnourished preschool children. *Human Biology*, **47**, 337–350.

Klein, R. E., Habicht, J-P., and Yarbrough, C. (1973). Some methodological problems in field studies of nutrition and intelligence. In *Nutrition, Development and Social Behavior*. DHEW Pub. No. (NIH) 73-242. U.S. Government Printing Office, Washington, D.C., pp. 61–75.

Maresh, M. M. (1966). Changes in tissue widths during growth. Roentgenographic measurements of bone muscle and fat widths from infancy through adolescence. *American Journal of Diseases of Children*, **111**, 142–155.

Pratt, C. W. M., and McCance, R. A. (1960). Severe undernutrition in growing and adult animals. 2. Changes in the long bones of growing cockerels held at fixed weights by undernutrition. *British Journal of Nutrition*, **14**, 75–84.

Pratt, C. W. M., and McCance, R. A. (1964). Severe undernutrition in growing and adult animals. 14. The shafts of the long bones in pigs. *British Journal of Nutrition*, **18**, 613–624.
Smithgall, E. B., Johnston, F. E., Malina, R. M., and Galbraith, M. A. (1966). Developmental changes in compact bone relationships in the second metacarpal. *Human Biology*, **38**, 141–151.
Takahashi, H., and Frost, H. M. (1966). Age and sex related changes in the amount of cortex of normal human ribs. *Acta Orthopaedica Scandinavica*, **37**, 122–130.
Tanner, J. M. (1962). *Growth at Adolescence*, 2nd Edition. Oxford: Blackwell Scientific Publications.
Virtama, P., and Helela, T. (1969). Radiographic measurements of cortical bone. *Acta Radiologica*, Suppl. 293.
Wolanski, N. (1967). Changes in bone density and cortical thickness of the second metacarpal between the ages of 3 and 74 years as a method for investigating bone mineral metabolism. *Acta Anatomica*, **67**, 74–94.
Yarbrough, C., Habicht, J-P., Malina, R., Lechtig, A., and Klein, R. E. (1975). Length and weight, in rural Guatemalan Ladino children birth to seven years of age. *American Journal of Physical Anthropology*, **42**, 439–448.

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Zusammenfassung. Der Zusammenhang zwischen Körperhöhe sowie Alter und kortikalem Knochenwachstum des zweiten Metacarpale wird bei einer Stichprobe von 1586 Röntgenaufnahmen von 1- bis 7-jährigen Ladino-Kindern aus Guatemala untersucht, die gering bis mäßig unterernährt waren. Bei gegebener Körperhöhe hängt das chronologische Alter positiv mit kortikaler Dicke und kortikaler Zone zusammen und negativ mit Periost- und Medullardurchmesser. Diese unterschiedlichen Partialkorrelationen werden als Hinweis auf verschiedene Wuchstendenzen gesehen. Es wird gezeigt, daß die Korrelationen der Variablen des kortikalen Knochens mit der Körpergröße innerhalb eines chronologischen Alters abzuleiten sind von dem allgemeinen Zusammenhang zwischen Alter, Körperhöhe und Maßen des kortikalen Knochens.

Résumé. La liaison de la stature et de l'âge avec des mesures de la croissance osseuse corticale du second métacarpien est recherchée dans un échantillon de 1586 radiographies prises chez des enfants Ladinos Guatémaltèques âgés de 1 à 7 ans dans un milieu de malnutrition endémique légère à modérée. Pour une stature donnée, l'âge chronologique est lié positivement à l'épaisseur corticale et à la surface corticale et lié négativement aux diamètres du périoste et de la médulla. Ces corrélations partielles différentes sont considérées comme témoins de différentes sortes de croissance. Il est montré que des corrélations des variables de l'os cortical avec le format corporel à âge chronologique donné dérivent de la relation générale entre l'âge, la stature et les mesures de l'os cortical.