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Studies of Haversian systems in man and some animals

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INTRODUCTION

In adult man and animals, bone turnover is achieved by the replacement of primary bone by secondary osteones; in cortical bone these systems form the units of structure, and their size and shape determine the appearance of the tissue. This varies in different species of animals, and it varies in man at different ages.

In 1947, Amprino described the microradiographic appearance of the cortical bone of a number of different animals. He demonstrated that there were variations in the appearance of the osteones in various species and that, in animals which live longer and are evolutionarily more advanced, there was a tendency for the primary bone to be replaced by osteones at an early age. In a 2-year-old human the femoral cortex consists largely of osteones (Jowsey, 1963), whilst in a 7-year-old rabbit it contains only an occasional one. In studies of human bone, Currey (1964) has shown that the size of the osteones varies with age; osteones in the femoral cortex became smaller while the Haversian canals remained essentially the same size.

The present study was designed to re-examine this observation and to determine the characteristics of osteones in different animals and in man at different ages.

METHODS

Specimens were taken from the femora of a number of animals of different species and stages of evolution (Table 1). Human cortical bone was obtained from both the rib and femur at biopsy; the subjects ranged in age from 20 to 90 years and there were three or more in each decade. The cause of death in these subjects was sudden trauma or cardiac infarction and all subjects were active at the time of death; the bone was considered to be normal by macroscopic and microradiographic criteria.

Cross-sections of the cortex were taken from the exact mid-shaft of the femur and in the rib from 8 to 20 cm from the spine. The specimens were fixed in alcohol and embedded in methyl methacrylate, and microradiographs of the undecalcified material were prepared (Jowsey *et al.* 1965). The sections were cut at right angles to the length of the shaft. Photographs at a magnification of 100 times were prepared of representative areas of cortical bone. The perimeters of the Haversian canals were measured with a map measurer; the size of an osteone was taken as the average of two perpendicular diameters, measured with a ruler, between cement lines. For inclusion in this study, an osteone (1) had to be a secondary osteone laid down in a resorption space (that is, an osteone formed by removal of primary bone) and (2) had to be cut in cross-section (any osteone in which the canal was twice or more as long in one direction than in the other was considered not to be running perpendicularly to the plane of section and was disqualified). Fifty osteones were measured for each animal; 100 or more were measured in each human specimen.

Measurements were also made of the thickness of the cortex of the rib and femur; these measurements were made on photographs and included the entire thickness of the cortex.

Table 1. *Some characteristics of osteones from the femur in man and some animals*

Animal	No. of animals	Approximate body weight (kg)	Cement-line diameter mean ± S.D. (μm)	Haversian canal perimeter, mean ± S.D. (μm)	Average bone density*	Range of density†
Rat	3	0·3	72 ± 14	36 ± 12	1·39	1·40–1·70
Rabbit	6	2·0	98 ± 22	54 ± 24	1·34	1·39–1·53
Cat	6	3·0	163 ± 30	102 ± 36	1·18	—
Dog	4	10·0	154 ± 38	85 ± 37	1·28	1·02–1·54
Monkey (*Rhesus*)	2	10·0	216 ± 52	167 ± 46	1·09	—
Man, adult	26	70·0	223 ± 50	173 ± 45	1·24	0·90–1·40
Cow, adult	4	400	250 ± 40	213 ± 47	—	1·11*1·50
Diadectes	1	400 (?)	236 ± 40	150 ± 45	—	—
Iguanodon	1	1000 (?)	246 ± 58	203 ± 55	—	— —

* Expressed as g of hydroxyapatite per cm^3. Data from Jowsey (1964), Variations in bone mineralization with age and disease. In *Bone Biodynamics*, pp. 461–479 (ed. H. M. Frost). Boston: Little, Brown and Company.

† Expressed as g of hydroxyapatite per cm^3. Data from Rowland, Jowsey, Marshall, (1959). Microscopic metabolism of calcium in bone. III. Microradiographic measurements in mineral density. *Radiation Res.* **10**, 234–242.

RESULTS

Animals. Table 1 summarizes the data characterizing the size of osteones (that is, the cement-line diameter) and the Haversian-canal perimeter in the femoral cortex of the various animals and of man. It is evident that, in small animals, the smaller the animal, the smaller is the size of the osteone and its canal. However, in those animals larger than a monkey, these values remain approximately constant with increasing body size.

Values taken from two previous studies for the mineral density of bone in these animals have been included in Table 1. The mean value, expressed as the weight of hydroxyapatite per unit volume of bone, is a measurement of the density of the entire sample of cortical bone and includes the lacunae of the bone cells or oseocytes; the ranges (that is, the lowest and highest values recorded) are of the mineral density in 35 μm^2 areas of bone tissue and include the canaliculi but not the lacunae. The results show that there are differences in mineral density in animals of different species.

Human osteone and Haversian canal sizes at different ages

Measurements of the size of the osteone and the canal perimeter were made in human cortical bone of femur and rib (Fig. 1 and Table 2). The results show that in the femur there is no significant change in the size of the osteones with age. The perimeter of the Haversian canals in the femur increase significantly ($P < 0.001$) in size with age; in subjects less than 50 years old the mean perimeter was 156 μm and in those more than 50 years old, 212 μm. In the rib there is a tendency toward a decrease in the size of the osteones with increasing age; however, the change was not statistically significant ($P > 0{\cdot}6$). The perimeter of the Haversian canals in the rib remains at approximately 165 μm throughout life.

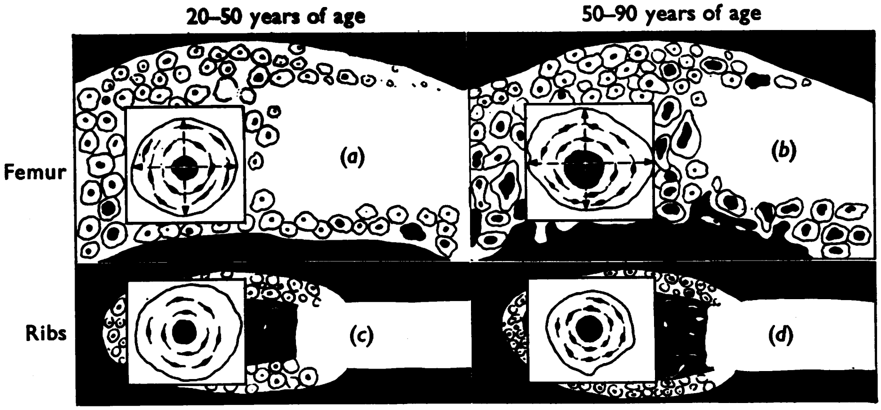

Fig. 1. Diagrammatic representation of the osteone (*HS*) size, canal perimeter (*HC*), and cortical (*C*) thickness of human rib and femoral cortex at different ages. (*a*) *HC* diameter 217 μm, *HC* perimeter 156 μm, *C* thickness 6·4 mm. (*b*) *HS* diameter 231 μm, *HC* perimeter 212 μm, *C* thickness 5·7 mm. (*c*) *HS* diameter 216 μm, *HC* perimeter 157 μm, *C* thickness 0·95 mm. (*d*) *HS* diameter 186 μm, *HC* perimeter 176 μm, *C* thickness 0·71 mm. (Figures represent mean values.)

Table 2. *Osteone size, Haversian canal perimeter and cortical thickness in man at different ages*

Age	Osteone diameter (μm)		Haversian canal perimeter (μm)		Cort. thickness (mm)	
	Femur	Rib	Femur	Rib	Femur	Rib
20–29	252 ± 24	213 ± 21	151 ± 25	154 ± 18	6·06 ± 1·0	1·12 ± 0·2
30–39	243 ± 12	217 ± 31	139 ± 18	167 ± 30	6·38 ± 1·0	0·98 ± 0·2
40–49	226 ± 21	222 ± 17	163 ± 15	159 ± 5·0	6·29 ± 0·6	0·98 ± 0.2
50–59	235 ± 13	214 ± 31	195 ± 11	181 ± 11	5·92 ± 0·8	0·79 ± 0·2
60–69	247 ± 14	164 ± 9·0	205 ± 14	176 ± 8·5	5·46 ± 0·4	0·83 ± 0.2
70–79	245 ± 15	167 ± 34	214 ± 29	170 ± 15	5·83 ± 0·6	0·67 ± 0·2
80–90	258 ± 47	—	221 ± 7·1	—	5·59 ± 0·4	0·46 ± 0·2

Cortical thickness in femur and rib

Figure 1 and Table 2 also demonstrate the thickness of the cortex in the femur and rib. In the femur it does not change significantly, although from inspection it appears that the dense cortical bone of the endosteum becomes filled with vascular spaces. In the rib this process progresses so that there is complete loss of endosteal bone, which leads to a significant decrease in cortical thickness with advancing age.

DISCUSSION

It might be argued that only those animals that live for more than a certain number of years—for example, more than five—have many secondary osteones. It

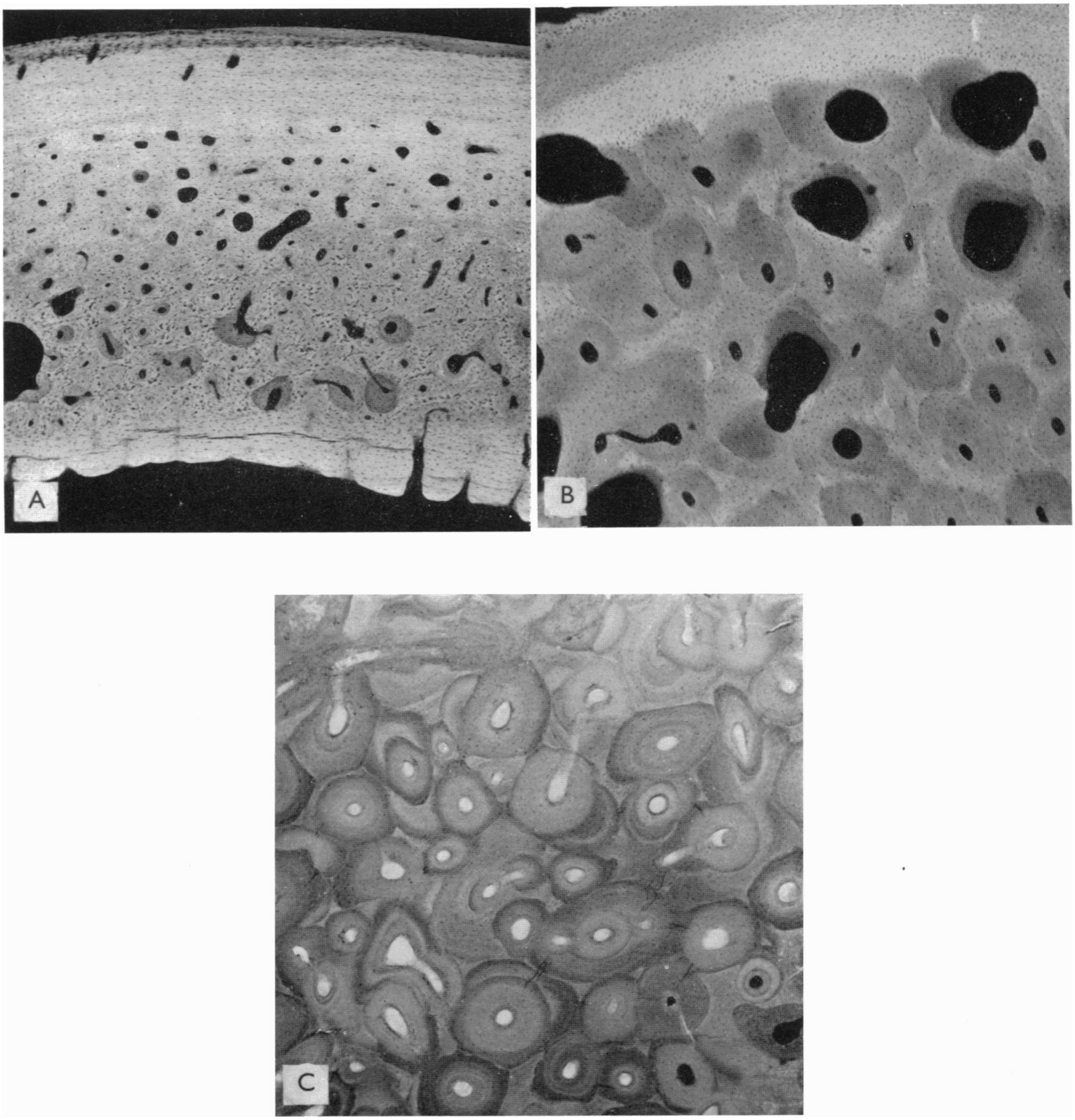

Fig. 2. Microradiographs through the femoral cortex of animals (× 50), *A*, Adult rabbit, *B*, young monkey, *C*, *Diadectes* (Devonian). Note variations in size of osteones among three animals; the Haversian canals seen in *C* are filled with chalk because the piece of bone from which the section was made was in a deposit of chalk.

is interesting in this respect that animals, such as the rat, which have very few such centres of secondary bone turnover do not close their epiphyses completely during their life. The suggestion here is that, when the remodelling of bone resulting from longitudinal growth ceases, osteones develop to maintain bone turnover and the exchange of mineral between the body and the skeleton; this function would be particularly necessary in species with inefficient calcium absorption. In man, such secondary osteones appear long before the epiphyses close. In contrast to primates, rodents generally have a diet rich in calcium and also tend to conserve calcium if put on a low-calcium diet; it is perhaps relevant both that they have few osteones and that, if their calcium supply is limited, osteones are formed (Ruth, 1953).

The size of osteones appears to reach a limit at approximately 250 μm and to show no further increase in size despite increase in the size of the body or of the individual bone of the particular animal (Fig. 2).

The considerable species differences in mineral density of bone tissue, which was first reported by Rowland, Jowsey & Marshall (1957), suggests significant differences in the composition of bone tissue in different animals. Newly formed bone of the rat has a mineral density that is as high as that of the most highly calcified bone in man. Rogers, Weidmann & Parkinson (1952) have shown large differences in total protein and collagen in the femora of rabbit, ox and man. The mineral differences may be related to differences in collagen or mucopolysaccharide content of the bone as suggested by Rogers, *et al.* (1952), Neuman, *et al.* (1952), and Nicolaysen, Eeg-Larsen & Malm (1953).

Studies in man demonstrate changes in appearance of osteones with age. Currey (1964) measured the size of osteones and Haversian canals in the femoral cortex of nineteen adults and found that the former decreased in size while the latter remained the same size. These results are not in accordance with the data from the twenty five adults presented here; the reason for this lies in the methods by which the measurements were taken. Currey assumed that any irregularity in the shape of an osteone or its canal is an artifact, meaning that such an osteone is not lying at right angles to the plane of section; he therefore measured only the minor diameter of each osteone or canal. The natural consequence of this method of measurement is that the more irregular (not elliptic) the osteones or canals became, the more inaccurate were the values. Since there is a tendency for an increasing number of osteones to become more irregular with increasing age, Currey's method naturally leads to an examination of a smaller and smaller proportion of osteones—that is, those that remain approximately circular.

Such an error has been avoided in this study by measuring two perpendicular diameters and also by making a distinction between elliptic osteones and those of irregular shape. Elliptic osteones were not measured for the same reason that Currey did not measure any irregular osteones. The size of the canals was based on the perimeter rather than on the smallest diameter. It appears from the present data that in the femoral cortex the osteones remain approximately the same size throughout life while the central canal increases in size. This accounts in part for the increase in porosity seen in cortical bone with increasing age (Jowsey, 1960).

In the rib, the canal remains of approximately the same size, although showing a slight but statistically insignificant tendency to increase with age. The osteones remain the same size, as reported also by Landeros & Frost (1964), although inspection of the individual points suggests a trend toward a decrease in size. This may be the result of the loss of endosteal bone, where the larger osteones are concentrated. Currey (1964) made this observation in femoral bone, and his measurements of the thickness of the femoral cortex suggested no change with age. He concluded that the decrease in size of osteones was real. The cortical thicknesses reported here confirm Currey's results on cortical thickness in the femur. In the rib, however, there is a complete loss of endosteal bone and this results in the disappearance of bone containing the larger osteones. The consequence is that the smaller, periosteal osteones form an increasingly larger proportion of the osteone population. The trend toward a decrease in the size of the osteone in the rib is therefore more apparent than real.

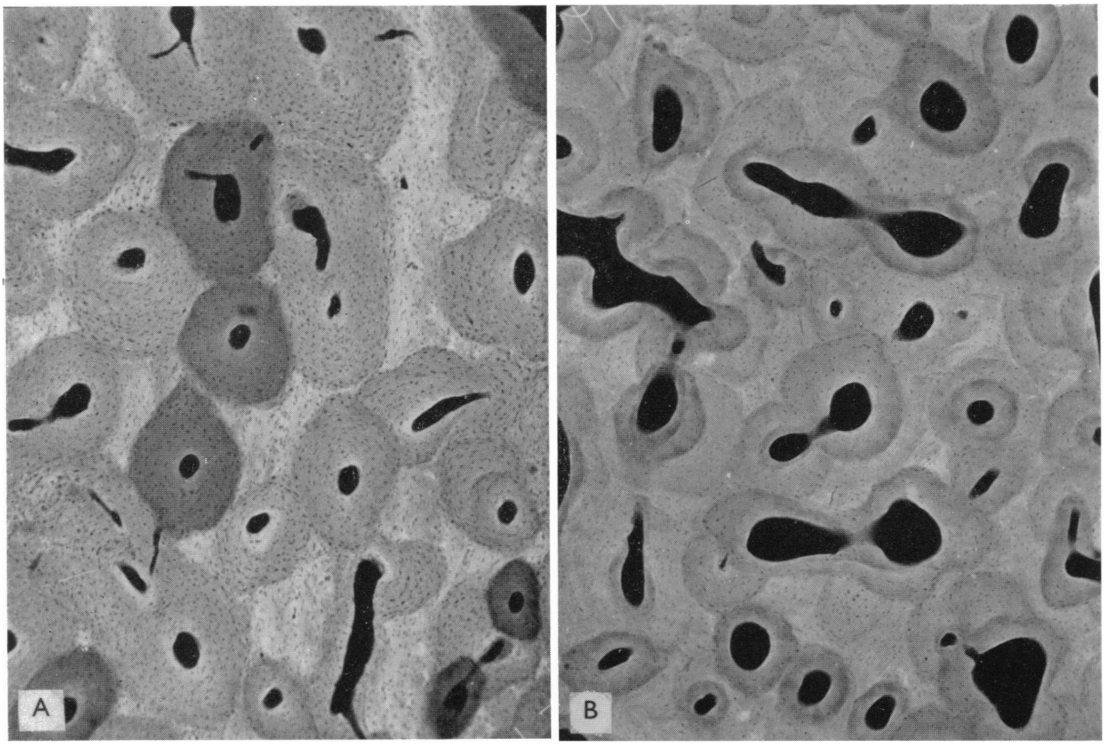

Fig. 3. Microradiographs of femoral cortex of 23-year-old (*A*) and 85-year-old (*B*) women, demonstrating increase in size of Haversian canal and irregularity of the osteones in the older person. (x50.)

Rowland (1964) used the remodelling of radium-burdened human bone to measure the rates of resorption and growth of cortical bone. His values for two subjects were 0·83 and 2·50 %, respectively, per year. Other data on bone turnover support this value (Jowsey, 1960), demonstrating the rather low replacement-rate of cortical bone. One consequence of this is that, in any population of osteones, the great proportion of them have existed for many years. Therefore, any change in the appearance of osteones in old persons must have begun a long time before the observation was made. The bone of persons more than 60 years old shows a tendency for the osteones to fail to complete their calcification (Jowsey, 1960); these characteristics must be features of osteones that are formed after the age of 40 years.

This change in the size and composition of the osteone which accompanies advanced age may reflect an alteration in metabolic behaviour. It has been suggested that osteoporotic persons are deficient in calcium (Nordin, 1960). The amount of bone resorption in the normal skeleton increases with age while the amount of formation of new tissue remains the same or shows only a slight increase; in osteoporotic persons, resorption of bone is abnormally increased (Jowsey, 1960; Jowsey *et al.* 1965). The increase in resorption may be interpreted as a response to a lack of calcium; the increase in the number of semimineralized osteones may also be a reflexion of calcium deficiency or perhaps of alteration in the structure of the collagen. The failure to complete the laying down of an osteone—that is, for bone formation to stop when the Haversian canal is still large—appears also to be a characteristic of ageing (Fig. 3). This primarily is not a fault of bone formation but of an increase in the size and number of resorption cavities resulting from an increase in the absolute and relative amounts of resorption. The incomplete mineralization of an osteone may be the most efficient way of maintaining strength in a cortex that is becoming increasingly full of holes because more tissue is being resorbed than is being formed. In other words, stronger bone is produced by half-filling all holes rather than completely filling only half of the holes.

SUMMARY AND CONCLUSIONS

1. Cortical bone was collected from the femurs of animals of different species and from femurs and ribs of humans of different ages. Sizes of osteones and their canals and thickness of cortex were measured.

2. There appears to be an upper limit to the size of the osteone in animals of different species.

3. In the femur and in the rib of man osteones remain approximately the same size throughout life.

4. In man Haversian canals increase in size with age in the femur cortex but remain in the same size in the rib; in the rib, this is accompanied by a decrease in cortical thickness.

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