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Received 18 April 1969

Bone Growth and Development in Prehistoric Populations from Sudanese Nubia

The analysis of a large sample of skeletons from a number of Sudanese Nubian cemeteries demonstrates the usefulness of this material in the study of bone growth and development. A skeletal series from the Meroitic (B.C. 350–A.D. 350), X-Group (A.D. 350–550), and Christian (A.D. 550–1400) period were utilized in determining the rate of bone development and age related changes in the internal structure of the femur. Specifically, we have been able to demonstrate the following:
(1) The growth velocity determined from the long bones in the Nubian sample was similar but somewhat more irregular than the growth velocity of long bones in American boys studied longitudinally.
(2) Growth symmetry of long bones determined by the ratio of lengths shows a greater stability than that which occurs in American boys.
(3) Decrease in femoral cortical thickness with age was significant in Nubian females ($P < 0{\cdot}001$), while the decrease in males was not significant. The loss of cortical bone tissue in Nubian females appears to begin earlier than similar changes in modern females.
(4) The density of femoral head trabecular bone organ volume decreases with age at similar rates in both males and females, but the females lose a larger percentage of density since they enter the age period (17 years) with a lower density.
(5) The average thickness of femoral head trabeculae decrease with age in males, while in females there is an increase in thickness. It appears that as cross-members decrease in thickness with age, struts increase in thickness.
(6) Microradiographic analysis of archeological material may provide an additional dimension to the study of bone turnover rates.

1. Introduction

Physical anthropologists have traditionally utilized skeletal material in assessing biological relationships between populations. In many instances, attempts to reconstruct the relationship between populations has been an end in itself. In our laboratories we have attempted to analyze skeletal material to aid in elucidating processes of bone growth and development. In this way, we not only focus on differences between populations but attempt to develop a basic understanding of bone biodynamics. Specifically, we have been interested in long bone growth and degenerative changes which are a result of the aging process. The degenerative changes studied include changes in cortical bone of the femur as well as changes in trabecular bone in the femur head.

Cultural setting

The material used in this study was excavated in cemeteries associated with the Meroitic (350 B.C.–A.D. 350) X-Group (A.D. 350–550) and Christian (A.D. 550–1400) cultural horizons in Sudanese Nubia (Figures 1 and 2). The reconstruction of Meroitic, X-Group and Christian cultural horizons is somewhat hampered by the fact that published reports of sites excavated in recent years are only now beginning to appear. Adams (1964, 1965) has reviewed the post-Dynastic cultural sequence in Nubia in the light of recent excavations. The reconstruction of cultural horizons has emphasized the basic adaptation to irrigation farming of these early agriculturalists. Specifically, Meroitic culture (350 B.C.–A.D. 350) was a period in which native Nubian culture attained its highest level of development. The center of this development, Meroë, was far to the south. Although most specialists believe that the Wadi Halfa area enjoyed the same growth as

areas nearer to Meroë, it is possible that the Wadi Halfa area never enjoyed the same level of development. Armelagos (1968, 1969) points out that mortality data indicates that during the Meroitic period, populations in Wadi Halfa were undergoing considerable stress. These conclusions are based on the comparison of Meroitic mortality patterns with those of subsequent X–Group and Christian patterns.

The problem is essentially one in which the X-Group period representing a phase following the break-up of the Meroitic empire is thought to be a time of cultural disintegration in the Wadi Halfa area. However, there is a possibility that the break-up of the Meroitic empire would not have drastically affected these populations. Adams suggested that proximity to Egypt may have accounted for this stability and lack of cultural decline during the X-Group period.

The Christian period (A.D.550–1400) saw the religious reunification of Lower Nubia and was a period of unheralded cultural growth. The archeological evidence reveals a long period of stability. Village growth and the development of writing and art independent of Egyptian influence are all evidence of this cultural growth. Even after the Muslim conquest of Egypt in A.D. 640–42, the Christians maintained their independence. During the classic period of Christianity there was an elaboration of church architecture and the first evidence of urbanization.

Adams (1964, 1965) and Lister (1967) have discussed the transition between Meroitic, X-Group and Christian horizons, and both suggest that there is no evidence of sharp discontinuities between these groups. Greene (1967) has shown on the basis of genetically determined dental characteristics that it is not possible to distinguish the populations on the basis of these biological traits.

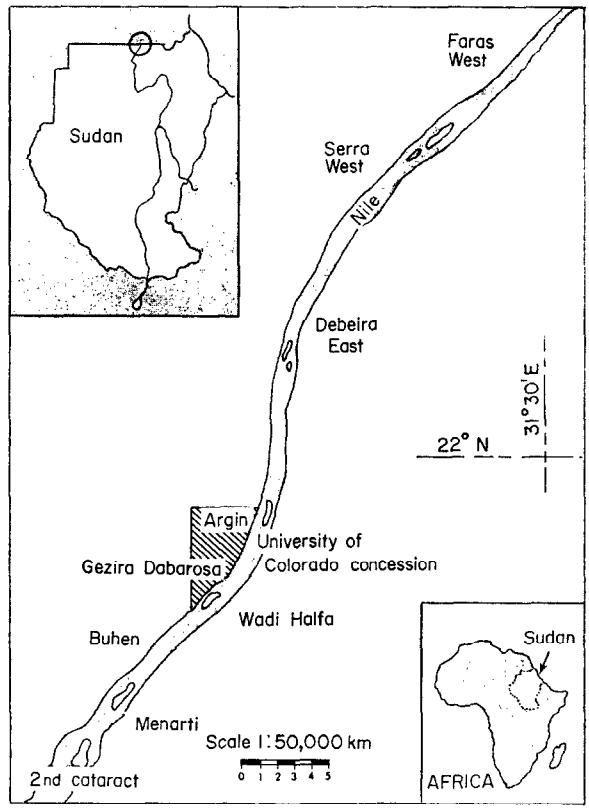


Figure 1. The Wadi Halfa area of Lower Nubia. The Colorado concession contained except NAX (from North Argin) and 2413 which was located at Serra West. The insert at upper left, the small circle, indicates the Wadi Halfa area.

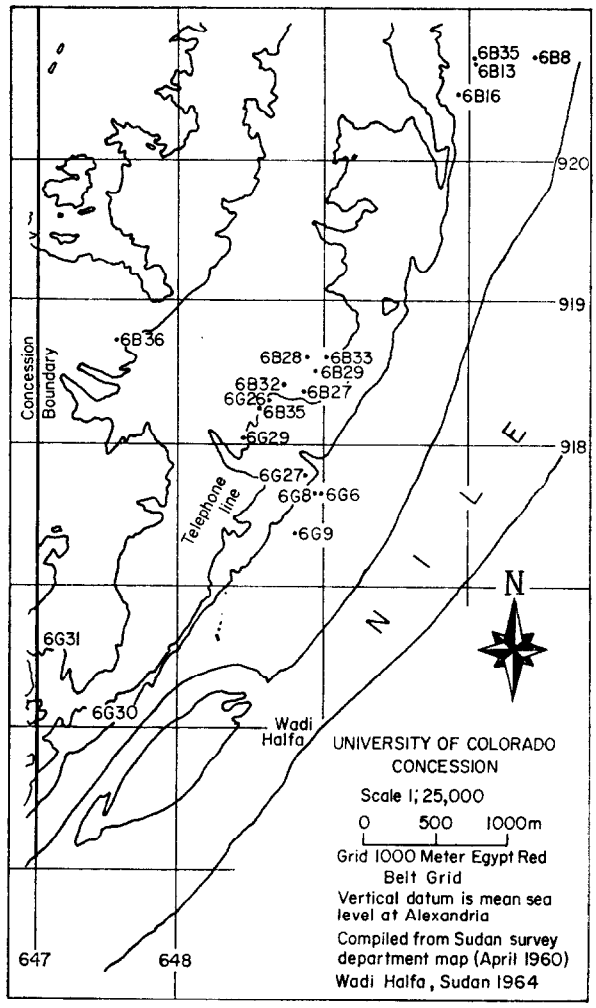


Figure 2. The University of Colorado concession. Note 130 M, 140 M, 150 M terraces.

2. Long Bone Growth

A description of long bone growth patterns (see Mahler, 1968, for complete report) provides information important for a morphological description of a prehistoric population. Long bone growth has been viewed as a critical aspect of the general features of skeletal growth (Garn, 1957). The relationship between long bone growth and stature is indicated by attempts to establish correlations which allow the prediction of stature from long bone length (Genoves, 1967; Trotter & Gleser, 1958).

The need for an approach central to human biology is suggested by the fact that growth studies today are largely done by those interested in child development rather than in approaching the processes of growth at the population level. There is then a necessity to revive the kind of interest in growth and growth patterns in populations that could add a new dimension to studies of human variability.

The purpose of this phase of our research was primarily the quantification of the rate and course of growth patterns of various long bones in the Nubian populations. Johnston (1962) presents the only other description of growth based on an archeological population

but limits his study to individuals aged between birth and five years. This study included individuals 31 years of age and older. The means and standard deviations were calculated for the measurements of the shaft lengths for six long bones in each age group. The long bones measured were the femur, tibia, humerus, radius, ulna and clavicle. Curves of growth distance and growth velocity were constructed to illustrate the total amount of long bone shaft length increase (length at each age), and to demonstrate the incremental nature of long bone growth (increase at each age). Long bone growth was examined during the infant, childhood and adolescent phases of development. In addition, the symmetry of proportionality of bone growth during these phases was determined.

Comparative data limited to American boys were examined in relation to growth velocity and symmetry. There are, however, a number of problems involved in an analysis of this type. For example, the size of the sample makes analysis difficult (Johnston, 1968). An archeological population of 1000 individuals would be necessary to approach an adequate sample of all age groups, and even in a population of this size a sufficient number of pubertal and post-pubertal individuals may not be assured. In this study, the large standard deviations are a reflection of small sample size.

There is, however, a more serious objection raised by Johnston (1962) in that growth curves such as those presented here do not represent normal healthy children, but, in many instances, children whose death was due to a pathological condition of indeterminate length.

In addition, a technical problem was encountered due to the manner in which long bones were measured. Long bone shaft length was measured between epiphyseal plates but excluding the epiphysis for individuals in age groups ½ to 16 years. However, for individuals over 16, epiphyseal union was complete and consequently their whole bone measurements were not directly comparable. It was therefore not possible to determine the amount of bone growth between age groups 13–16 and 16–20.

(*a*) *Method and materials*

Chronological ages were obviously unknown, and it was necessary to establish criteria which could place samples into developmental age groups. Examination of dental eruption patterns provided the criteria used to establish developmental ages. Eruption patterns for the Nubian population were determined by extraction and examination of each tooth (Greene, 1967, p. 11). These developmental ages based on dental morphology were guided by standards of eruption set by Graber (1966), Moorrees, Elizabeth, Faning & Hunt (1963) and Massler & Schour (1940).

With the placement of each sample according to dental development, the mean and standard deviation of measurements of maximum shaft length of the six long bones was calculated for each developmental age group (Table 1) with no distinction made on the basis of sex.

Measurements from a total of 115 individuals aged between ½ and 31 years were used in the analysis. An additional 37 individuals aged over 31 years were also measured to verify cessation of growth.

(*b*) *Results and discussion*

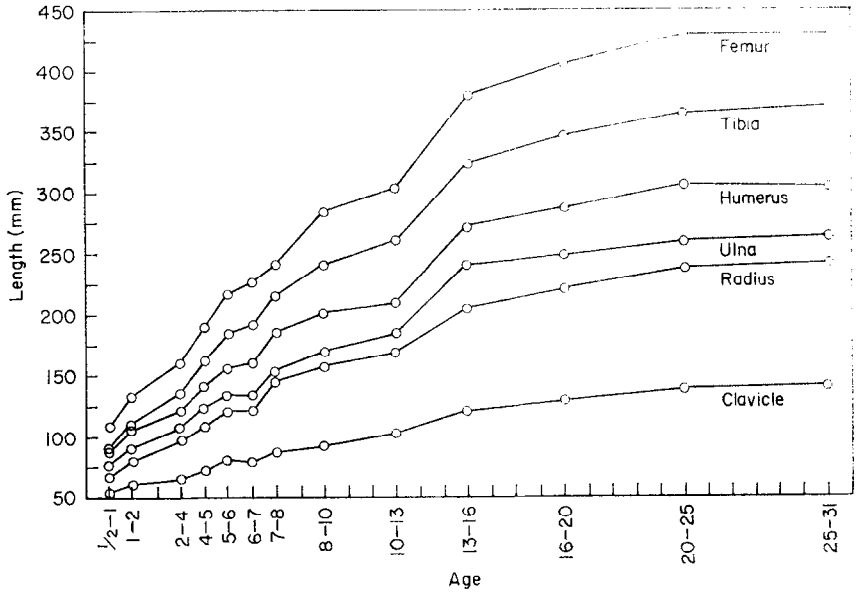
A continuous incremental increase in long bone length is evident upon examination of mean shaft length (Table 1). It is apparent (Figure 3) that long bone growth is greatest

Table 1 **Long bone lengths (mm): mean shaft length and standard deviation from the mean (S.D.)**

Developmental age (years)		Femur		Tibia		Clavicle		Humerus		Radius		Ulna	
	N	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
½–1	7	109·0	15·1	92·2	12·6	54·8	5·9	87·1	9·6	69·6	9·0	77·8	9·0
1–2	5	134·4	12·7	113·2	10·6	60·3	1·7	106·2	10·5	82·0	7·1	92·7	5·5
2–4	6	162·2	17·0	136·8	16·0	65·5	6·2	122·0	11·0	98·0	9·3	107·0	7·4
4–5	5	192·4	11·8	163·8	11·5	73·7	2·9	141·4	7·9	109·8	7·7	124·0	6·1
5–6	5	218·5	16·2	185·8	15·8	81·3	5·4	156·2	9·1	121·3	5·8	134·8	6·4
6–7	13	226·3	21·2	191·9	18·4	80·5	5·7	161·6	14·8	122·7	10·8	135·2	13·8
7–8	4	243·3	18·6	216·5	26·7	87·5	0·5	185·7	18·7	144·0	16·9	156·7	15·2
8–10	6	285·2	11·7	243·0	18·2	93·4	3·9	202·0	9·2	157·2	6·7	172·2	5·7
10–13	4	304·5	17·6	261·3	21·0	103·0	0·0	212·3	9·3	169·5	7·0	185·3	6·5
13–16	6	382·2	27·1	324·3	10·8	121·0	7·9	273·8	16·0	206·8	21·2	235·2	16·6
†16–20	7	406·0	33·4	346·0	33·1	129·3	12·6	288·7	26·1	223·7	22·0	248·3	25·3
†20–25	24	430·2	34·0	367·5	30·0	138·2	8·3	306·1	19·2	237·6	19·3	260·0	20·8
†25–31	23	432·8	21·0	371·3	22·9	139·9	9·5	305·2	18·5	242·2	14·3	267·4	14·3

† Measurement includes epiphysies.

Figure 3. Distance curves: long bone shaft length growth (+ include epiphyses).



initially (½–1, age group) and during the adolescent period (13–16 age group). Major growth appears to have subsided by the 25–31 age group.

Another indication of growth velocity is relative per cent increase (Table 2). Figure 4 illustrates an initial deceleration of growth. Falkner (1966, p. 35) provides a description of deceleration for the final month of fetal life and the first month of postnatal life in modern material. A possible mid-childhood growth spurt is evident as well as a sharp acceleration of the adolescent growth spurt. The nature of the midchildhood growth spurt is not clear; it may be the result of sampling error or an example of catch-up growth. Figure 4 also provides comparative data from an American sample collected from radiographs by Maresh (1955, pp. 728–729). Because Maresh did not provide mean long bone lengths, a correlation was arbitrarily made between Nubian means and data from the fiftieth percentile range of her sample. Her data on the growth of girls was not utilized.

Our comparison reveals that American boys are larger than Nubians, and that the early childhood deceleration of American boys is uninterrupted, that is, there is no mid-childhood growth spurt. The adolescent growth spurt appears to begin earlier in American boys, but the intensity is probably not as great. The actual growth for this period (13–16) is not ascertainable because Maresh includes the epiphyses in her measurements at this point. This variation between Nubians and American boys reflects nutritional as well as genetic differences.

(*c*) *Growth symmetry*

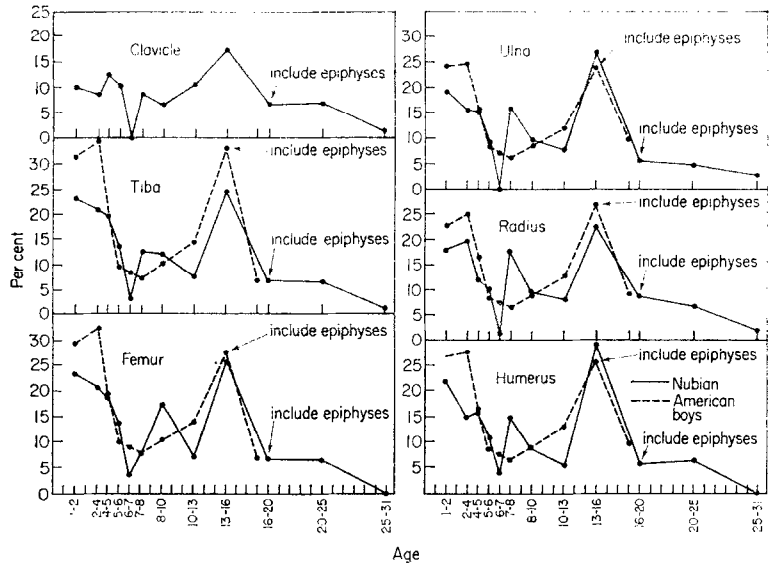
The symmetry of long bone growth among the Nubian sample (Table 3) is illustrated by Figure 5. Figure 5 demonstrates the ratio of long bone length (tibia, humerus, radius and clavicle) to femoral length. The tibia to femur ratio (approximately 0·85) shows striking regularity throughout both the initial infant growth rate deceleration and

Table 2 **Incremental increase (I.I.) in millimeters (mm) and relative increase in per cent (R.I.P.): Nubian (N) and American boys (A.B.)†**

Developmental age (years)	Femur			Tibia			Clavicle		Humerus			Radius			Ulna		
	I.I. (mm)	R.I.P. N	R.I.P. A.B.†	I.I. (mm)	R.I.P. N	R.I.P. A.B.†	I.I. (mm)	R.I.P. N	I.I. (mm)	R.I.P. N	R.I.P. A.B.†	I.I. (mm)	R.I.P. N	R.I.P. A.B.†	I.I. (mm)	R.I.P. N	R.I.P. A.B.†
1–2	25·4	23·3	29·6	21·0	23·0	31·4	5·5	10·0	19·1	21·9	26·8	12·4	17·8	26·6	14·9	19·1	24·1
2–4	27·8	20·7	32·5	23·6	20·8	34·1	5·2	8·6	15·8	14·9	27·4	16·0	19·5	25·0	14·3	15·4	24·8
4–5	30·2	18·6	19·0	27·0	19·7	19·7	8·2	12·5	19·4	15·9	16·6	11·8	12·0	16·4	17·0	15·9	15·8
5–6	26·1	13·6	10·0	22·0	13·4	9·6	7·6	10·3	14·8	10·5	8·6	11·5	10·5	8·3	10·8	8·7	8·2
6–7	7·8	3·6	8·7	6·1	3·3	8·3	0·0	0·0	5·4	3·5	7·5	1·4	1·1	7·3	0·4	0·0	7·0
7–8	17·0	7·5	7·7	24·6	12·8	7·3	7·0	8·7	24·1	14·9	6·6	21·3	17·3	6·4	21·5	15·9	6·1
8–10	41·9	17·2	10·1	26·5	12·2	10·1	5·9	6·7	16·3	8·8	8·9	13·2	9·2	8·8	15·5	9·9	8·1
10–13	19·3	6·8	13·9	18·3	7·5	14·6	9·6	10·3	10·3	5·1	13·0	12·3	7·8	12·6	13·1	7·6	12·1
13–16	77·7	25·5	27·5	63·0	24·1	32·8	18·0	17·5	61·5	29·0	25·4	37·3	22·0	26·5	49·9	26·9	23·8
§16–20	23·8	6·2	‡6·6	21·7	6·7	‡6·6	8·3	6·8	14·9	5·4	‡9·6	16·9	8·2	‡9·3	13·1	5·6	‡9·6
§20–25	24·0	6·0		21·5	6·2		8·9	6·9	17·4	6·0		13·9	6·2		12·3	4·9	
§25–31	2·8	0·1		3·8	1·0		1·7	1·2	0·0	0·0		4·6	1·9		6·8	2·6	

† American boys (Maresh '55) age-chronological.
‡ American boys only to chronological age 18.
§ Epiphyses included (Nubian); included for American boys at age group 13–16.

Figure 4. Relative per cent increase in growth: Nubian vs. American boys (exclude clavicle).



adolescent growth acceleration. The humerus, radius, ulna and clavicle apparently fall behind femoral growth during the infant phase, until approximately the six- to eight-year age group. Following developmental age eight, proportions of growth rates appear to stabilize. This proportional stability is maintained during the adolescent growth acceleration. Clavicle growth appear somewhat slower in reaching a point of stable

Figure 5. Ratio of long bone length to femoral length: Nubian. F, femur; T, tibia; H, humerus; R, radius; U, ulna; C, clavicle.

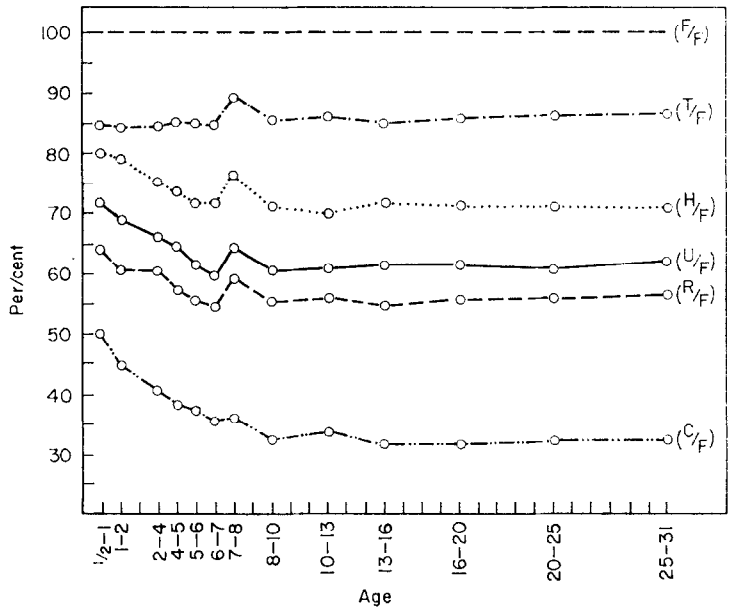


Table 3 **Ratio of long bone length to femur and tibia length†**

Developmental age (years)	T/F	H/F	R/F	U/F	C/F	F/T	H/T	R/T	U/T	C/T
½–1	0·846	0·800	0·639	0·714	0·503	1·182	0·945	0·755	0·844	0·593
1–2	0·842	0·790	0·610	0·690	0·449	1·187	0·938	0·724	0·819	0·533
2–4	0·843	0·752	0·604	0·660	0·404	1·186	0·892	0·716	0·782	0·479
4–5	0·851	0·735	0·571	0·644	0·383	1·175	0·863	0·670	0·757	0·450
5–6	0·850	0·715	0·555	0·617	0·372	1·176	0·841	0·653	0·725	0·437
6–7	0·848	0·714	0·542	0·597	0·356	1·179	0·842	0·639	0·705	0·419
7–8	0·890	0·763	0·592	0·644	0·360	1·124	0·858	0·665	0·724	0·404
8–10	0·852	0·708	0·551	0·604	0·327	1·174	0·831	0·647	0·709	0·384
10–13	0·858	0·697	0·557	0·609	0·338	1·165	0·812	0·648	0·709	0·361
13–16	0·849	0·716	0·541	0·615	0·317	1·178	0·844	0·638	0·725	0·373
‡16–20	0·852	0·711	0·551	0·612	0·318	1·173	0·834	0·646	0·718	0·374
20–25	0·854	0·711	0·552	0·606	0·321	1·171	0·833	0·646	0·709	0·376
25–31	0·858	0·705	0·560	0·618	0·323	1·166	0·822	0·652	0·720	0·377

† Nubian.
‡ Include epiphyses.
F = femur; T = tibia; H = humerus; R = radius; U = ulna; C = clavicle.

proportionality (note Figure 5). The irregularity at the 7–8 year age group indicates that femoral growth suddenly slows in comparison with the other long bones. No reason for such a cessation of femoral growth is evident, excepting the small sample size of this age group again may result in sampling error.

Maresh's (1955) data on American boys provides a comparative illustration of long bone growth symmetry (Table 4 and Figure 6). The ratio of tibia to femur does not appear as stable as the Nubian example. The tibia appears to grow faster than the other long bones. A slower initial growth rate of the humerus, radius and ulna, in comparison with femoral and tibial growth rates, is similar to Nubian proportions. During the adolescent growth spurt, the tibia again appears to grow proportionately faster than other long bones, but the difference is not great. Despite variation with data on American boys (some of which is to be expected), proportionality of long bone length and the maintenance of this proportionality from middle childhood to maturity is

Table 4 **Ratio of long bone length to femur and tibia length: American boys (Maresh '55)**

Developmental age (years)	T/F	H/F	R/F	U/F	F/T	H/T	R/T	U/T
½–1	0·795	0·785	0·626	68·08	1·260	0·988	0·788	0·865
1–2	0·806	0·768	0·593	65·09	1·241	0·953	0·735	0·817
2–4	0·816	0·738	0·559	62·00	1·226	0·905	0·685	0·760
4–5	0·820	0·723	0·546	60·03	1·219	0·881	0·666	0·735
5–6	0·818	0·714	0·538	59·04	1·223	0·873	0·658	0·726
6–7	0·815	0·706	0·531	0·584	1·227	0·867	0·652	0·717
7–8	0·812	0·698	0·524	0·575	1·232	0·861	0·646	0·709
8–10	0·812	0·692	0·518	0·565	1·232	0·852	0·639	0·696
10–13	0·816	0·686	0·512	0·556	1·225	0·840	0·627	0·681
‡13–16	0·850	0·674	0·508	0·540	1·176	0·793	0·600	0·635
‡16–18	0·850	0·693	0·521	0·555	1·177	0·816	0·613	0·653

† Include epiphyses.
F = femur; T = tibia; H = humerus; R = radius; U = ulna.

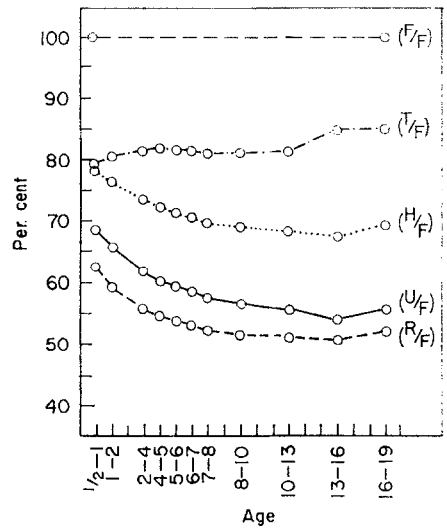


Figure 6. Ratio of long bone length to femoral length: American boys (data from Maresh, 1955).

apparent. The great deviation occurs in the ½ to 7 year age group in which the femur and tibia appear to grow faster than the other long bones.

The growth patterns of the prehistoric Nubian population examined in this study show no significant evidence of any general malnutrition or deficiency disease. At least, they are not severe enough to result in the marked stunting of long bone growth. However, the suggestion of catch-up growth, or a catch-up growth effect in the adolescent growth spurt, may indicate a moderate nutritional inadequacy that obstructs normal growth in a minor degree throughout the earlier growth period. The secondary or less severe effects of an inadequate diet on growth are noted by Baldwin (1921), Meredith (1935) and Schuttleworth (1939) in a discussion of growth differences across socio-economic levels in modern populations. Greulich (1951, 1957) compared the growth of Guamanian and Japanese children with American children and found statural differences correlated to dietary differences.

3. Femoral Cortical Involution

Although the processes involved in skeletal growth and modeling (Frost, 1967) are essentially complete with epiphesial union between ages 16 and 20, McLean & Rowland (1963) state: "Internal remodeling of compact bone continues throughout the life of the individual. By providing a continuing supply of reactive bone mineral, from which calcium lost from the blood in a rapid turnover of this element is replaced, this performs a function essential to life" (1963, p. 381).

Under ideal conditions remodeling proceeds through the resorption of bone tissue followed by redeposition without changing the net amount or geometry of the bone involved (Frost, 1967), however, a wide variety of conditions have been observed to alter the relationship between bone resorption and formation rates so that a progressive loss of skeletal tissue occurs. Such skeletal rarefication or osteoporosis according to Urist, MacDonald, Moss & Skoog (1963, p. 386):

> "... may be present or absent in individuals with a number of diverse conditions, as, for example, acromegaly, diabetes, hyperthyroidism, gonadal agenesis, Cushing's syndrome (endogeneous and exogenous), pernicious anemias, starvation, tumors, cirrhosis, von Gierke's

> disease of the liver, post traumatic metabolic syndrome, and postpregancy state. The proportion of these diagnoses in the total number of patients with osteoporosis is 19%. The proportion of osteoporosis in otherwise healthy individuals, between 50 and 75 years of age, generally classified in hospital records as postmenopausal or senile types is 81% (Moon & Urist, 1962). Osteoporosis is frequently more severe in patients with than in patients without the above diseases but the causative relation is indirect and involves poorly understood complex reactions of bone tissue."

Jowsey (1963, p. 467), through microradiographic analysis, observed:

> "It was apparent that in normal individuals an increase in amount of bone resorption is what produces the porosity characteristic of aging bone. Osteoporotic bone appeared to be an exaggeration of the normal aging process in that increased resorption caused porosity."

The apparent association between aging and osteoporotic bone loss has become a major focus of research in recent years. Specimens for the study of osteoporosis are usually obtained from autopsy (Arnold, 1965; Bartley & Arnold, 1965; Arnold, Bartley, Tont & Jenkins, 1965; Jenkins, 1968) and biopsy (Frost, 1963; Nordin, 1964) or the process of involution is studied in the living by radiographic methods (Garn & Hull, 1966; Garn & Rohmann, 1966; Urist *et al.*, 1963). Autopsy and biopsy offer practical problems in obtaining adequate sample sizes and despite recent improvements, radiographic analysis may not record loss until there is a 30 to 50% decrease in cortical bone (Urist *et al.*, 1963). In addition, Van Gerven, Armelagos & Bartley (1969) using femora from a Mississippian prehistoric population compared Smith and Walker's (1964) X-ray technique with direct measurement of femoral cortex, and observed that errors of up to 11·7% were produced by the inability of the X-ray process to distinguish compact from porous bone. In addition, errors of up to 26·6% were produced by sampling bias resulting from the two-dimensional quality of the X-ray image allowing only two measurements of cortical thickness and one measurement of periosteal diameter.

Recent research on autopsy material (Bartley & Arnold, 1965) using direct linear measurement of cortical thickness from transversely cut femoral mid-shafts indicated that there was a 40% reduction of femoral cortical thickness among females by the eighth decade and a corresponding loss of 12% among males.

Epker & Frost (1966) reported that while there was continued periosteal apposition of new bone in the fifth, sixth and seventh ribs of 92 individuals aged 2 to 72 years, who had been labeled *in vivo* with a tetracycline, nevertheless, there was a net cortical loss resulting from an even greater amount of endosteal involution.

Although the uniformity of such results strongly suggests a positive relationship between bone loss (cortical thinning) and increasing age in modern populations (Jarcho, 1964) noted that osteoporosis has not been observed in archeological populations.

It was felt that the study of osteoporosis within the prehistoric Nubian populations would be of major importance in establishing whether osteoporotic bone loss is an age-related degenerative process having historical depth. Furthermore, if the process were found to occur in the ancient populations, comparisons with modern populations would be a rich source of information on the effects of variables such as cultural development.

Although there are limitations in the use of archeological skeletal material, the large homogeneous sample provided by the Nubian skeletal material overcomes these drawbacks. The descriptive information available on the chronological position and cultural patterns adds further to the potential such a skeletal sample has in providing historical depth to problems of bone biodynamics. The Nubian femoral material was deemed

especially valuable in providing data readily comparable with that from modern populations. However, future analysis of skeletal sites not readily obtainable in modern samples is anticipated.

(*a*) *Materials*

Sections, 8 to 9 cm long, were taken from just below the lesser trochanter of the femur by the physical anthropologists of the University of Colorado Nubian Expedition during the 1963–1964 season (Armelagos, Ewing, Greene & Greene, 1965). With the exception of the material from a Christian cemetery on the island of Meinarti, which had been periodically inundated by flood waters of the Nile, the condition of the bone was excellent. Most of the samples had mummified tissue adhering to them.

(*b*) *Technique*

The distal face of the femur section was cut with a bandsaw to insure a vertical plane from which measurements would be made. Six measurements of cortical thickness were made, using "CENCO" Vernier sliding calipers (accurate to 0·10 mm) on the distal face of the femur section. All specimens were measured at the same pre-selected points—three medial and three lateral (Figure 7). In addition, two measurements of the diameter of the medullary cavity were made: anterior-posterior and medial-lateral. This provided constant control of the measurements since the medullary diameter plus the lateral and medial cortical thickness equals the shaft diameter.

After measuring, sex determination and age at death data were recorded from the anthropometric records of the University of Colorado Nubian Expedition (see Armelagos, 1968, for a discussion of the procedures for aging and sexing). The cortical measurements were made prior to the recording of the age and sex of each individual.

(*c*) *Statistics*

For the analysis of the data, we utilized a fixed-model two-way analysis of variance program (Maxwell, 1966) computed on a model 1108 UNIVAC computer at the University of Utah Computer Center. The program tested for homogeneity of variance, computed F values at the 0·05 level of confidence, and performed means multiple range tests on

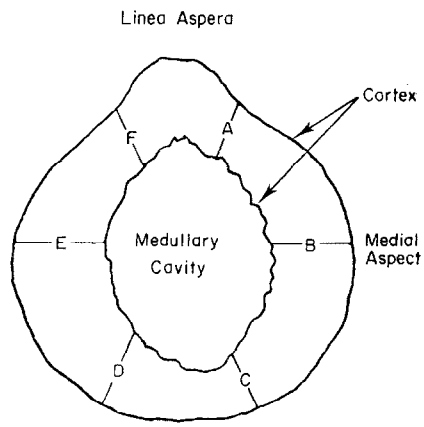


Figure 7. Cross-section of the distal end of the proximal one-third of the left femur showing points at which cortical thickness was measured.

the variables: age and sex. The use of analysis of variance on the Nubian series necessitated grouping the data into four age groups: 16–21; 22–31; 32–41; 42–50+. Sixteen years of age was arbitrarily established as the minimum for the first age group. It was assumed that this would generally include those in the earliest stages of skeletal maturation in both males and females. In a static study, skeletal involution cannot be measured prior to skeletal maturation since growth is still occurring. Only in pathological conditions would one expect more cortical involution than deposition to occur prior to skeletal maturation.

(d) Gross morphology

The females show a definite and progressive involution from age 20 to 50+ years, while the males, in general, appear to maintain their femoral cortical thickness until the fifth decade before exhibiting a great amount of bone loss. The total amount of bone resorption is smaller in the males than in the females.

Most resorption activity, as inferred from the amount of trabeculated bone and porosity around the medullary cavity, appears to be endosteal. Some specimens, upon gross examination of the face of the cross-section, appear to have some intra-cortical porosity; however, it may be that these areas are actually on the inner surface of the endosteum and represent the newest points of endosteal resorption.

These observations fit the generally accepted observations (from modern populations) that during bone remodeling the greatest resorptive activity takes place on the endosteal surface, while bone is being laid down on the sub-periosteal surface. This would also account for the evident increase in diameter of the femur and the consequent thinning of the cortex with advancing age.

Males of the age group 22–31 show little or no decrease in the thickness of the cortex, but cortical thinning becomes obvious in the females of the same age group.

By ages 32–41 years, a few specimens from the male sample show some cortical involution. In general, however, the integrity of the cortical thickness is being maintained. The reverse holds true for the females of the same age group. Nearly all of the female specimens of this age group show considerable cortical bone loss and often what appears to be intra-cortical porosity.

In the fifth decade, nearly all the males show some cortical involution and obvious areas of endosteal resorption are evident. The amount of cortical resorption for the females appears to have diminished somewhat, although it is still evident.

By the sixth-plus decade (over 50 years), the male specimens approximate a nearly bimodal distribution (i.e. those with obvious cortical thinning, and an equal number with little apparent cortical bone loss). The specimens from the oldest females are consistently thin-walled.

The relationship of cortical thickness to age and sex is presented graphically in Figure 8 for the combined Nubian populations (83 males and 120 females).

The male population shows an increase of 0·035 cm at age categories one and two, then a decrease of 0·007 cm between the second and third age intervals. A further decrease of 0·070 cm is shown between the third and last intervals. Total decrease for the entire age range is 0·042 cm. The largest difference (0·077 cm) occurs between the second and fourth age groups.

The combined female populations reveal a fairly steady decrease in femoral cortex. Between age groups 16–21 years and 22–31 years, a loss of 0·033 cm occurs. A loss of 0·064 cm of cortex occurs between the second and third age intervals, while 0·030 cm

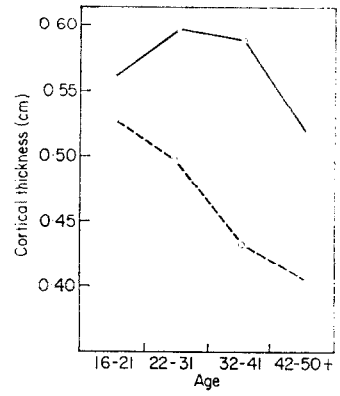


Figure 8. Relationship of femoral cortical thickness to age in years of the combined Meroitic, X-Group and Christian populations. $N = 203$ (82 males, 120 females). Differences in males is not significant ($P<0{\cdot}05$) while differences in females is significant ($P<0{\cdot}0001$).

is lost during the years covered by age groups three and four. Total bone loss for the entire age range is 0·124 cm.

The mean difference in the amount of cortex between males and females of the combined population is 0·030 cm at ages 16–21. The difference increases to 0·098 cm at 22–31 years, 0·155 cm at the 32–41 year interval, and to 0·112 in the 42–50+ year group. The males show greater cortical thickness than females at all ages.

The probability that cortical bone decreases with advancing age in the male population is not statistically significant at the 0·05 level of confidence, whereas the probability that this relationship does exist in the female population is statistically significant at the 0·001 level of confidence.

(*e*) *Percentage of femoral involution: Nubian and Modern*

Bartley & Arnold (1965, pp. 1–2) show the percentage of femoral cortical involution by decade in males and females of a sample from a modern population. Bartley & Arnold used the same technique (direct measurement of the cortical thickness of specimens from the mid one-third of the femur) as was used on these Nubian specimens (see Table 5).

Table 6 shows the percentages of femoral bone reduction within the Nubian population. The rate of bone loss shows total percentage reductions (column 5) of 13·75% for males and 23·39% for females, with the base percentage at the 22–31 year level. Total reduction for males corresponds with the 12% loss recorded for Bartley & Arnold's ninth decade group, but the total reduction in the Nubian females is 14·53% below that of their ninth decade females. The 10% loss for males and 17% loss for females recorded for Bartley and Arnold's sixth decade group correspond well with the percentage of bone loss for the respective sexes of the Nubian 42–50+ year

Table 5 **Percentage of cortical bone loss in a modern population sample (adapted from Bartley & Arnold, 1965, pp. 1–2)**

(1) Third decade	(21–30 years):	males 0%;	females 0%
(2) Fourth decade	(31–40 years):	males 5%;	females 14%
(3) Fifth decade	(41–50 years):	males 8%;	females 9%
(4) Sixth decade	(51–60 years):	males 10%;	females 17%
(5) Seventh decade	(61–70 years):	males 12%;	females 28%
(6) Eighth decade	(71–80 years):	males 10%;	females 31%
(7) Ninth decade	(81–90 years):	males 12%;	females 40%

Table 6 **Percentage of cortical bone loss in the combined Nubian populations**

		A 16–21	B 22–31	C 32–41	D 42–50+	Total % loss
Zero % referent	Male	0	−6·25	−5·00	−7·50	−13·75
	Female	0	−6·25	−18·00	−23·39	−23·39
Zero % referent	Male	−5·88	0	−1·17	−12·94	−12·94
	Female	−6·63	0	−12·87	−18·30	−24·93

level, especially in the more comparable group in which zero percentage was established at the 22–31 year level (Table 6). The discrepancy between the fourth decade Nubians and the Moderns is great, with the Nubian males showing less bone loss and the Nubian females exhibiting greater femoral involution than the modern population.

The greater femoral involution (40%) in the modern females for the ninth decade compared to the nearly 25% total for the female Nubians (Table 6), and the close correlation between the two in the fourth decade would indicate the possibility that there were few, if any, Nubian females in the sample who lived much past the age of 50.

The greatest percentage (12·94%) of cortical involution in the combined Nubian male sample (Table 6, column 4) occurred in the 42–50+ age group. The females show greatest loss (12·87%) in the 32–41 year age group. These values are almost the reverse of the data shown for the modern population (Bartley & Arnold, 1962, p. 2) which shows the greatest loss (5%) in males between 31 and 40 years and 11% loss in the seventh decade females.

The steady decline in the thickness of the femoral cortex of the Nubian females from the earliest age groupings, as seen in Figure 8, indicates that skeletal maturation was probably achieved by 16–21 years of age.

(*f*) *Conclusions*

Statistical analysis (analysis of variance) revealed that there was a significant relationship ($P < 0{\cdot}001$) between sex and cortical thickness in the Nubian females but that the relationship in the males ($P > 0{\cdot}25$) was not significant. According to Bartley *et al.* (1966), this sexual difference in femoral cortical involution obtains in modern populations as well.

Nubian females have 0·065 cm less femoral cortex than the Nubian males at skeletal maturity and then appear to lose bone at nearly twice the rate of the males—the greatest involution occurring between the ages of 22 and 41 years (Table 6).

These data suggest that femoral cortical bone involution among these Nubian females is not primarily a disorder of oestrogenic hormonal aetiology. The apparent steady decline in femoral cortical thickness from very early adulthood weakens the post-menopausal hypothesis. With oestrogenic hormone influence, one would expect bone loss curves to show a plateau area until the age of menopause (*c.* 40 years) and then a rapid decline during the following years.

The early age for the onset of osteoporosis in Nubian females might better be explained as a combination of inadequate calcium intake and extended lactation during the period of nubility. Jackson (1967, p. 2) calculates that a lactating woman loses about 300 mg of calcium per day or about 100 g in nine months (one-tenth of the total calcium in the average skeleton). Mothers in primitive societies tend to nurse their offspring for long periods, often as long as two to four years (Mead, 1955, p. 209) and wean the child

only when they become pregnant again. Primitive agriculturists emphasize the importance of having large families, and it is perfectly feasible that many women in such a society would spend the greater part of the period of nubility either pregnant or lactating.

Although not within the scope of this present work, Dewey, Armelagos & Bartley (1969) have analyzed cortical bone loss between the Meroitic, X-Group, and Christian populations. An important aspect of this study was the observation that statural variation between these populations necessitates normalization of cortical thickness values. Normalization was produced by dividing cortical thickness by femoral length and multiplying the results by 100 (Dewey, Bartley & Armelagos, 1969).

4. Ash and Bone Density

Another important avenue of research into the problem of osteoporotic bone loss centers around the determination and quantification of ash and bone density changes as a function of age.

However, weights and volumes used in density determinations need definition and clarification. Bone weight refers to the weight of the protein and mineral phases of bone. Wet bone weight refers to the weight of these two phases hydrated through some constant procedure, and dry bone weight refers to the weight of these two phases dried through some constant procedure.

Several different volume determinations have been used in previous studies:

(1) whole bone volume refers to an entire specific bone such as the tibia, femur, etc.; or a specific portion of a bone such as the femur head, femur neck, femur shaft, etc., containing both cortical and trabecular bone and included interstitial spaces;

(2) bone organ volume refers to the major constituent—trabecular and/or cortical bone tissue and included interstitial spaces—of a specific skeletal site such as trabecular bone for the femur head, cortical bone for the mid-shaft of the femur, trabecular and cortical bone for the rib, etc;

(3) bone tissue volume refers to the protein and mineral phases of bone excluding interstitial spaces. As in the mass of bone, bone tissue volume may be measured wet or dry and may be measured before or after fat extraction. Thus, four volumes of bone tissue may be determined: dry bone tissue; wet bone tissue; dry, fat-free bone tissue; and wet, fat-free bone tissue.

In as much as ash and bone density studies on cortical bone from the Nubian material are currently in progress, only the results from our analysis of trabecular bone in the femur heads will be reported.

The proximal ends of femora were obtained from individuals form the X-Group cemetery, designated NAX. The sample consisted of 72 adults—35 males with a mean age of 32 years, and 37 females with a mean age of 30 years.

A segment of bone was cut from the femur head approximately 0·5 cm dorsally or ventrally from the mid-sagittal plane (see Figure 9). The bone was sectioned into approximately 1·5 cm cubes on a band saw with a number 18, $\frac{1}{4}$-inch skiptooth blade. All cortical bone was removed from the samples. No attempt was made to clear the marrow cavities of soft tissue remnants.

The bone segments were first oven dried for 24 hours at 60°C (a temperature high enough to evaporate water rapidly, but not high enough to destroy the protein component of bone) and then placed in a desiccator over phosphorus pentoxide for an

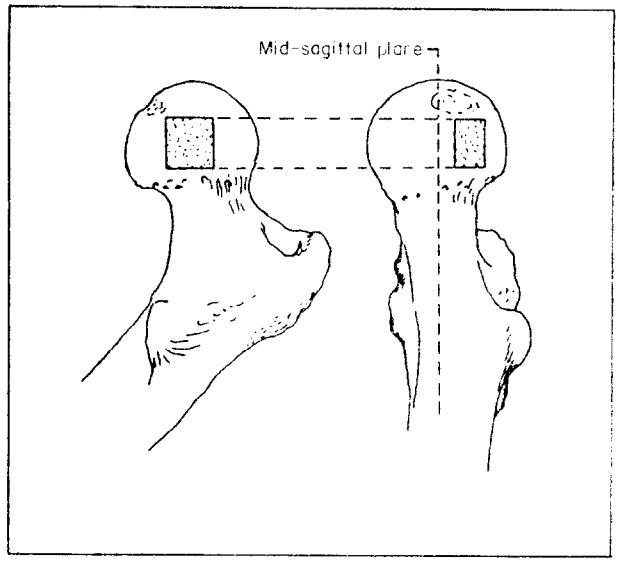


Figure 9. Drawing of the proximal end of the femur showing the area from which the samples were taken.

additional 24 hours before initial weights were determined on an analytical balance to the nearest 0·1 mg. This was the dry bone weight.

As suggested by Arnold (1960, p. 168), the samples were then hydrated by submerging them in beakers of distilled water, which were placed in a cooled vacuum chamber. The chamber was evacuated to 95 mmHg for about two hours in order to remove the air from the samples. The immersed samples were then allowed to stand at atmospheric pressure for one hour to ensure saturation of all evacuated spaces. The samples were weighed under water by suspending them on a thin, stainless steel wire anchored to the balance arm. The wire was cleaned with acetone before measurement, ensuring constant wetting during the weighing process. After each sample's weight was noted, a slight jarring would free the sample from the wire so the tare could be determined by weighing only the wire in water. The sample weight minus the tare was recorded as the actual underwater weight. The underwater weight subtracted from the initial weight gave the weight of the water displaced. Water temperature was recorded so that the volume could be computed from the density. The result was the volume of dry bone tissue.

After measuring the volume of dry bone tissue, a determination of the weight and volume of wet bone tissue was undertaken. The samples were placed in centrifuge tubes in which the bottoms were padded with absorbent cotton covered by a layer of filter paper. Several drops of water were added to the tubes and allowed to stand for one hour before insertion of the samples, ensuring 100% humidity (moreover, damp paper will absorb water displaced from the specimens more readily than dry paper). The tubes containing the samples were sealed and centrifuged in a Lourdes Beta-Fuge Model "A" refrigerated centriguge at 3200 **g** for one hour at 4°C. Humidified centrifuge tubes and the low temperature prevented evaporation during centrifugation.

Immediately after centrifuging, the samples were weighed (wet bone weight), placed in a drying oven for 24 hours at 60°C, then placed in a desiccator over phosphorus pentoxide for an additional 24 hours, and reweighed dry. Since most of the samples lost a small amount of bone during centrifugation, computation of the proportion of bone remaining was necessary. The second dry weight divided by the initial dry weight provided the correction factor which, when multiplied by the underwater weight,

yielded the weight that the centrifuged sample would have had under water. This weight, when subtracted from the centrifuged wet weight, gave the weight of the water displaced by the wet bone tissue, which was converted to volume in cubic centimeters.

In order to make measurements of only the protein and mineral phases of bone, all fat present had to be extracted in a Soxhlet apparatus using a 2–1 mixture of anhydrous ether and 95% ethanol for 72 hours. The solution was changed at 24-hour intervals to ensure sufficient liquid for constant refluxing.

Upon removal from the Soxhlet apparatus, the samples were placed in a drying oven for 24 hours, and then weighed (dry, fat-free bone weight). The samples were again hydrated, weighed under water, centrifuged, and weighed wet. This weight was the wet, fat-free bone weight. The samples were then oven dried, desiccated and re-weighed dry. The difference between the dry, fat-free bone weight and its weight under water yielded the weight of the water displaced, which was converted to volume in cubic centimeters for the dry, fat-free bone tissue. Again, the samples lost a small amount of bone during centrifugation and required correction for the volume of wet, fat-free bone tissue.

The technique of Arnold, Bartley, Tont & Jenkins (1966) to measure the trabecular and cortical bone organ volume of rib was modified to obtain the volume of trabecular bone organ. In order to facilitate paraffining, the specimens were first placed in a refrigerated desiccator and then dipped in liquid paraffin. The excess paraffin was removed by scraping with a warm spatula. The paraffin-coated samples were then weighed in air and under water. The underwater weighing required the addition of a copper sinker; the tare was determined for the sinker and wire and subtracted from

Table 7 **Outline of the laboratory procedure**

1. Cut the sample
2. Oven dry
3. Desiccate
4. Weigh dry (dry bone weight)
5. Hydrate
6. Weigh under water
7. Centrifuge
8. Weigh wet (wet bone weight)
9. Oven dry
10. Desiccate
11. Weigh dry
12. Soxhlet
13. Oven dry
14. Desiccate
15. Weigh dry (dry, fat-free bone weight)
16. Hydrate
17. Weigh under water
18. Centrifuge
19. Weigh wet (wet, fat-free bone weight)
20. Oven dry
21. Desiccate
22. Weigh dry
23. Cool
24. Paraffin coat
25. Weigh paraffin-coated dry
26. Weigh paraffin-coated under water
27. Ash
28. Desiccate and cool
29. Weigh dry (ash weight)
30. Store the sample

each sample's weight under water, and the difference was recorded as the actual underwater weight. The difference between the weight in air and under water of this block, when converted to volume in cubic centimeters, was the volume of bone organ. A problem of air adhering to the block was resolved by briefly immersing the coated segments and copper sinker into a 1% solution of liquid detergent and then weighing them in distilled water. The samples were then ashed in a muffle furnace for 48 hours at 580°C, as suggested by Arnold (1960, p. 169), and allowed to cool in a desiccator for 24 hours. They were then weighed (ash weight) and stored for future chemical analysis.

An outline of the procedure is given in Table 7. It is well to point out the differences of the procedure used here and that of others with comparable material (Arnold, 1960; Arnold *et al.*, 1966; Mueller, Irias & Ray, 1966). The drying temperature used in this study was 60°C, and the centrifugation was done with 3200 **g**; this conforms to the procedure of Mueller and his colleagues. Arnold (1960) used 100°C for drying, and 8000 **g** for centrifugation; and Arnold *et al.* (1966) used 10,000 **g**. Further, the others reported their results in terms of specific gravity rather than density as is done here.

Results and discussion

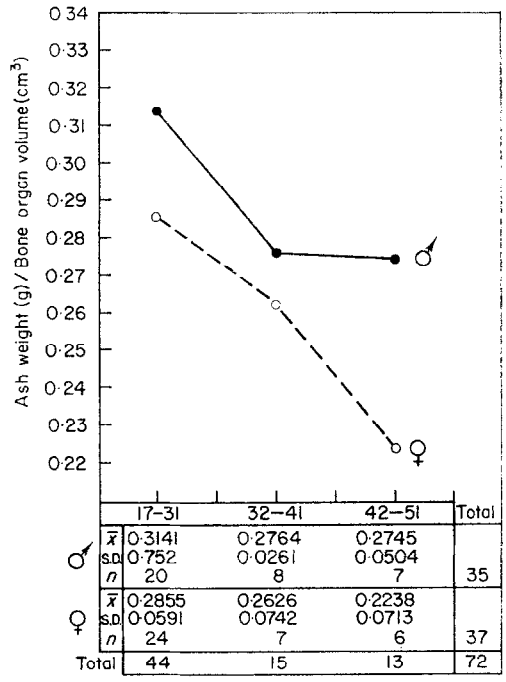
The analysis of the densities of bone organ (the trabecular bone tissue and included interstitial spaces) were highly conclusive. A two-way analysis of variance applied to the ash density of bone organ using three age levels is given in Table 8, and the relationship of the means is shown in Figure 10. The results of this analysis indicate that males and females, averaged over the three age levels, differ significantly at the 0·08 level, and that the three age levels, averaged over the males and females, differ significantly at the 0·05 level. Since the interaction (sex × age) mean square is not significant ($P < 0{\cdot}5$), the factors—sex and age—are uncorrelated: and since multivariate normality is assumed, sex and age are concluded to be independent factors. Hence, there are not significant differential responses due to sex and age. Since the standard error of the factor age was large, a multiple range test for these means did not detect any significant differences. It can be seen, however, that females of age level 17–31 have higher ash density of bone organ than age level 42–51 for both sexes. Comparing the densities for the males and females for each age level, there is a progressive loss of ash density

Table 8 **Two-way analysis of variance with three age levels**

	Males			Females		
Age level	$\bar{x}^a$	s^b	n^c	$\bar{x}$	s	n
17–31	0·3141	0·0752	20	0·2855	0·0591	24
31–41	0·2764	0·0261	8	0·2626	0·0742	7
42–51	0·2745	0·0504	7	0·2238	0·0713	6

Source	df^d	Sum of squares	Mean square	F^e	P^f
Sex	1	0·0125	0·0125	3·11	<0·08
Age	2	0·0262	0·131	3·25	<0·05
Interaction (sex × age)	2	0·0054	0·0027	0·67	<0·50
Error	66	0·2663	0·0040		
Total	71	0·3104			

[a] $\bar{x}$ = mean; [b] s = standard deviation; [c] n = sample size; [d] df = degrees of freedom; [e] F = F ratio; [f] P = probability level.



		17–31	32–41	42–51	Total
♂	$\bar{x}$	0·3141	0·2764	0·2745	
	s.d.	0·752	0·0261	0·0504	
	n	20	8	7	35
♀	$\bar{x}$	0·2855	0·2626	0·2238	
	s.d.	0·0591	0·0742	0·0713	
	n	24	7	6	37
Total		44	15	13	72

Figure 10. Relationship of the mean values of ash density of bone organ using three age levels. $\bar{x}$ = mean, s.d. = standard deviation; n = sample size.

for both sexes. The males show less percentage loss of initial density than do females over the three decades, 12·58% (0·0396 g/cc) as compared to 21·59% (0·0617 g/cc).

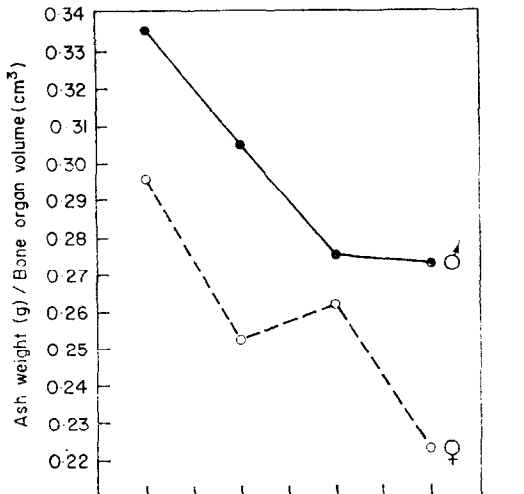
Since the sample for the youngest age level was large, this cell was split for each sex. This was done to determine if the loss might occur at an age younger than 30. This analysis excluded a 29-year-old male with a clearly pathological sacrum, pelvis, and cranium. The two-way analysis of variance is given in Table 9, and the relationship of the means is shown in Figure 11. Again the analysis shows the sexes to be different, the age levels to be different, and the factors—age and sex—to be independent. The males differ from the females at the 0·03 level, and the age levels differ at the 0·02 level.

Table 9 **Two-way analysis of variance with four age levels**

	Males			Females		
Age level	$\bar{x}^a$	s^b	n^c	$\bar{x}$	s	n
17–25	0·3362	0·0735	11	0·2962	0·0577	18
26–31	0·3053	0·0499	8	0·2533	0·0556	6
32–41	0·2764	0·0261	8	0·2626	0·0742	7
42–51	0·2745	0·0504	7	0·2238	0·0713	6

Source	df^d	Sum of squares	Mean square	F^e	P^f
Sex	1	0·0170	0·0170	4·84	<0·03
Age	3	0·0385	0·0128	3·64	<0·02
Interaction (sex × age)	3	0·0122	0·0040	1·15	<0·50
Error	63	0·2219	0·0035		
Total	70	0·2896			

[a] $\bar{x}$ = mean; [b] s = standard deviation; [c] n = sample size; [d] df = degrees of freedom; [e] F = F ratio; [f] P = probability level.



		17–25	26–31	32–41	42–51	Total
♂	$\bar{x}$	0·3362	0·3053	0·2764	0·2745	
	s.d.	0·0735	0·0499	0·0261	0·0504	
	n	11	8	8	7	34
♀	$\bar{x}$	0·2962	0·2533	0·2626	0·2238	
	s.d.	0·0577	0·0556	0·0742	0·0713	
	n	18	6	7	6	37
Total		29	14	15	13	71

Figure 11. Relationship of the mean values of ash density of bone organ using four age levels (pathological male excluded). $\bar{x}$ = mean; s.d. = standard deviation; *n* = sample size.

The standard error for age was too large for the multiple range test to be very instructive; the mean of the oldest age level of females is indicated to be lower than that of the youngest age level of males. It can be seen that the females have lower mean values for ash density than have males at any particular age level. There is a general loss of density with age for both sexes, from the youngest age level on; the slight rise in the fourth-decade females is contributed by one 32-year-old female with a very high value. The percentage loss of initial density in males, over the three decades, is less than in females, 18·34% (0·0617 g/cc) as compared to 24·44% (0·0724 g/cc).

In order to test the linearity of the progressive decrease in density of bone organ with age, linear regression and correlation analyses were performed on these values. The males and females were analysed separately. The scatter diagrams and regression lines for the ash density of bone organ as a function of age for males and females are presented in Figures 12 and 13, respectively. The pathological male was excluded from the analysis but is indicated on the scatter diagram. The regression equation for the males is $Y = 0{\cdot}3774 - 0{\cdot}0023\,X$, significant at the 0·02 level. The correlation coefficient is −0·41 and is significant at the 0·02 level. The values range from 0·2186 to 0·4377 g/cc. For the three decades, there is a 21·45% (0·0728 g/cc) decrease of initial density. The regression equation for females is $Y = 0{\cdot}3578 - 0{\cdot}0029\,X$, significant at the 0·01 level. The correlation coefficient is −0·43 and is significant at the 0·01 level. The values range from 0·1418 to 0·4184 g/cc. There is a loss of 28·57% (0·0887 g/cc) of the initial ash density over the three decades. Males are again shown to have denser bone than females as measured by ash density, and they lose a smaller percentage of their bone over the three decades. Arnold (1960) found the ash specific gravity of vertebral bone organ ranged from 0·05 to 0·20. The vertebrae lost density after the age of 40. Arnold *et al.* (1966) found the ash specific gravity of vertebral bone organ to range from 0·05 to 0·24, and rib specific gravities to range from 0·20 to about 0·70. The vertebrae increased in

Figure 12. Scatter diagram and regression line of ash density of bone organ as a function of age for males (pathological male indicated □, Osteoporotic).

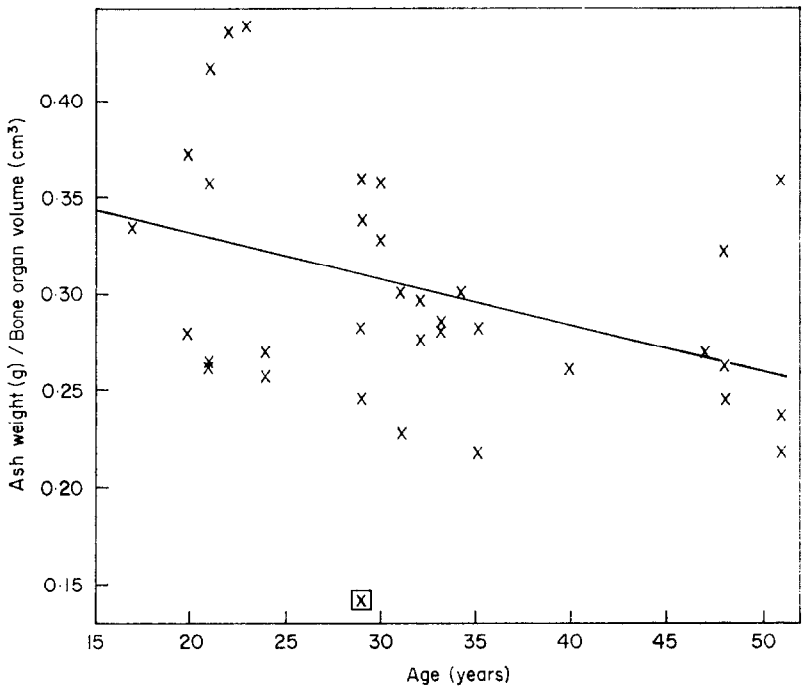
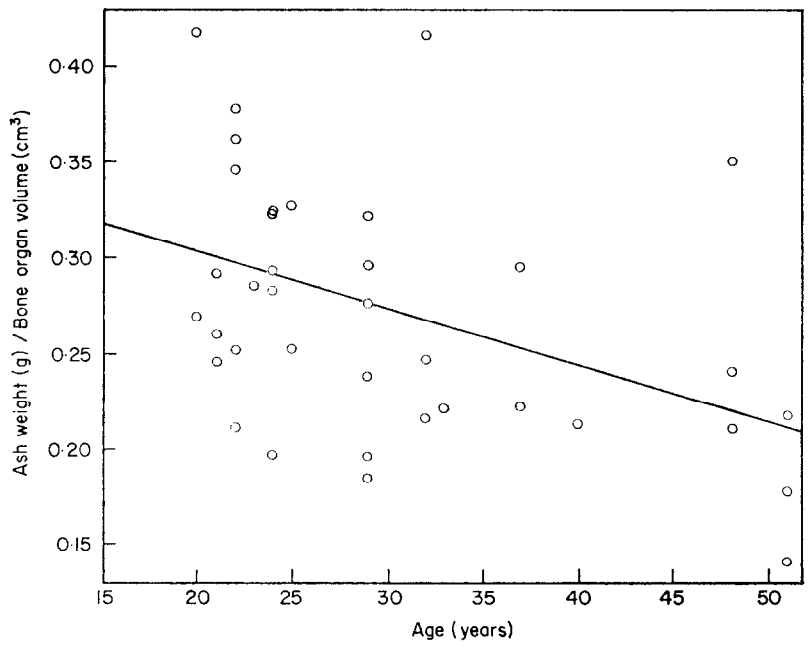


Figure 13. Scatter diagram and regression line of ash density of bone organ as a function of age for females.



density until the age of 20 and then decreased; the rib lost density from childhood on. Mueller *et al.* (1966) found the ash specific gravity of vertebral bone organ ranged from 0·05 to 0·25, with a somewhat later decline.

Regression and correlation analysis of the wet, fat-free bone density of bone organ was performed. The scatter diagrams and regression lines of this density as a function of age for males and females are shown in Figures 14 and 15, respectively. The regression equation for the males is $Y = 0{\cdot}6786 - 0{\cdot}0048\ X$, significant at the 0·02 level. The correlation coefficient is −0·39 and is significant at the 0·02 level. The values range from 0·2240 to 0·7608 g/cc. The loss of initial density over the three decades is 24·52 % (0·1480 g/cc). The regression equation for females is $Y = 0{\cdot}6332 - 0{\cdot}0048\ X$, significant at the 0·02 level. The correlation coefficient is −0·38 and is significant at the 0·02 level. The values range from 0·2524 to 0·7437 g/cc. There is a 27·00 % (0·1495 g/cc) loss of initial bone density over the three decades.

Regression and correlation analysis was also performed for dry, fat-free bone density of bone organ. The scatter diagrams and regression lines for these values as a function of age for males and females are shown in Figures 16 and 17, respectively. The regression equation for the males is $Y = 0{\cdot}5404 - 0{\cdot}0038\ X$, significant at the 0·02 level. The correlation coefficient is −0·39 and is significant at the 0·02 level. The values range from 0·1693 to 0·6191 g/cc. There is a 24·30 per cent (0·1168 g/cc) loss of initial density over the three decades. The regression equation for females is $Y = 0{\cdot}4989 - 0{\cdot}0037\ X$, significant at the 0·03 level. The correlation coefficient is −0·36 and is significant at the 0·03 level. The values range from 0·1982 to 0·5958 g/cc. There is a 25·82 % (0·1135 g/cc) loss of initial bone density over the three decades.

The analysis of variance with the three age levels shows that the ash density of bone organ is lower in females than in males. This analysis also shows age differences, the older ages having lower values. Expanding the number of age levels from three to four increases the significance of both the sex and age differences. In a test of the linearity of this decrease with age of ash density as well as of dry, fat-free bone densities of bone organ, both the regression and correlation coefficients are significant for both males and females and are similar for each of the three densities, but the Y intercept is lower for females than for males in each case. Thus, females and males lose bone density with age at about the same rate; the females show a larger percentage loss of initial density since they have less bone at the beginning.

In order to ascertain the correspondence between ash and bone densities, regression and correlation analyses were performed on these data. The scatter diagrams and regression lines for the ash density of bone organ as a function of wet, fat-free bone density of bone organ for the males and females are shown in Figures 18 and 19, respectively. The regression equation for males is $Y = 0{\cdot}0389 + 0{\cdot}4900\ X$, significant at the 0·0001 level. The correlation coefficient is 0·95 and is significant at the 0·0001 level. The regression equation for females is $Y = 0{\cdot}0258 + 0{\cdot}5035\ X$, significant at the 0·0001 level. The correlation coefficient is 0·96 and is significant at the 0·0001 level.

For the ash density of bone organ as a function of dry, fat-free density of bone organ, the regression equation for males is $Y = 0{\cdot}0326 + 0{\cdot}6310\ X$, significant at the 0·0001 level. The correlation coefficient is 0·96 and is significant at the 0·0001 level. The regression equation for females is $Y = 0{\cdot}0215 + 0{\cdot}6434\ X$, significant at the 0·0001 level. The correlation coefficient is 0·97 and is significant at the 0·0001 level.

These analyses of ash density of bone organ as a funcuion of the bone densities of bone organ show large correlation coefficients which are very highly significant. Thus, any one of the three densities is a good measure of the density of bone organ. The similarity

Figure 14. Scatter diagram and regression line of wet, fat-free bone density of bone organ as a function of age for males (pathological male indicated □, Osteoporotic).

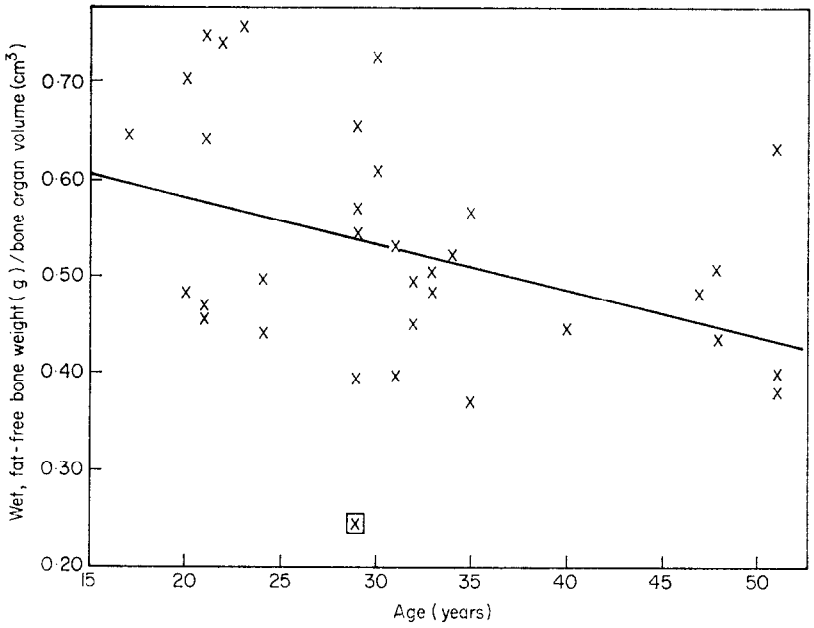


Figure 15. Scatter diagram and regression line of wet, fat-free bone density of bone organ as a function of age for females.

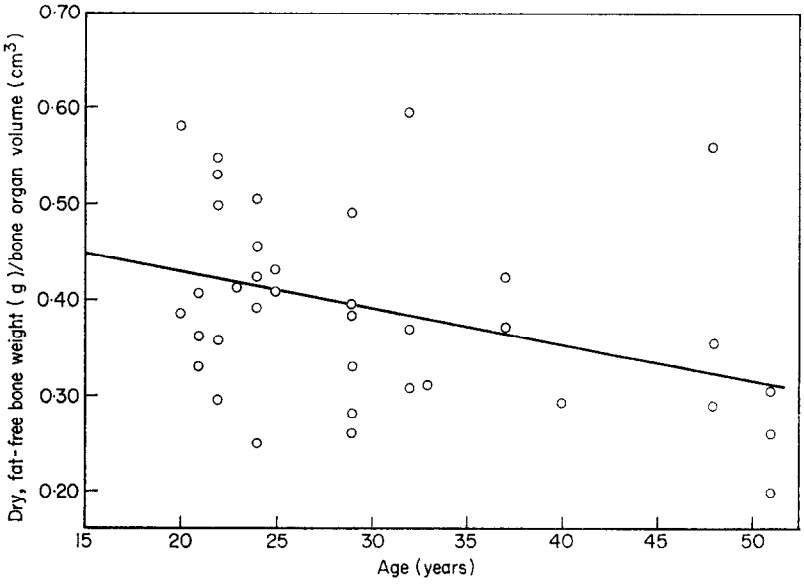


Figure 16. Scatter diagram and regression line of dry, fat-free bone density of bone organ as a function of age for males (pathological male indicated □, Osteoporotic).

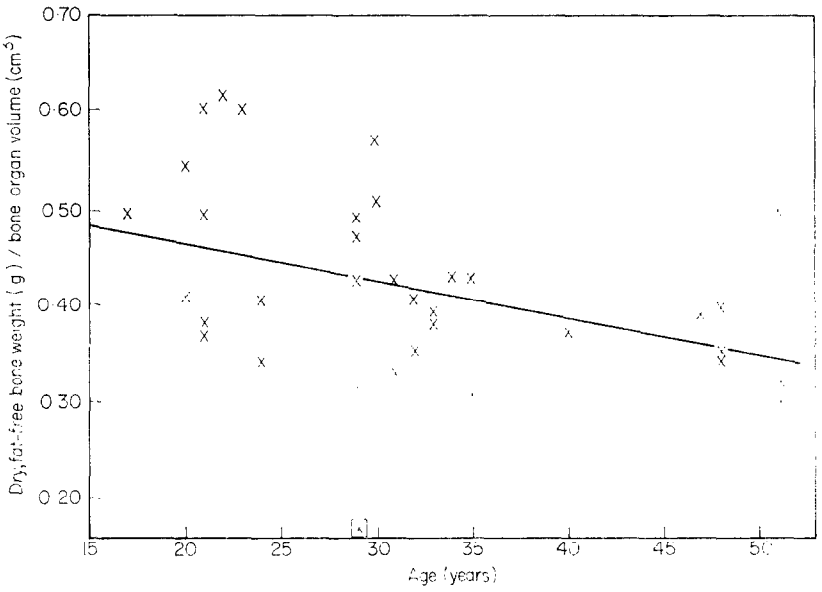


Figure 17. Scatter diagram and regression line for drys, fat-free bone density of bone organ as a function of age for female.

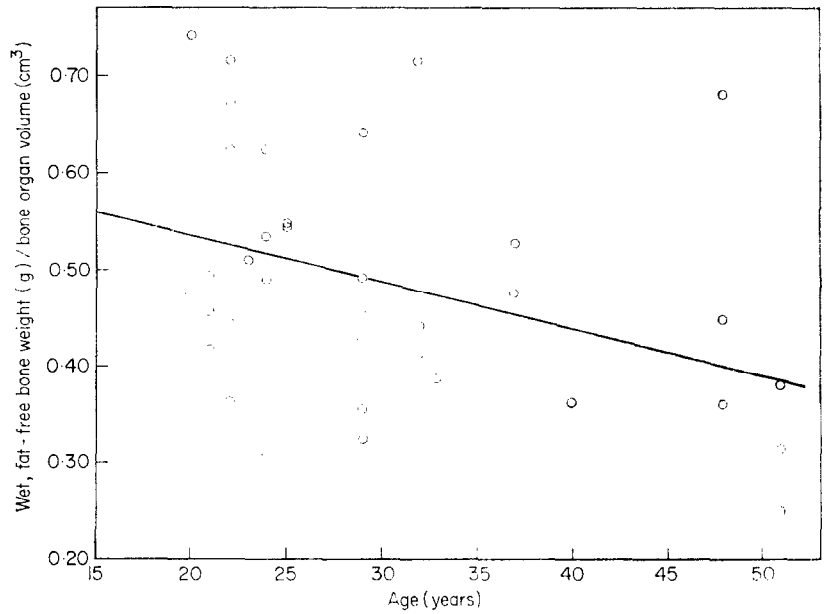
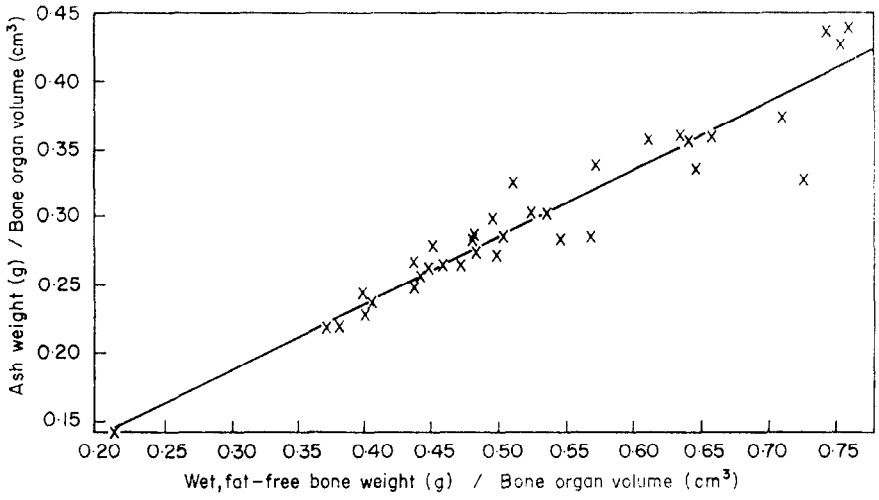


Figure 18. Scatter diagram and regression line of ash density of bone organ as a function of wet, fat-free bone density of bone organ for males.

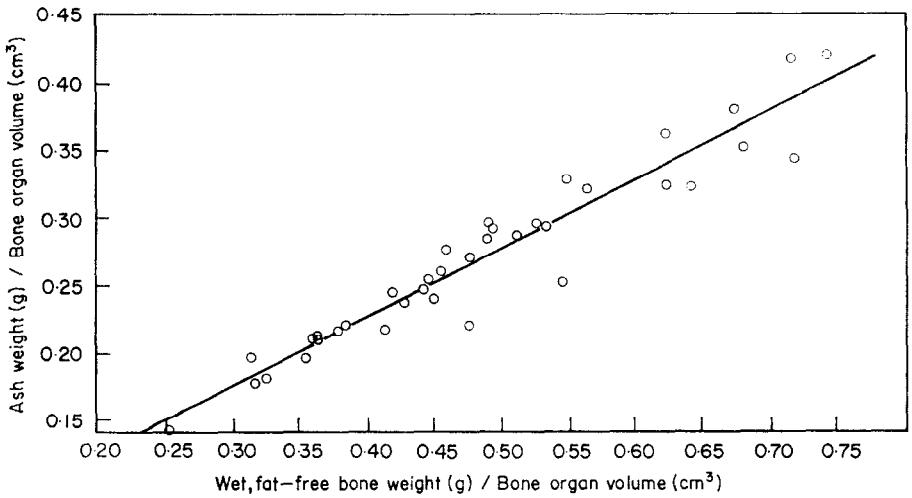


of the slopes for males and females in both instances indicates that the relationship between ash and bone is similar in both sexes.

5. Future Work

The results of the completed work leads to a number of unanswered questions. We are proceeding in a number of areas of related research, the first of which focuses on changes within the head of the femur with an attempt to ascertain changes in trabecular bone development.

Figure 19. Scatter diagram and regression line of ash density of bone organ as a function of wet, fat-free bone organ for females.



(*a*) *Trabecular bone—femur head*

The X-Group (NAX) specimens were drawn from the Nubian sample. A $\frac{1}{4}$ inch thick longitudinal section was obtained from the mid-sagittal plane of the femur heads and hand-ground to 200 μ on 280 grit carborundum paper. After grinding, the sections were rinsed in an alcohol and water mixture to remove any material trapped within the trabeculae.

The thickness of individual trabeculae (struts and cross-members) were measured using a "Gneupel" vernier sliding caliper (accurate to 0·01 mm) while the specimen was projected against a grid for the purpose of measuring area and volume. Magnification was corrected to obtain a reading of thickness in microns.

In order to obtain bone involution patterns and to facilitate comparison with previous studies, the 73 specimens (33 males and 40 females) were divided into the same age groups used by Dewey (1968). The data were subjected to linear regression and multiple correlation using a "RABIES (does all sorts of fits)" program (Maxwell, 1968). The analysis included the measurement of average trabecular thickness consisting of both cross-members and struts (uprights) and the analysis of cross-members and struts separately.

Values (Figure 20) for average trabecular thickness (struts + cross-members/2) revealed that males decrease 20 microns with age. The regression equation was $Y = 291{\cdot}6 - 0{\cdot}6\,X$, not significant at 0·05%. The correlation coefficient was −0·26 also not significant at 0·05%. Male values ranged from 231 to 427.

Females, on the other hand, gained a total of 15 μ in average thickness as age increased. The regression equation was $Y = 256{\cdot}7 + 0{\cdot}5\,X$ not significant at 0·05%. The correlation coefficient was 0·20, also not significant at 0·05%. Average values ranged from 233 to 344 μ.

Although the results were not significant, the trends were unexpected since the study of cortical bone and ash density of the femur head showed females losing a greater percentage of bone than males. In order to ascertain the factors involved in these changes, an analysis of cross-member and strut (upright) thickness was evaluated separately.

Cross-member trabecular thickness for males decreased 55 μ over the total age span (Figure 21). The regression equation was $Y = 295{\cdot}1 - 1{\cdot}8\,X$, significant at $P < 0{\cdot}01$. The correlation coefficient was −0·49 significant at $P < 0{\cdot}01$. Male values ranged from 173 to 297 μ.

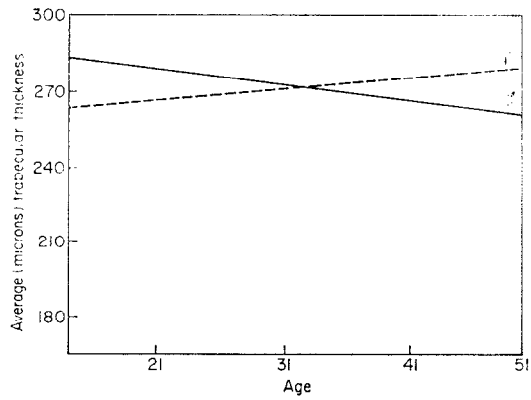


Figure 20. Regression lines for average thickness of femoral head trabecular (cross member and struts).

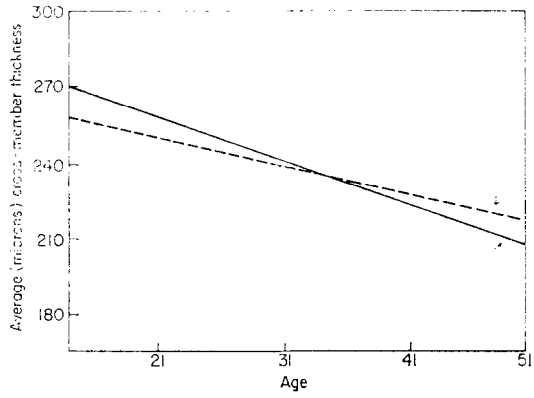


Figure 21. Regression lines for average thickness of femoral head cross member thickness.

The total reduction in female cross-members was 37 μ. The regression equation was $Y = 272{\cdot}7 - 1{\cdot}1\ X$, significant at $P < 0{\cdot}05$. The correlation coefficient was $-0{\cdot}31$, significant at $P < 0{\cdot}05$. Female values ranged from 167 to 330 μ.

Linear regression and correlation analysis was then performed on strut thickness (Figure 22) with both sexes showing an increase in thickness as age increased.

Male increase totaled 15 μ by the oldest age group. The regression equation was $Y = 288{\cdot}1 + 0{\cdot}5\ X$ not significant at 0·05 %. The correlation coefficient was 0·14 also not significant at 0·05 %. Male values ranged from 233 to 393 μ.

A 68 micron increase was observed for females. The regression equation was $Y = 240{\cdot}7 + 2{\cdot}1\ X$, significant at $P < 0{\cdot}01$. The correlation coefficient was 0·48, significant at $P < 0{\cdot}01$. The values ranged from 239 to 427 μ.

It is apparent from these results that the differences in average trabecular thickness are due to a significant increase in strut thickness (68 μ) in females compared to the smaller (15 μ) increase in males. We are at present attempting to see if the increase in female strut thickness occurs in response to loss of cortical and trabecular tissue in the neck of the femur. In other words, as trabecular tissue in the neck is lost, strut thickness would increase along lines of stress to stabilize the femur head. It should be pointed out that this hypothesis is tentative and is in the process of being tested in our laboratory.

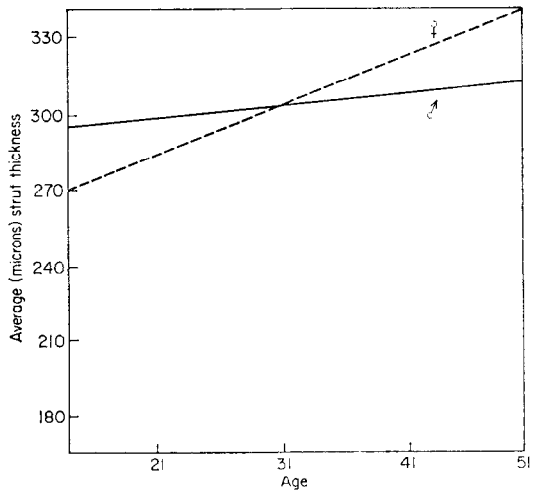


Figure 22. Regression lines for average thickness of femoral head strut upright) thickness.

(*b*) *Microradiographic analysis*

The second phase of our future research centers around a microradiographic analysis of femoral sections. The bones are embedded, sectioned, and microradiographed in the procedure which follows.

The bone specimens are embedded in polyurethane to form blocks which were attached to mounting plates for cutting.

The sectioning saw (Plate 1) was a converted Benchmaster horizontal milling machine, model MHZ, with an M 30 longitudinal power feed. The mill allows for ten separate spindle speeds: 450: 850, 1400, 2100, 3300 and 3900 rev/min. The longitudinal power feed has four (reversible) speeds: 1·2, 2·1, 3·2 and 4·5 inches per minute (30·48, 53·34, 81·28 and 114·30 mm per minute). Adaptation for thin sectioning includes a plastic tray mounted on the table so that water may be drained off and a special mounting plate for anchoring of the specimen. In addition, a plastic (Lucite) hood was fabricated to contain the spray mist and provide safety for the operator in case of blade fracturing. The arbor is a Benchmaster M–20 with a 1″ (25·4 mm) outside diameter and $\frac{1}{2}$″ (12·7 mm) collars.

Jeweller's slotting blades 4″ × 0·020″ (101·6 × 0·5080 mm) and 5″ × 0·023″ (127 × 0·5852 mm) of high speed steel are used for cutting the embedded bone specimens at a spindle speed of 2100 rev/min and a table feed speed of 1·2 i.p.m. (30·43 mm.p.m.). Three variable spray mists are attached to the table assembly to provide adequate cooling and lubrication during the cutting period. Tap water (room temperature) with 0·1 % detergent is used as the coolant and is sprayed (as a fine mist) at 25 lb (10·9 kg) pressure to the front of the blade and forward one-third of each side of the blade.

Following the sectioning, specimens were hand-ground on powdered abrasive to 100 μ thick sections.

After hand grinding, the microradiographs were taken at 20 kV for 20 minutes utilizing a modified General Electric XRD-5F1 X-ray defraction unit with a specially constructed camera attachment (Plate 2) which allows the use of $3\frac{1}{4} \times 4\frac{1}{4}$ Eastman 649-0 spectroscopic plates. The unit has a General Electric CA–8X X-ray tube with a beryllium window and a tungsten filament and is full wave rectified. The camera is constructed so that the spectroscopic plates can be positioned at 20, 22·5, 25 and 27·5 cm from the target. The camera is $\frac{1}{2}$″ (12·7 mm) thick, $2\frac{3}{4}$″ (69·85 mm), (outside diameter) stainless steel tube stepped to $3\frac{1}{2}$″ (88·9 mm) (OD) at the rear. The inside diameter at the base is $2\frac{1}{2}$″ (63·5 mm). The camera back is built to hold a graphic 4 × 5 inch (91·6 × 127 mm) film holder, in which the $3\frac{1}{4} \times 4\frac{1}{4}$ inch (82·55 × 107·95 mm) spectroscopic plate (Eastman 649-0) is positioned by use of a standard $3\frac{1}{4} \times 4\frac{1}{4}$ inch (82·55 × 107·95 mm) plate adapter. The specimens are mounted on a $3\frac{1}{4}' \times 4\frac{1}{4}'' \times \frac{1}{16}''$ (82·55 × 107·95 × 1·587 mm) steel plate with a 2-inch (50·8 mm) hole in the center. The bone section is hung on a 15 μ thick polyester film so that it is in direct contact with the emulsion on the spectroscopic plate.

Standard methods for the development of spectroscopic plates are used.

With the microradiograph (Plate 3) analysis will proceed with an analysis of the following:

(1) Microradiographic determination of number and size of osteon and osteon fragments.
(2) Microradiographic determination of trabecular size and development.
(3) Microradiographic determination of the degree of mineralization of osteon and occlusion of haversian canals.

With this information and following the Frost & Wu (1967) formulation, turnover rates will be determined for the sample adding a microscopic level to the study. We will thus be able to analyse bone development at the macroscopic and microscopic level.

(c) Conclusions

The results of our study show clearly the value of skeletal material in the analysis of problems in bone growth and development. Specifically, the analysis of long bone growth adds another dimension to the comparative analysis of populations. The study of age-related changes in cortical thickness provides insight into a condition which has clinical importance. The availability of large homogeneous samples not available in autopsy and biopsy material is especially important.

Research supported by grant (HD-AM 02771-01, 02) from United States Public Health Service, National Institute of Child Health and Human Development.

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Plate 1. Modified milling machine used for sectioning bone.

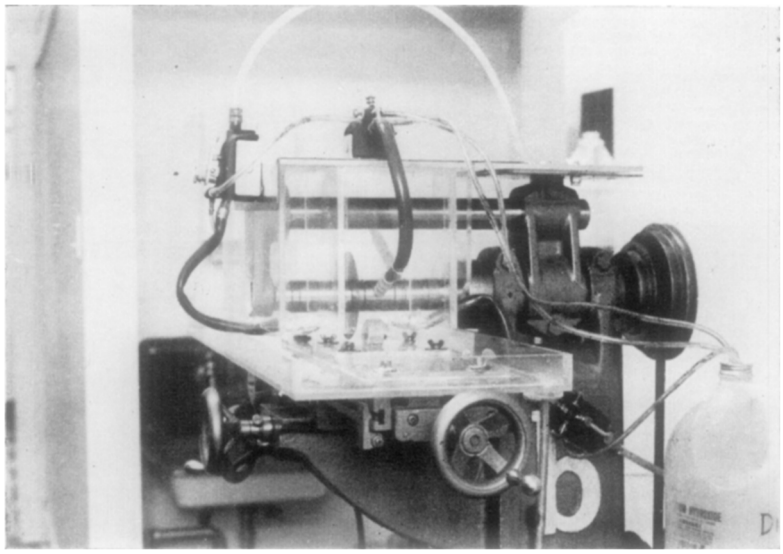


Plate 2. Camera for making microradiograph.

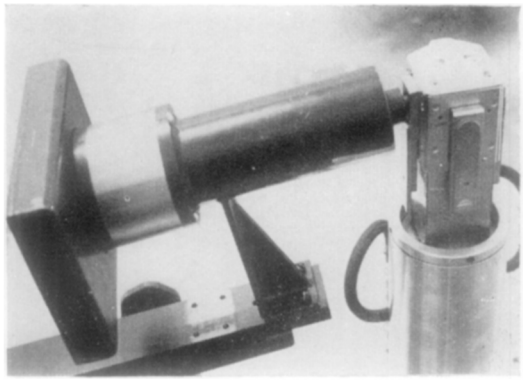
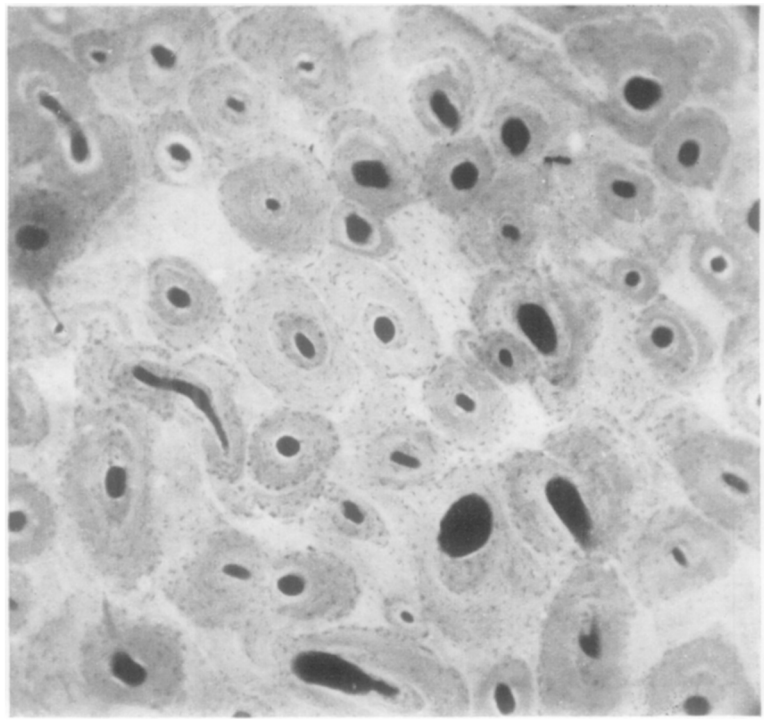


Plate 3. Microradiograph showing variation in mineralization of osteons



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This paper formed one of the contributions to a Symposiumon Population Biology of the Early Egyptians organized by B. A. Chiarelli (Institute of Anthropology, University of Turin) and D. R. Brothwell (British Museum of Natural History, London). The Symposium was held at the Montaldo Castle (Turin) from April 16th to 18th 1969.