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## CORTICAL BONE IN MAN

### 1. *Variation of the Amount and Density with Age and Sex*

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In an earlier study the authors have examined on autopsy specimens the occurrence of osteoporosis in spongiosa at different ages, the grading being made on the basis of the apparent density (2).

Opinions differ on how the development of osteoporosis in the spongiosa affects the cortical bone, but it is generally considered that the amount of cortical bone diminishes. Since no major systematic studies have been carried out on this point we have conducted a study with the object of establishing whether there is any variation with age and sex of (i) certain dimensions and the density, (ii) tensile strength, (iii) compressive strength, (iv) chemical composition, and (v) the microscopic picture, and whether there is any correlation between these parameters in cortical bone. The study was performed on bone from the humerus and femur from autopsy specimens of subjects aged 15 to 89 years of both sexes. It was begun in 1961 and preliminary reports have been published (3-5).

#### MATERIAL

Bone specimens were taken at autopsies in 1961-62 at St. Görans's Hospital and the Institute of Forensic Medicine, Stockholm. The hospital has about 1000 beds, and about 700 autopsies are performed annually. Most of the patients are more than 40 years of age, and the specimens from the younger age groups were obtained chiefly from the Institute of Forensic Medicine. The distribution is given in Table 1.

Specimens were taken from 4 subjects of each sex in the age groups 15-19 years, and thereafter every decade up to 80-89 years, a total of 64 subjects.

The cause of death is not reported in detail; for the clinical cases it was usually cardiovascular disease and for the forensic cases external violence or poisoning. None of the subjects had died from tumours, had been confined to bed for a long period or had had fractures or bone diseases other than osteoporosis.

Table 1. Distributions of subjects with respect to age and type of autopsy  
—clinical or forensic.

Age	15-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	Total
Forensic	7	8	7	2	0	0	0	0	24
Clinical	1	0	1	6	8	8	8	8	40
Total	8	8	8	8	8	8	8	8	64

The material cannot be regarded as a random selection from the population but in all the cases over 40-50 years it probably represents an average clientele with cardio-vascular disease.

#### METHODS

The middle half of the humerus and femur and the distal femoral epiphysis from the right side were removed, usually 24 hours after death (8-60 hours). From the distal epiphysis of the femur the spongiosa was taken for determination of the apparent density by the method described earlier (2). The long bones were freed from soft tissues, including the periosteum, with a rasp. From the middle of these specimens exactly 100 mm long pieces were sawn in a special jig. The specimens were at this time slightly fatty and were wiped.

During the period between this treatment and the various examinations (measurement, weighing, density determination)—usually up to 14 days—the specimens were stored in air at 3-5° C. Before the measurements they were placed in ordinary water for 24 hours and then wiped. The variation in weight during storage in air will be dealt with in a future study—part IV of this series.

*Diameter.*—The two halves of the long bones, each 100 mm were fitted together and the frontal diameters were measured at 6 equidistant sites with calipers to an accuracy of 0.1 mm. The mean of the measurements was calculated for each bone, account being taken of the loss of bone through sawing (1.5 mm).

*Weighing.*—Immediately after removal from the water and wiping the two halves of the long bones were weighed to an accuracy of 0.01 g.

*Volume.*—The two halves of the long bone were immersed in water and the displaced volume was determined to an accuracy of 0.01 ml. As the specimens had previously lain in water and were quite fatty on the surface any penetration of hollows by the water was not considered to incur a significant error.

*Density.*—Obtained as the quotient of weight by volume.

*Mean cross-sectional area.*—Although the thickness of the wall of a long bone varies along its length and around its circumference it can nonetheless be regarded as a measure of the sturdiness and strength of the bone. The mean cross-sectional area was considered to give a more representative estimate of these parameters than a single arbitrary cross-section. It was obtained as the quotient of volume by length. No account was taken of the bone lost through the saw-cut.

*Statistical analysis.*—The mean variation, standard error and regression coefficient were obtained by the usual statistical methods (1. p. 16).

## RESULTS

*Apparent Density*

For the femoral epiphysis the apparent density diminished with age and was lower for women than men. The results were thus in agreement with those for the earlier study of the relationship between the apparent density of the proximal epiphysis of the tibia and the lumbar vertebrae with age and sex reported for another series in an earlier paper (2). The relationship of the apparent density to the mean cross-sectional area of the femur is reported below (Figure 4).

*Mean Diameter*

The diameter of the humerus was 13 per cent larger in men than women; the difference was significant (\*\*\*) (Table 2). The mean diameter of the humerus and the femur increased significantly (\*\*\*) with age in both men and women (Figure 1).

*Table 2. Means of external diameter, density and mean cross-sectional area for femur and humerus.*

	Men		Women	
	Femur	Humerus	Femur	Humerus
<i>External diameter (mm)</i>				
Mean, S.D.	32.9 ± 0.4	25.9 ± 0.3	29.9 ± 0.3	22.9 ± 0.2
Range	(28.7 — 38.2)	(22.6 — 29.9)	(27.4 — 33.4)	(20.4 — 26.5)
<i>Density</i>				
Mean, S.D.	1.90 ± 0.02	1.77 ± 0.02	1.80 ± 0.02	1.72 ± 0.03
Range	(1.57 — 2.33)	(1.44 — 2.01)	(1.52 — 1.96)	(1.40 — 2.03)
<i>Mean cross-sectional area (cm<sup>2</sup>)</i>				
Mean, S.D.	4.33 ± 0.14	2.31 ± 0.09	3.39 ± 0.09	1.57 ± 0.06
Range	(2.09 — 6.09)	(0.95 — 3.50)	(2.02 — 4.47)	(0.92 — 2.21)

*Density*

The difference in density for the sexes was significant (\*\*\*) for the femur but not the humerus (Table 2). In a comparison of the density for the femur and humerus the density was invariably higher for the former; the difference was significant (\*\*\*) for both sexes.

Above 50 years the density of the femur and humerus in the men increased significantly (\*\*) with age (Figure 2). In the women there was a slight but non-significant reduction in the density with age.

Mean diameter

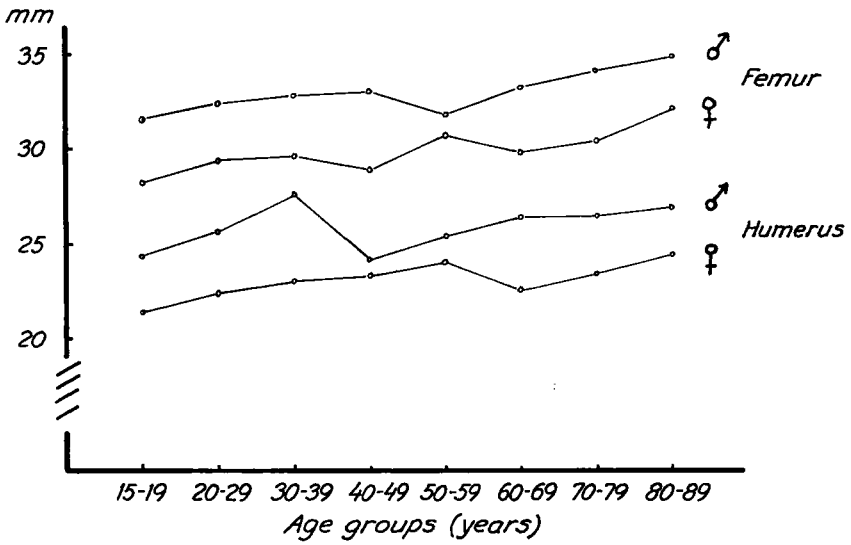


Figure 1. Variation of mean diameter of femur and humerus with age; men and women.

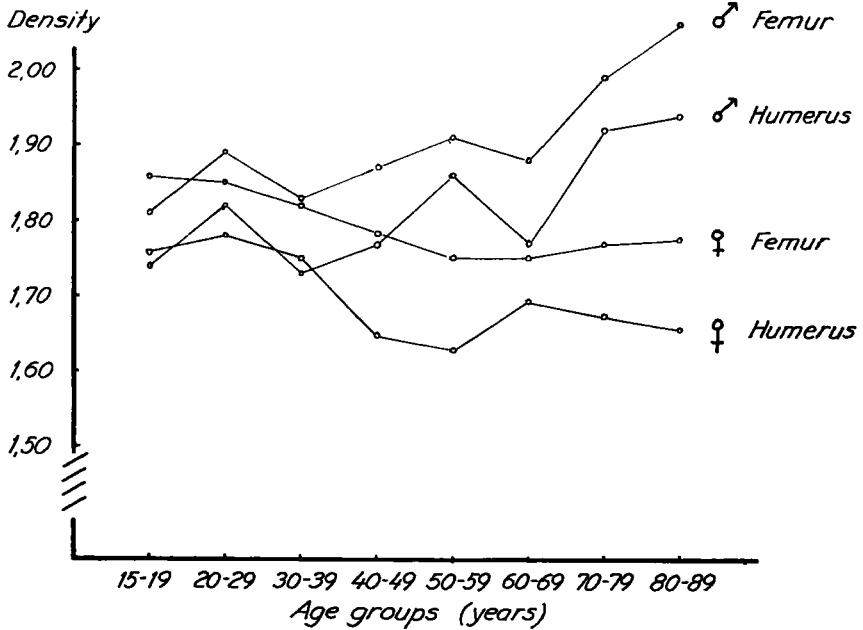


Figure 2. Variation of mean density of femur and humerus with age; men and women.

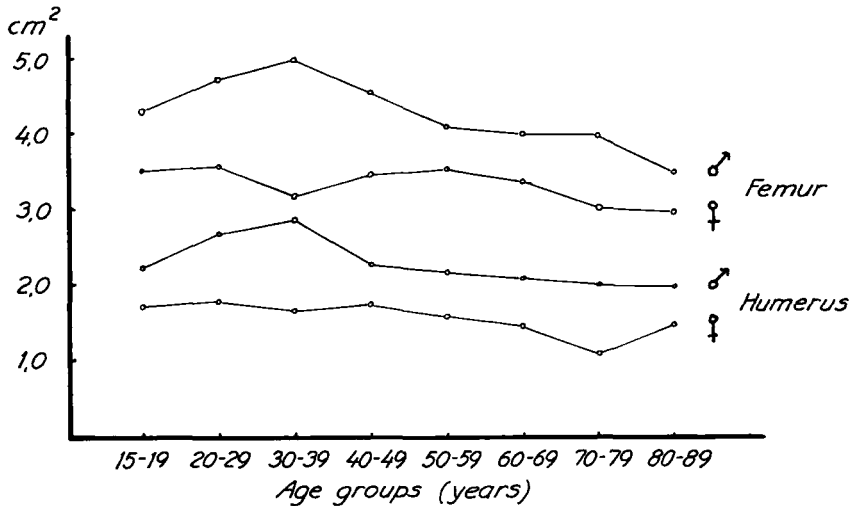
*Mean cross-sectional area*

Figure 3. Variation of mean cross-sectional area of femur and humerus with age; men and women.

*Mean Cross-Sectional Area*

For the femur this was on average 28 per cent greater for the men (significant \*\*\*, Table 2). For the humerus the mean was on average 47 per cent greater for the men (significant \*\*\*).

For both sexes and both bones there was a tendency for the mean cross-sectional area to decrease with age after 30-39 years (Figure 3). This reduction was significant only for the men (\*\*).

For all subjects there was a significant correlation (\*\*) between the mean cross-sectional area of the cortical bone of the femur and the apparent density of the spongiosa from the distal femoral epiphysis (Figure 4).

## DISCUSSION

The object of the study was to examine the properties of cortical bone in connection with the grade of osteoporosis and to find whether there is any change in the cortical bone with age and sex. Just as in the case of the spongiosa, it was of interest to obtain an impression of the total amount of cortical bone and its quality.

It would have been preferable to measure the total amount of cortical and spongiosa bone in the body and then find its relationship to suitable

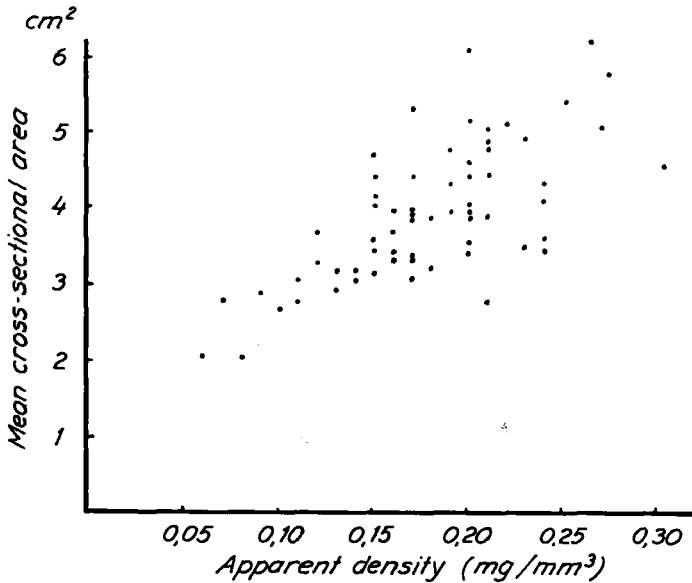


Figure 4. Relationship between cross-sectional area of femoral cortical bone and apparent density of spongiosa at distal part of femur.

parameters such as length, body weight or lean body weight. As this was impracticable for various reasons it was necessary to obtain an indirect impression of these total amounts. The mean cross-sectional area of the femur and humerus in the middle 10 cm of the bone was considered to represent the amount of cortical bone, and the density a measure of its quality. Cortical bone is also referred to as compact bone, and in the earlier literature it is often stated that this always has the same density and chemical composition except for malacic and rachitic bone. However, a gross examination suffices to show that cortical bone has a varying surface, and on sawing through, it is seen to vary in compactness, there being smaller porosities and the border with the spongiosa being more or less continuous. This difference between different specimens of bone is still more pronounced in the microscopic picture, where the number of spaces (osteocytic lacunae, Haversian canals, blood vessels and resorption cavities) varies widely in number and size. The density of various specimens might therefore serve as a measure of the quality or compactness of the bone. There was no correlation between the apparent density of the femoral spongiosa and the density of the compact bone in this material. On the other hand, there

was a correlation between the mean cross-sectional area (amount of cortical bone) and the grade of osteoporosis in the spongiosa of the tibia.

The reduction in cross-sectional area of the femur with age was significant for men and parallel with a significant increase in the mean outer diameter of the femur. This would suggest that with age the resorption from the marrow space is more rapid than the periosteal growth on the surface.

The lower density recorded for all the subjects for the humerus than the femur specimen indicates a difference in function that is reflected in the composition of the bone. The lower density may be ascribed to a smaller amount of bone salts in the humerus.

The relatively moderate mean variations contrast sharply with the extremely large individual variations for all parameters. If the mean cross-sectional area is taken as a measure of the total amount of bone in the skeleton the weight of the skeleton would vary by a factor of 4.3 on the basis of the extreme values for density and mean cross-sectional area. In the individual cases the values of density and mean cross-sectional area were combined so that the extreme variation corresponded to a factor of 2.2. This extremely large variation may be of interest in the calculations of the lean body weight, when it is usually considered that the skeletal weight is fairly constant and proportional to the body weight or the height.

The differences between the sexes were large and significant for practically all the parameters. The fact that the difference in mean cross-sectional area between the sexes was significant greater for the humerus than for the femur would suggest that in women the legs, but not the arms, are constantly exposed to mechanical stress and that mechanical stress is one of the factors that determines the thickness and strength of the long bones.

#### SUMMARY

On cortical bone from the humerus and femur and spongiosa from the femur obtained from 64 autopsy cases of all age and of both sexes determinations of the apparent density, mean diameter, density and mean cross-sectional area were made. There were significant differences between the sexes and between the femur and the humerus. For most of the parameters there were significant changes with age. The apparent density of the spongiosa was correlated with the mean cross-sectional area of the femoral cortical bone; this indicates that in osteo-

porosis in the spongiosa there is a simultaneous reduction in the amount of cortical bone.

#### RESUME

Il a été pratiqué sur des spécimens d'os cortical de l'humérus et du fémur provenant de 64 autopsies de sujets de tout âge et des deux sexes, des examens pour déterminer la densité apparente, le diamètre moyen, la densité et la surface moyenne de section. On a constaté des différences appréciables entre les sexes et entre le fémur et l'humérus. Pour la plupart des paramètres, il y avait des modifications significatives avec l'âge. La densité apparente du tissu spongieux était liée à la surface moyenne de section de l'os cortical du fémur; cela indique que dans l'ostéoporose du tissu spongieux, il se produit une réduction simultanée de l'os cortical.

#### ZUSAMMENFASSUNG

Am kortikalen Knochen des Humerus und Femur und der Spongiosa des Femur, die von 64 Autopsiefällen aller Altersgruppen und beider Geschlechter erhalten wurden, ist eine Bestimmung der augenscheinlichen Dichte, des mittleren Durchmessers, der Dichte und der durchschnittlichen Querschnittsfläche ausgeführt worden. Es wurden bezeichnende Verschiedenheiten zwischen den Geschlechtern und zwischen dem Femur und Humerus gefunden. Die Mehrzahl der Messungen ergaben bezeichnende Altersveränderungen. Die augenscheinliche Dichte der Spongiosa stand in Beziehung zur durchschnittlichen Querschnittsfläche des femoralen, kortikalen Knochens. Dies weist darauf hin, dass bei der Osteoporose der Spongiosa eine gleichzeitige Herabsetzung der Menge des kortikalen Knochens vorhanden ist.

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