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Sexual Dimorphism in Bone Growth as a Function of Body Size in Moderately Malnourished Guatemalan Preschool Age Children

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ABSTRACT The sexual dimorphism in second metacarpal bone growth was investigated in 710 malnourished Guatemalan children one to seven years old to determine if the sex differences seen are only the result of differences in stature and weight. The study sample was mixed-longitudinal and consisted of 1,586 annual examinations. Boys have greater mean stature, weight, periosteal diameter, medullary diameter and cortical area than girls the same age, while girls have greater age specific mean cortical thickness and percent cortical area than boys. When the effects of stature, weight and age are removed boys still have significantly larger periosteal and medullary diameters and less cortical thickness and percent cortical area than girls. These differences between boys and girls therefore cannot be explained by sex differences in body size. However, no sex differences in cortical area remain after accounting for differences in stature, weight and age.

Sexual dimorphism in bone dimensions has been well documented (Garn, '70). Males usually have greater periosteal diameters, medullary diameters and more cortex than females at every age. As males generally exceed females in height and weight, it has been suggested that these sex differences in the bone dimensions are primarily the result of larger body size (Owen et al., '66; Wolanski, '67). In this report we test this hypothesis in moderately malnourished preschool age children.

We have shown elsewhere that in malnourished preschool age children taller and heavier children have greater second metacarpal cortical dimensions than smaller children their age and sex (Himes, '75). Further, children who were growing faster in stature and weight were also growing faster in cortical bone.

The purpose of the present paper is to determine if the sexual dimorphism seen in measures of second metacarpal bone growth in malnourished preschool age children is only a reflection of sex differences in body size, or if there is a significant factor in the growth of cortical bone due to sex *per se*, independent of body size.

MATERIALS 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 et al., '73). The study is being conducted in four rural Ladino villages in Guatemala where mild to moderate protein-calorie malnutrition is endemic (Habicht et al., '73).

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TABLE 1

Number of annual examinations

Age	Boys (n = 372)	Girls (n = 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

The study sample is mixed-longitudinal in nature and consists of 1,586 annual examinations of 710 Ladino children one to seven years of age (table 1). The present analyses treat the data cross-sectionally so that a single child may be represented more than once in the total sample.

All examinations were made within seven days of the child's birthday. At each examination standardized x-rays of the left hand and wrist were taken at a fixed tube distance of 76 cm. Stature was measured as recumbent length to the nearest millimeter throughout the age range. Weight was measured nude to the nearest 10 grams.

The periosteal (PD) and medullary (MD) diameters of the second metacarpal were measured at the midshaft point (excluding the epiphysis) by a single observer (JHH). Metacarpal diameters were measured with a graduated loupe 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: $CA = 0.785\ (PD^2 - MD^2)$ (Garn, '70). The relative amount of the periosteal area occupied by cortex (percent cortical area) was estimated: $PCA = [(PD^2 - MD^2)/PD^2]\ 100$ (Garn, '70). The variability due to measurement of bone and body size variables was well within other published values and is given elsewhere (Himes et al., '75).

RESULTS

Figure 1 presents the absolute differences between boys and girls age specific

TABLE 2

Sex effects in multiple regression after removing effects of stature, weight and age (n = 1586) [1]

	Partial r	Difference between sexes ($b \pm SE_b$)	t
Periosteal diameter	0.32	0.238 ± 0.018 mm	13.44 [2]
Medullary diameter	0.33	0.332 ± 0.024 mm	13.74 [2]
Cortical thickness	−0.15	−0.093 ± 0.016 mm	−5.93 [2]
Cortical area	0.02	0.076 ± 0.085 mm²	0.89
Percent cortical area	−0.23	−4.785 ± 0.508%	−9.41 [2]

[1] For the regressions sex was coded: 1 = boys, 0 = girls.
[2] $p < 0.001$.

TABLE 3

Comparison between means of boys and girls 90 cm tall

	Boys (n = 41)		Girls (n = 40)		
	Mean	S. D.	Mean	S. D.	t
Age (months)	44.19	8.24	47.20	9.39	−1.63
Stature (cm)	89.98	0.64	90.00	0.64	−0.10
Weight (kg)	13.14	0.94	12.92	0.88	1.10
Periosteal diameter (mm)	4.75	0.33	4.41	0.34	4.53 [2]
Medullary diameter (mm)	3.35	0.43	2.91	0.38	3.85 [2]
Cortical thickness (mm)	1.41	0.26	1.50	0.36	−1.37
Cortical area (mm²)	8.90	1.49	8.47	1.51	1.29
Percent cortical area (%)	50.37	8.49	56.28	12.34	−2.50 [1]

[1] $p < 0.05$.
[2] $p < 0.001$

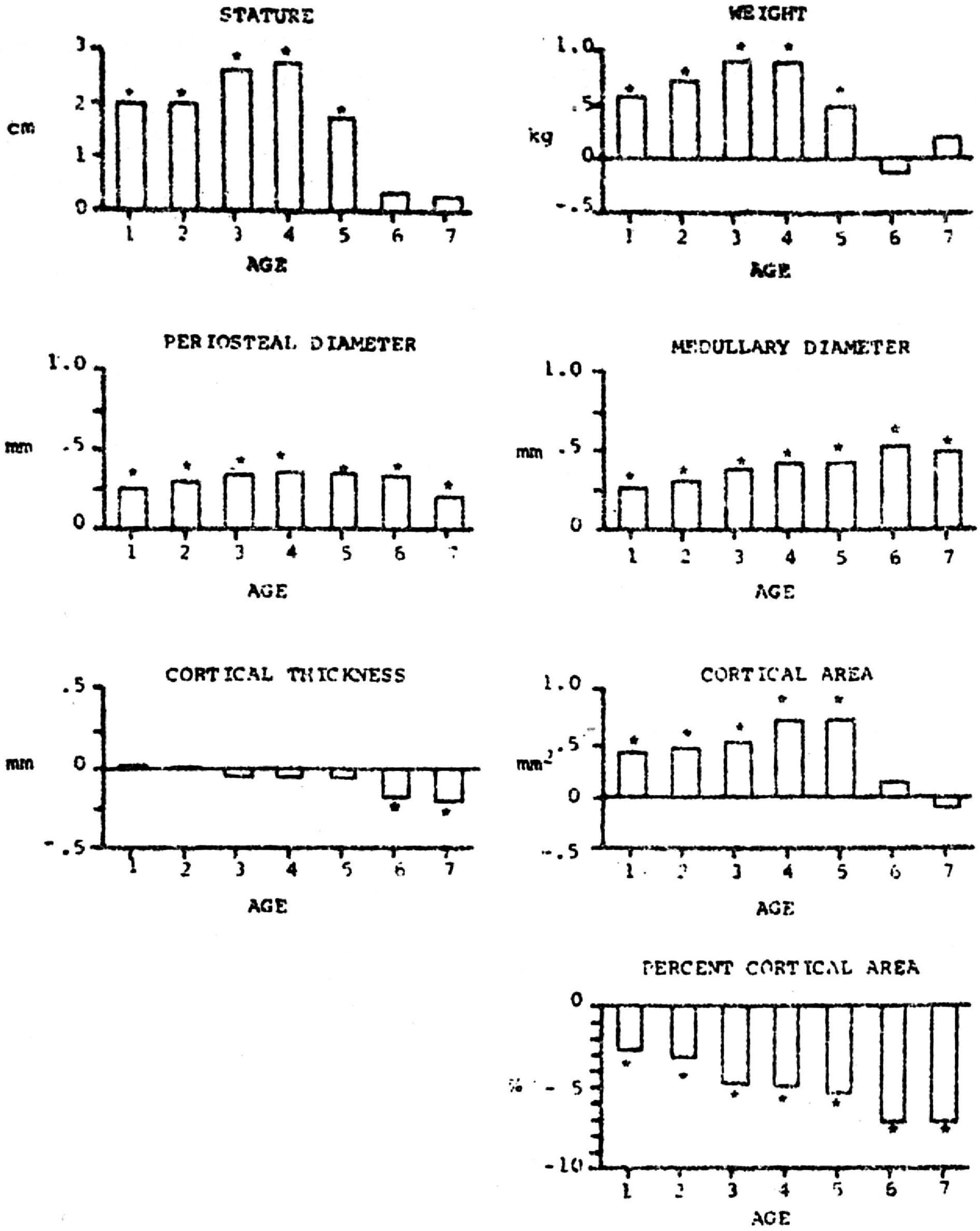

Fig. 1 Absolute differences between age specific means of boys and girls (boys — girls) for the body size and metacarpal variables. * Boys' and girls' means are significantly different ($p < 0.05$).

means for the measures of second metacarpal cortical growth and stature and weight. We have reported the age-sex specific mean values elsewhere (Himes et al., '75). The boys are systematically taller and heavier than the girls and have greater mean periosteal and medullary diameters and cortical area. Girls have significantly greater mean percent cortical area and generally greater cortical thickness than boys the same age. The difference in cortical thickness increases with age to attain significance at six and seven years.

Some of these sex differences in bone might be explained by the greater stature and weight of boys than girls of the same age. We have shown elesewhere that besides stature and weight, age is also related to the metacarpal cortical bone variables (Yarbrough et al., '76). Therefore, we have taken stature, weight and age into account in examining the sex differences in the cortical bone variables by multiple regression analysis.

Table 2 presents the partial correlations and regression coefficients of the cortical bone variables with sex, after stature, weight and age have been partialled out. There is no significant effect on cortical area of sex independent of stature weight and age, while periosteal and medullary diameters still remain greater in boys than girls of same stature, weight and age. The differences of girls as contrasted with boys of a same age of cortical thickness and percent cortical area (fig. 1) become even more marked when stature, weight and age are the same in both sexes.

Similar results are obtained from discrete analyses pursuing the same question. Children were grouped according to stature regardless of age, weight or sex. Although the results are similar for any stature, we present as an example 90 cm, a stature that corresponds approximately to the midpoint of the age range, three and one-half years.

For children in the sample who were 90 cm tall (89.0–91.0 cm), table 3 presents the means for body size and bone growth of boys and girls compared by t-test. When matched for stature, boys have significantly larger periosteal and medullary diameters than girls, while the sexes are not significantly different in cortical thickness and cortical area. Girls, on the other hand, have significantly greater percent cortical area than boys of the same stature.

DISCUSSION

These Guatemalan children present the same pattern of sexual dimorphism in second metacarpal cortical bone as has been reported for similarly malnourished children in Central America (Garn and Rohmann, '66, '67), and for well nourished children elsewhere (Garn, '70; Gryfe et al., '71), with the single exception that the Guatemalan girls generally have a greater mean cortical thickness than boys of the same age.

In the present paper we have shown by regression analysis that if the girls were the same stature, weight and age as the boys they would still have smaller periosteal and medullary diameters than the boys. This is an example, then, of sexual dimorphism beyond that expected for body size differences.

The medullary cavity of tubular bones is occupied to a large extent by the red bone marrow which has as a primary function the production of red blood cells. The erythropoetic mass is related to the oxygen needs of the body which in turn are closely associated with lean body mass (Viteri et al., '68). Therefore, it has been suggested that the greater medullary diameters seen in males may be associated with an increased need for red blood cells commensurate with a greater body mass (Smithgall et al., '66). However, this does not seem to be a likely explanation in the present population as we have shown that after accounting for sex differences in stature and weight boys still have greater medullary diameters than girls. Although it may be argued that accounting for stature and weight cannot be considered equivalent to controlling for lean body mass, Flynn et al. ('70) found no sex differences in lean body mass, as determined by ^{40}K, in Negro and white children four to six years of age of similar stature and weight. In contrast, the sex difference in cortical area is unlike that of periosteal and medullary diameters, in that cortical area only reflects greater stature and weight rather than differences in sex *per se*.

It is generally held that boys and girls respond differentially to disease and nutritional stress (Tanner, '62). If this were true in this mildly to moderately malnourished population, the greater medullary diameters of the boys might be explained by increased endosteal resorption relative to the girls in the face of nutritional stress, rather than a difference associated with gender alone. The reported relationship may, in part, reflect an interaction of sex and nutritional state, although the data do not allow inference as to the extent or significance of such interactions. Unfortunately, we are aware of no comparable data for well nourished children that could help clarify this point. However, we know that at least for stature and weight these boys and girls are equally retarded with respect to age-sex specific standards (Yarbrough et al., '75). Moreover, such an explanation could not account for the greater periosteal diameters of the boys when compared to girls of the same stature, weight and age.

CONCLUSIONS

In summary, there are three types of sexual dimorphism in measures of second metacarpal growth in Guatemalan children with respect to body size. Sex differences in cortical area arise from boys being larger than girls. On the other hand, sexual dimorphism in cortical thickness and percent cortical area is unrelated to sex differences in body size. Finally, periosteal and medullary diameters are greater in boys than girls, hence to an extent related to sex differences in body size. But when the effects of body size and age are removed boys still have greater medullary and periosteal diameters than girls.

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