Acta orthop. Scandinav. 38, 141–147, 1967

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# CORTICAL BONE IN MAN

## II. *Variation in Tensile Strength with Age and Sex*

*By*

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Received 8.VI.66

This is the second of a series of studies on cortical bone that are being published in this journal.

### MATERIAL

The material, an account of which has been given in the previous paper (4), consisted of 100 mm lengths of the femur and the humerus. The specimens were cut out from the middle of the long bones from 64 autopsy subjects of a wide range of ages. Since the femur is slightly curved, concave backwards, the anterior half is usually subjected to traction and the posterior half to compression. As this might be considered to be reflected in a difference in the strength of the bone (functional adaptation) the anterior part of the femur was used for tests of tensile strength. As regards the humerus it was often difficult to obtain long and thick enough test bodies, and for this reason these had to be taken from the thickest part of the circumference.

### METHODS

*Storage.*—Because the bone shrinks slightly owing to evaporation and also changes its properties with time it would have been desirable to perform all the strength tests directly after the specimens had been removed. Since this was impracticable and some loss of moisture could hardly be avoided during the experiment, a varying period was accepted between the dissection of the specimen and the performance of the strength tests. During this period the specimens were kept in air at 3–5° C. They were prepared at room temperature (18–20° C). Thereafter they were kept in a special test room where the temperature and relative humidity were maintained constant at 20 ± 1.0° C and 65 ± 3 per cent, respectively. By repeated weighing it was found that an equilibrium state was attained—usually within 20 days—the specimens remaining constant in weight (± 0.1 mg).

Since the object of the study was mainly to *compare* the various specimens, any small changes in their properties after dissection do not interfere with the results, as all the specimens were treated in the same way.

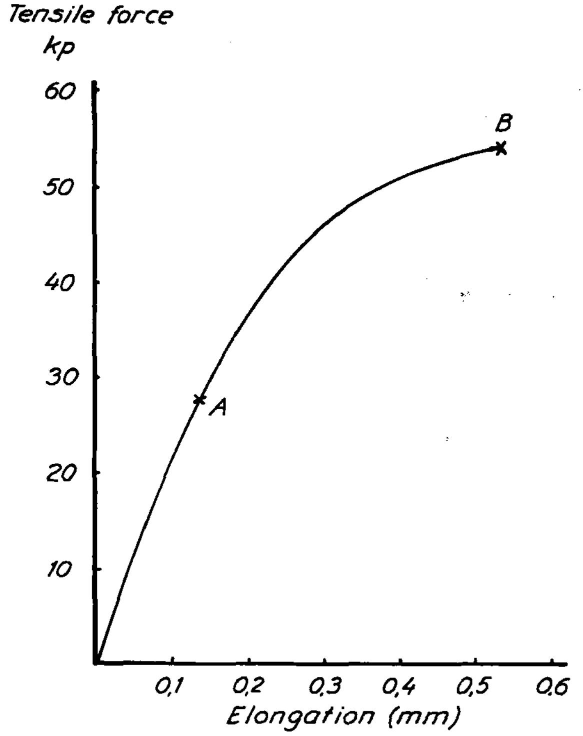


*Figure 1. The load–deformation curve for the tension test on bone samples. From the origin to the point A the curve is approximately linear and the deformation is proportional to the applied load. The unit stress (load/initial area of section) at A is the* limit of proportionality. *The stress at B, the point at which the specimens breaks is the* ultimate strength. *The* deformation at failure *of the sample is the increase in length at the point B, expressed as a percentage of the initial gauge length. The* modulus of elasticity *is the ratio of stress to strain, that is*

$$\frac{\textit{load/initial area of section}}{\textit{deformation/gauge length}}$$

*for the linear part of the curve (O–A).*

*The test bodies.*—As it was intended to examine the properties of the bone as a material, irrespective of the shape of the individual bone, the determinations were made on standardized test bodies. For measuring the tensile strength strips 6–8 cm long were obtained in the longitudinal direction of the bone by means of facing cutters, run at a low speed to avoid heating. The cross-section of the test body was rectangular and the area, measured with a micrometer, ranged from 1.3–1.8 by 2.0–3.3 mm for the various specimens. The variation for the individual specimen did not exceed 0.01 mm. Test bodies with gross defects in bone structure were not used, since the bone may then be weakened locally and give wrong test values. Two or 3 test bodies were made from each bone (humerus and femur), but in some cases only one was acceptable, while in others no bone could be obtained owing to small dimensions, irregular shape and porosity of the bone.

*Apparatus.*—The bones were prepared and tensile strength tests performed at the National Materials Testing Institute, Stockholm, with the appropriate apparatus (Alwetron). The gauge length was 20 mm and the rate of deformation 0.5 mm/min. The deformation was recorded continuously and from the curves so obtained the ultimate strength, elongation at rupture, limit of proportionality and modulus of elasticity were determined (Figure 1).

*Statistical methods.*—These were the same as those used in a previous study (3, p. 16).

## RESULTS

### *Ultimate Tensile Strength*

See Table 1. The difference between the sexes as regards ultimate strength was not significant. The value was higher for the humerus than the femur (highly significant ***).

Except for the women aged 15–19 the tensile strength decreased with age for both sexes and for both bones (Figure 2). The reduction was about 10 per cent (significant **).

### *Deformation at Failure*

See Table 1. There was no significant difference either between the sexes or between the femur and humerus.

*Table 1. Means of strength parameters. The values in parentheses are ranges.*

| | Men | | Women | |
|---|---|---|---|---|
| | Femur (n = 29) | Humerus (n = 27) | Femur (n = 30) | Humerus (n = 16) |
| Ultimate tensile strength ($kp/mm^2$)* | 14.1 ± 0.2 (12.2 — 16.1) | 14.9 ± 0.2 (12.0 — 17.5) | 13.4 ± 0.3 ( 8.5 — 16.7) | 15.1 ± 0.5 (11.9 — 18.1) |
| Deformation at failure (%) | 2.0 ± 0.1 (1.4 — 3.1) | 2.2 ± 0.1 (1.5 — 3.3) | 1.8 ± 0.1 (0.5 — 2.4) | 1.9 ± 0.1 (1.0 — 2.6) |
| Limit of proportionality ($kp/mm^2$)* | 4.4 ± 0.1 (3.1 — 5.7) | 4.3 ± 0.1 (3.2 — 5.4) | 4.2 ± 0.1 (2.6 — 5.7) | 4.3 ± 0.2 (2.9 — 5.3) |
| Modulus of elasticity ($megap/mm^2$)§ | 1.52 ± 0.03 (1.19 — 1.88) | 1.56 ± 0.03 (1.16 — 1.89) | 1.50 ± 0.04 (1.08 — 2.02) | 1.61 ± 0.08 (0.72 — 2.08) |

* kp (kg f) see below. 1 $kp/mm^2$ = 1422 pound per square inch.

§ megap = 1000 kp. 1 kp (kilopond) = 9.80665 newtons = 2.2046 pounds force". 1 $megap/mm^2$ = 1,422,000 pounds per square inch.

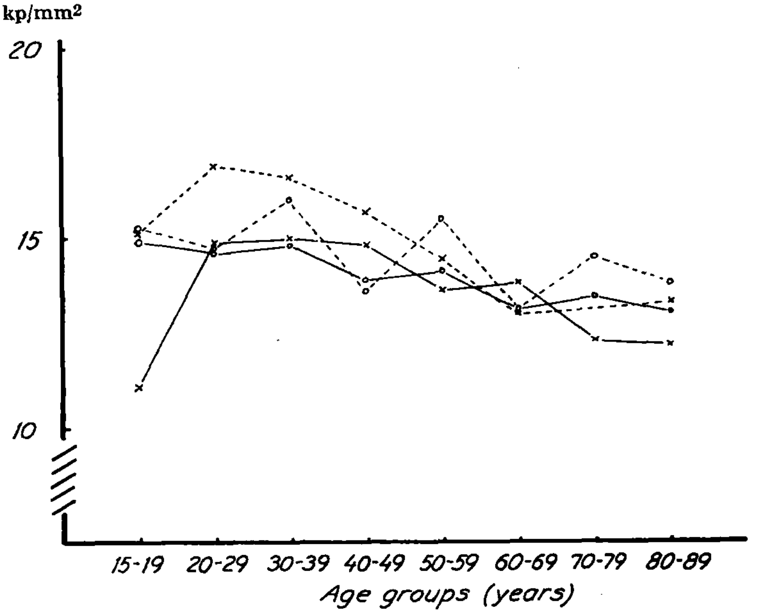


*Figure 2. The variation of the mean ultimate strength with age for the femur and humerus, and for both sexes.*
Men o, women x, femur ———, humerus – – – – –.

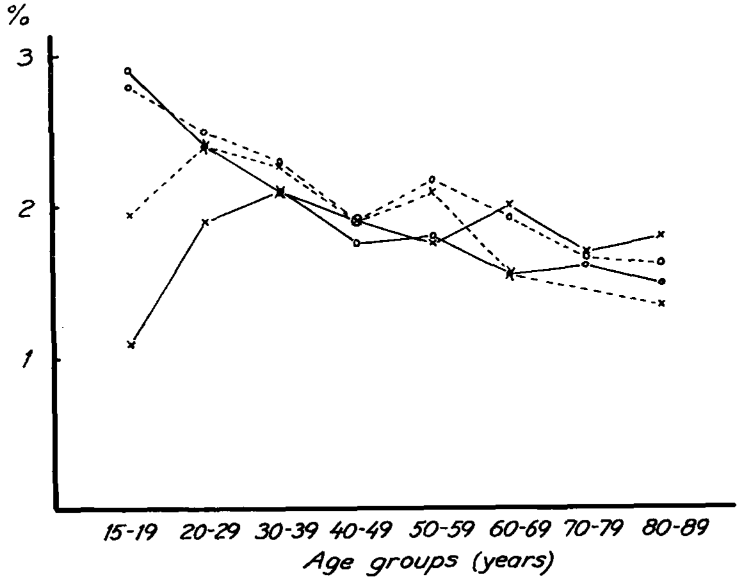


*Figure 3. The variation of the mean deformation at failure with age for femur and humerus, and for both sexes.*
Men o, women x, femur ———, humerus – – – – –.

Except for women aged 15–19, the deformation at failure decreased with age for all groups (Figure 3). The difference was about 35 per cent (significant ***).

*Limit of Proportionality*

See Table 1. The differences between the sexes and between the femur and humerus were not significant. Nor was there any variation of this value with age.

*Modulus of Elasticity*

See Table 1. The differences between the sexes and between the femur and humerus were not significant. There was no variation in this value with age.

## DISCUSSION

Studies of the mechanical properties of bone have been performed since the end of the 1800s (reviewed by *Evans* (1)). *Evans & Lebow* (2) found no significant changes in the mechanical properties with age either in their own material (6 cases) or in the literature. In the present study, which was performed on a fairly large selection from all age groups, there was a definite change in the quality of the bone with age; this was reflected in a reduction of about 10 per cent in the tensile strength and of about 35 per cent in the deformation at failure; both these changes were significant. The limit of proportionality and modulus of elasticity, on the other hand, showed no significant changes with age; these properties can be determined only approximately, since it is presupposed that the load – deformation curve is linear over some range (Figure 1); but this is almost never the case, so that for most materials, including bone, the limit of proportionality in particular, will be approximate.

There was no difference between the sexes with respect to the mechanical properties of the bone.

In a comparison between the femur and humerus it was found that the tensile strength (ultimate strength) was about 10 per cent higher for the humerus than for the femur (significant ***). In other respects there was no difference between these bones. Since the humerus is exposed to traction more than the femur this difference may be a manifestation of functional adaptation.

The inter-subject ranges were extremely large for all the properties

(Table 1); particularly in view of the extremely large individual variation in the amount of cortical bone (4) this means an enormous range for the strength of the individual bone (femur, humerus), These large differences are also observed in the clinic, they being manifested in the large variation in the individual resistance to fractures.


## SUMMARY

Specimens of cortical bone from the femur and humerus of 64 autopsy subjects of both sexes and a wide age range were examined with respect to the ultimate tensile strength, deformation at failure, limit of proportionality and modulus of elasticity. The means and ranges are reported. There was a qualitative change in the cortical bone with age, reflected in a reduction in ultimate tensile strength and deformation at failure. The tensile strength was significantly higher for the humerus than the femur. The individual differences were extremely large.

## RESUME

Des spécimens d'os cortical du fémur et de l'humérus provenant de 64 autopsies de sujets des deux sexes et d'âge très différent ont été examinés en ce qui concerne la fore ultime de tension, la déformation à la rupture, la limite de la proportionnalité et le module d'élasticité. Il est rendu compte des données obtenues. Il se produit un changement qualitatif de l'os cortical avec l'âge qui se reflète par une réduction de la force ultime de tension et une déformation à la rupture. La force de tension s'est montrée sensiblement plus élevée pour l'humérus que pour le fémur. Les variations individuelles sont d'ailleurs très étendues.

## ZUSAMMENFASSUNG

Corticale Knochengewebsproben des Femur und des Humerus von 64 Autopsiefällen beider Geschlechte verschiedener Altersgruppen wurden untersucht in Hinblick auf die höchste Dehnungsfestigkeit, die Deformierung bei Versagung, die Grenze der Proportionalität und des Elastizitätsmodulus. Die Mittel und die Resultate der Versuche werden besprochen.

Eine qualitative Veränderung des corticalen Knochengewebes beim Altern, die sich in Verminderung der ultimalen Dehnungsfestigkeit und der Deformierung bei Versagung äusserte, wurde gefunden. Die Dehnungsfestigkeit war signifikant grösser im Humerus als im Femur. Die individuellen Unterschiede waren sehr gross.

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