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PATTERNS OF CORTICAL BONE GROWTH IN CHILDREN: AN EXAMPLE FROM MEDIEVAL POPULATIONS

ABSTRACT: The analysis of a sample of subadult skeletons from two medieval cemeteries demonstrates the usefulness of this material in the study of bone growth and development. These series were utilised in determining the pattern of age-related changes in the length, width and cortical thickness of the femur and tibia.
It was found that while growth in length as well as in total width remains fairly well-maintained, cortical thickness and other derivative variables (cortical index and percent cortical area) show growth curves which reflect excessive endosteal resorption.

KEY WORDS: Compact bone-remodelling – Bone loss – Subadults-skeletal populations

INTRODUCTION

The skeletal system of man is responsible for the support of the muscles, protecting the vital organs such as the brain and the eyes, producing red blood cells, and maintaining chemical balance in the organism. It, similar to other systems, changes during the process of ontogenesis. The development of the different bones depends on a number of factors, such as genetic susceptibility, age, sex, and resiliency. Furthermore, there is a hierarchical response in how an individual responds to stressors. Soft tissues are generally said to be more severely affected by malnutrition and diseases than skeletal materials (Mc Cance, 1960; Mc Cance et al., 1961, 1962). Even within the skeletal system there is a hierarchy of response, since teeth are better buffered than bones (Garn et al., 1965). Roentgenometrical analysis of bone provides clues to the overall physiological state of an individual up to the point of death. Since bone reacts to stress in a limited number of ways (by resorbing and depositing), defining the pattern of remodelling will aid in understanding the process of skeletal development. While specific patterns of diseases may not be immediately apparent, differences in bone remodelling rates may reveal less specific conditions resulting from metabolic disorders and nutritional disturbances.

A number of studies concerning the remodelling of cortical bone have been undertaken on modern groups (Becker 1984; Garn et al., 1967; Stini 1990). This phenomenon has also been examined in archaeological materials (Armelagos et al., 1972; van Gerven et al., 1969; Gunness-Hey, 1985; Macchiarelli, 1988; Mielke et al., 1972). The analysis of stressors in prehistoric and historic populations is valuable in unravelling the success and difficulties that a cultural system, a population and an individual may have had in adjusting to their environment. Furthermore, a variety of populations (modern and archaeological) can be compared, temporally and spatially, to determine differentials in skeletal development and to discover genetic or environmental factors which may have influenced rates of bone turnover. Archaeological material, even considering its limitations, can help to solve current problems in bone biodynamics.

Rarefaction of bone tissue seems to be the most important of the phenomena concerning bone remodelling. It is also a major problem for nutritional research. It may relate to the composition of the foods consumed and their physical properties. It is a problem of mineral nutrition, traditionally including calcium and phosphorus but possibly magnesium as well, concerning the bone's ability to absorb and retain them. Qualitative analyses on ancient skeletal samples, limited to the spongy bone, were later successfully extended to a more specific qualitative analysis of the cortical tissue. In the studies realised on human skeletal remains of archaeological interest, physical anthropologists mainly employed the femur and tibia, which are commonly better represented and preserved (Atkinson et al., 1962; Dewey et al., 1969; Ericksen, 1982).

Although most studies on bone loss deal with adults, the patterns of bone growth in children has also been investigated (Armelagos et al,1972; van Gerven et al., 1985; Hummert, 1983). Research of this type in subadult long bones is based on the fact that dental development is less affected by stressful conditions than skeletal growth and that dental age distributions of subadult skeletons will accurately represent the real distribution of an entire cemetery population.

Therefore, long bone cortical growth and maintenance may be plotted against dental age. Since long bone growth in length may be maintained at the expense of cortical thickness, comparisons of long bone width and length curves may provide a hierarchy of growth responses to stress.

Growth-related and health-related studies of past populations are based primarily on long bone measurements. Then the succeeding evaluations are carried out in one of two ways. First, the pattern of indicators (for example, Harris lines) can be compared to published data for modern populations. Second, a comparison can be made between two or more prehistoric groups to see if there is a difference in the pattern of indicators. In both cases the physiological and morphological difference between those who die and those who survive, which is termed biological mortality bias, is assumed to be negligible and constant across groups.

There are two other kinds of biases that can affect samples of skeletons. The first one includes what might be termed cultural mortality bias, and produces differential representations of individuals in cemeteries because of variations in mortuary practices (Walker et al., 1988; Saunders, Hoppa, 1993). The second is the environmental mortality bias, resulting from the differential effects of skeletal preservation depending upon soil composition, acidity, humidity, and internment conditions, as well as mortuary practices.

However, the potential bias due to mortality selection within a sample seems to be minimal, and is far less than the range of error or variation that results from methods of ageing using tooth formation and the cross-sectional nature of the samples, which may have a standard deviation for diaphyseal length (Saunders, Hoppa, 1993).

In this study, we will undertake both direct measurements of subadult femora and tibiae and a roentgenometric analysis of compact tissue of these bones from two medieval Polish cemeteries. The patterns of long growth and cortical bone loss as a function of age will be discussed. Specifically, changes in cortical thickness, cortical index and percent cortical area will be determined.

MATERIALS AND METHODS

The sample consists of 114 femora and tibiae of subadults aged from 1 to 16 years from two medieval Polish cemeteries, namely Cedynia and Słaboszewo. The authors have not found statistically significant differences in the mean values and variations of the investigated variables between these two groups, so they were treated as a single sample. In the first step of the analysis, the lengths of all bones (femur and tibia) were measured, but only left bones were selected for further examination. Then the radiographically detectable cortical layer of the bones was evaluated. Direct measurements from the radiographs were made using a calliper with a 0.05 mm readout. Total subperiosteal width (T) and medullary diameter (MD) at the midshaft were measured. On the basis of these measurements other derivative variables were calculated, namely, cortical thickness $CT = T–MD$, cortical index $CI = CT/T$, and percent cortical area $PCA = (T^2–MD^2)/T^2$. Developmental ages were assigned based on the sequence of dental formation and eruption, following the standards presented by Ubelaker (1987).

The findings concerning the investigated group have been compared with data coming from medieval Christian population at Kulubnarti (Hummert, 1983), in which dietary inadequacies were involved in producing stress among subadults.

A BRIEF DISCUSSION OF RESULTS

Length and width show continuous increase in each age group *(Figures 1, 2)* which is normal throughout childhood even in malnourished children (Garn et al., 1964, 1969; Himes et al., 1975). Unlike linear growth, cortical thickness, cortical index, and percent cortical area decrease in several age categories *(Figures 3–5)*. Standards of normal growth in modern living populations indicate that patterns of cortical apposition parallel those for linear growth (Garn et al., 1969). However, the present data suggest that growth in length and total width continued at the expense of cortical bone maintenance. This is evident in growth patterns of cortical index and, especially, percent cortical area. The latter variable expresses the balance of endosteal resorption at the inner surface and the subperiosteal

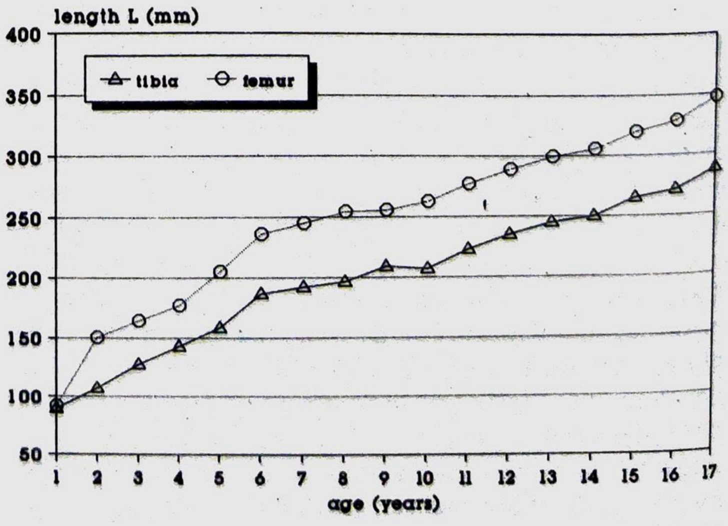

FIGURE 1. Growth patterns in particular age groups for length.

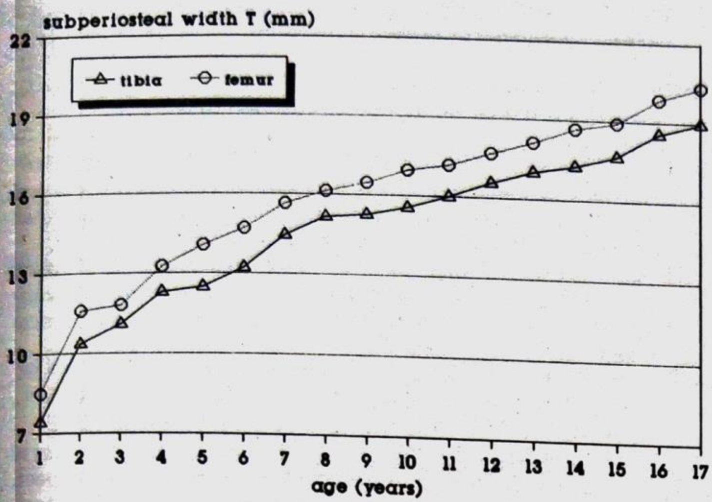

FIGURE 2. Growth patterns in particular age groups for total subperiosteal width.

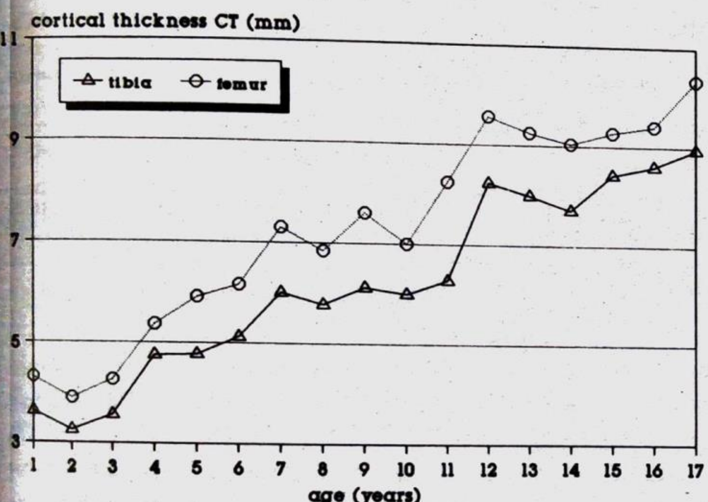

FIGURE 3. Growth patterns in particular age groups for cortical thickness.

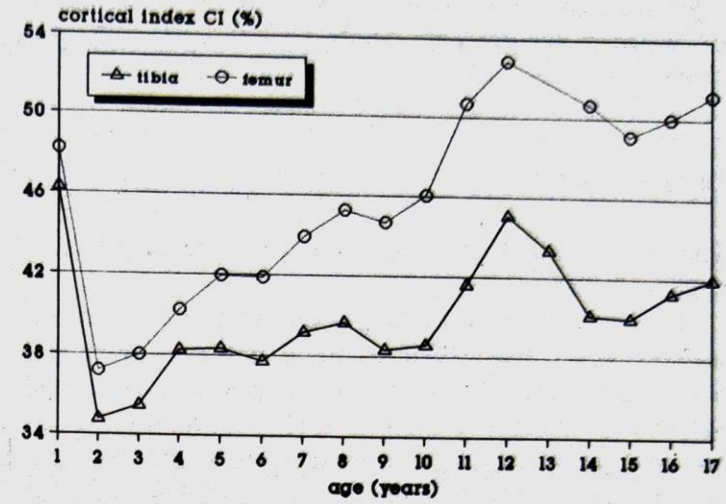

FIGURE 4. Growth patterns in particular age groups for cortical index.

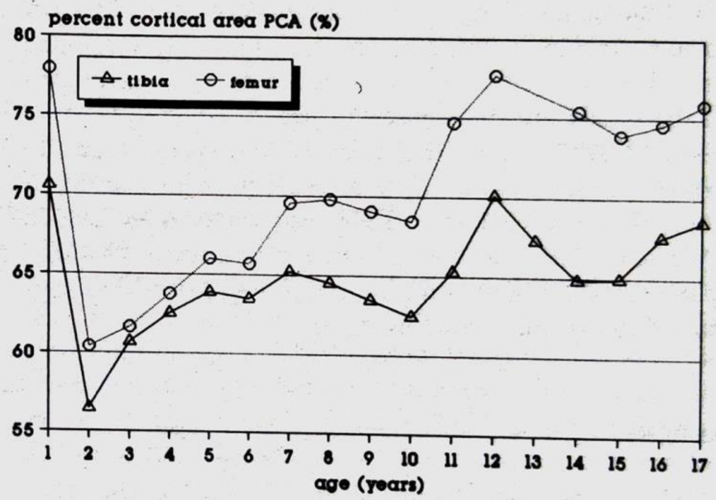

FIGURE 5. Growth patterns in particular age groups for percent cortical area.

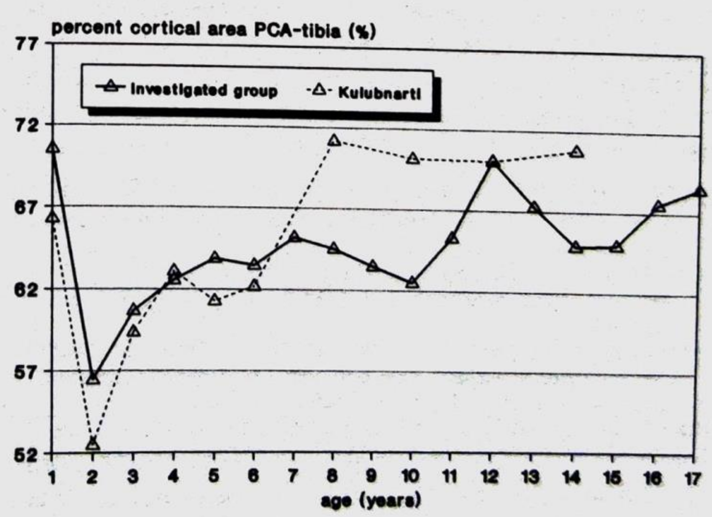

FIGURE 6. Comparison of the percent cortical area between the investigated group and Kulubnarti population.

apposition at the outer surface of the bone. In normal development, the second process exceeds the first one until the age when menopausal bone loss occurs. In childhood, however, abnormal growth patterns of PCA may result from excessive endosteal resorption which, in turn, may reflect states of severe undernutrition. If this were a case of long-term protein-energy deficiencies, subperiosteal apposition rather than endosteal resorption would be affected (Himes et al., 1975). The growth curve for PCA decreases severely in the youngest children, especially at the age of two. This growth pattern was also found in a comparison between the investigated group and the Kulubnarti population *(Figure 6)*. This finding may explain the greater susceptibility of growth to undernutrition in this phase of progressive ontogenesis. Weaning stress and malabsorption resulting from the high incidence of infectious diseases and other morbid states characteristic for this age category (for example, diarrhoea, pathogens) may have also caused a decrease in relative bone loss (Hummert, 1983).

Numerous studies indicate that the period from birth until about 3 years of age is the most crucial with respect to osseous tissue development. At this time the highest nutritional demands by the body, as well as susceptibility to infection related to weaning, are observed (Guerrant et al., 1983; Rowland et al., 1988). As a result, the first few years of life represent a period when adverse factors can have a significant and lasting effect on growth. After about

3 years of age, children tend to be consistently advanced or retarded during their whole growth period (Bogin, 1994).

CONCLUSIONS

The findings for the investigated populations are summarised as follows:

1. The results of this study show the value of skeletal material in the analysis of problems in bone growth and development. Specifically, examination of bone length and age-related changes in cortical thickness are of great importance. The comparison of these two variables throughout ontogenesis may provide insight into the hierarchy of growth responses to stress.

2. Patterns of growth expressed in terms of curves for tibial and femoral length and total subperiosteal width seem to be normal in the examined medieval groups. Continued growth of these parameters in children may have been maintained at the expense of cortical thickness.

3. Variables describing relative bone loss, especially percent cortical area, show unusual growth patterns in several age categories. This indicates an excessive endosteal resorption, and may have been due to both qualitative and quantitative undernutrition and/or malabsorption of many important nutrients.

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