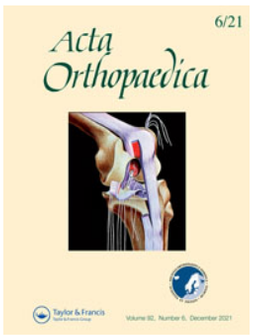

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CORTICAL BONE IN MAN

III. *Variation of Compressive Strength with Age and Sex*

By

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This is the third of a series of studies on cortical bone, reports of which have been published in earlier issues of this journal (2, 3).

MATERIAL

A full account of the material for this study has been given elsewhere (2). Compact cortical bone was taken from the femur and humerus of 64 autopsy subjects of various ages. As the femur is slightly curved the specimens for the compression test were taken from the posterior circumference of the bone, which is usually subjected to compression, while the tensile tests (3) were carried out on specimens from the anterior part generally subjected to traction. From the humerus the specimens were taken where the cortical bone was thickest and yielded most material.

METHODS

Storage

The specimens were stored in air at 3–5° C (3). After preparation they were kept at constant temperature and relative humidity (20° C and 65 per cent, resp.) until equilibrium with respect to the latter had been reached.

Test Bodies

The compressive tests were performed on test bodies, 2.1–3.8 mm long, removed in the axial direction of the bone by means of a facing cutter, run at a low milling speed so as to avoid heating. The bodies were of rectangular and uniform cross-section throughout their length with the dimensions 1.3–2.0 × 2.7–3.3 mm. These dimensions were measured with a micrometer, and a variation of up to 0.01 mm was accepted within any particular test body. Two such bodies were made for each bone (femur, or humerus) with a few exceptions where, because of the small dimensions and porosity, only one could be obtained.

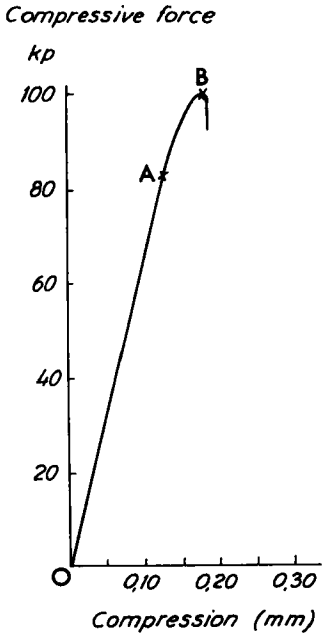

Figure 1. Force-compression diagram for compression tests on a bone specimen. From O to A the curve is approximately straight and the compression proportional to the applied force. The stress (compressive force/cross sectional area of the body) for the bone at A is the limit of proportionality (kp/mm²). The compression at rupture (B) is expressed as the percentage deformation of the original length of the body. The modulus of elasticity is the ratio of stress to strain, that is:

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

for the lineal part of the curve (O–A).

Apparatus

The test bodies were made and the compression tests carried out with an Alwetron apparatus at the National Testing Laboratory, Stockholm. The rate of deformation was 0.05 mm/min. The deformation was recorded continuously, and on the basis of the graphs so obtained the ultimate strength, compression at rupture, limit of proportionality and the modulus of elasticity were obtained (Figure 1).

Statistical Methods

The statistical analysis was performed with the same methods as in an ealier study (1).

RESULTS

The results are summarized in Table 1.

Table 1. Means of compressive strength parameters.
The values in parenthesis are ranges.

	Men		Women	
	Femur (n = 30)	Humerus (n = 30)	Femur (n = 30)	Humerus (n = 19)
Ultimate strength (kp/mm²)*	19.7 ± 0.3 (14.8–22.2)	18.8 ± 0.4 (13.3–21.4)	18.3 ± 0.4 (12.7–22.4)	19.1 ± 0.3 (16.4–21.7)
Compression at rupture (%)	5.3 ± 0.5 (3.5–14.8)	4.5 ± 0.3 (2.8–9.6)	4.3 ± 0.2 (2.8–7.7)	3.9 ± 0.2 (2.3–6.4)
Limit of proportionality (kp/mm²)*	15.8 ± 0.4 (10.1–18.3)	16.1 ± 0.4 (10.6–19.1)	15.7 ± 0.4 (9.3–20.5)	16.7 ± 0.3 (13.6–19.2)
Modulus of elasticity megap/mm²†	1.05 ± 0.06 (0.30–1.76)	1.10 ± 0.05 (0.45–1.58)	1.07 ± 0.05 (0.46–1.55)	1.20 ± 0.07 (0.71–1.85)

* 1 kp/mm² = 1422 lb/in² (psi).
1 megap = 1000 kp. 1 kp (kgf) = 9.80665 newtons = 2.2046 lb force.
1 megap/mm² = 1,422,000 lb/in² (psi).

Compressive Strength

There was no difference in the ultimate strength between the femur and humerus. The femur was significantly (**) stronger in men than women, with a mean difference of 8.0 per cent. There was a decrease in this property with age from 20 years upwards in both men and women and for both the femur and the humerus (Figure 2). The mean reduction was about 15 per cent and was significant (**).

Compression at Rupture

For all age groups and both sexes the compression at rupture was greater for the femur than for the humerus; the difference was significant (***).

For the men below 40 years there was a significant (**) reduction with age of about 40 per cent in the compression at rupture for both humerus and femur (Figure 3).

For women there was no such variation.

Limit of proportionality

This property showed no difference between the sexes or between the femur and the humerus. After 20 years there was a reduction of about 15 per cent with age (almost significant *) (Figure 4).

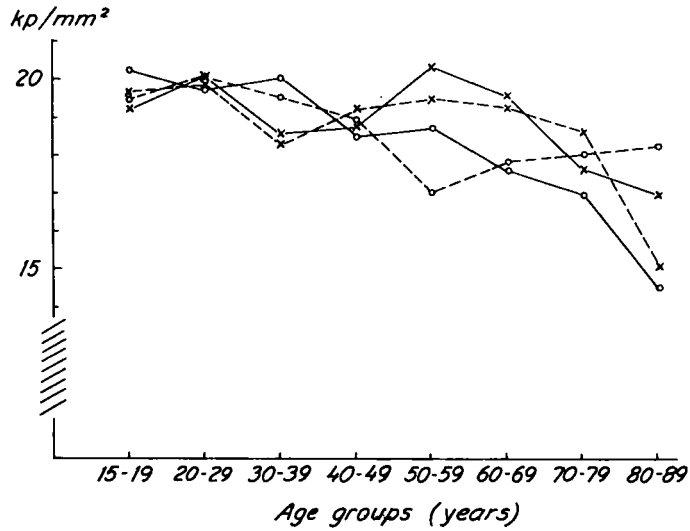

Figure 2. Mean compressive ultimate strength for the femur and humerus, both sexes and various age groups. Men ○, women ×, femur ——, humerus – – – –.

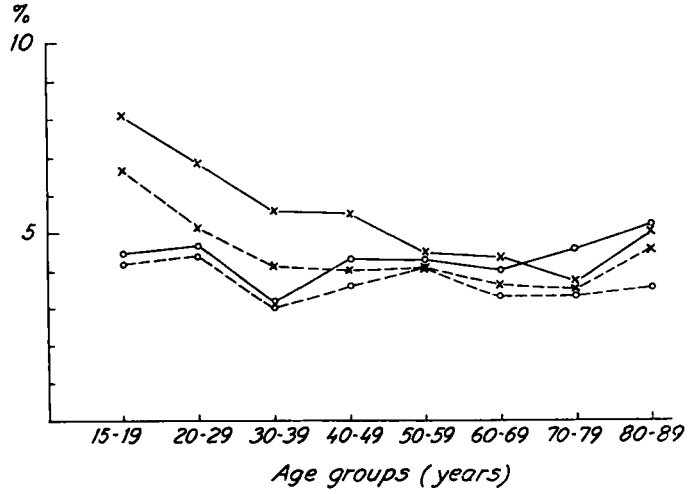

Figure 3. Mean compression at rupture for the femur and humerus, both sexes and various age groups. Men ○, women ×, femur ——, humerus – – – –.

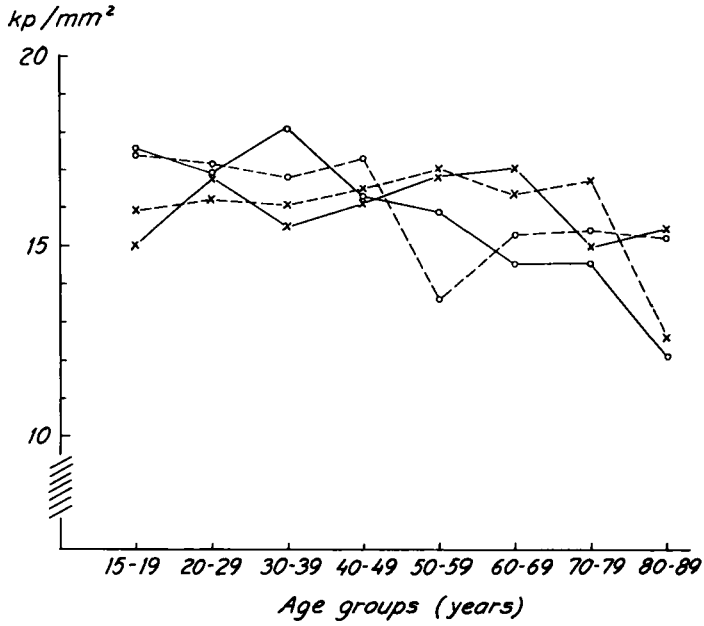

Figure 4. Mean limit of proportionality for the femur and humerus, both sexes and various age groups. Men ○, women ×, femur ——, humerus - - - -.

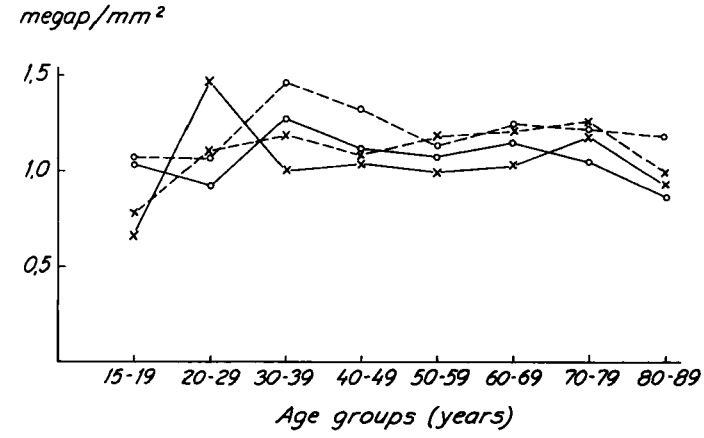

Figure 5. Mean modulus of elasticity for the femur and humerus, both sexes and various age groups. Men ○, women ×, femur ——, humerus - - - -.

Modulus of Elasticity

There was no difference between the sexes as regards the modulus of elasticity, but in practically all the age groups and for each sex the value was higher for the humerus than for the femur; the difference was almost significant (*). There was no variation with age (Figure 5).

DISCUSSION

As in the case of the tensile strength, the measurement of the compressive strength indicated the presence of qualitative changes in the bone with age. The ultimate strength decreased by 15 per cent, the compression at rupture by 40 per cent and the limit of proportionality by 15 per cent. Whereas the humerus had a higher ultimate strength at tension, the femur showed a higher compression at rupture. This would seem to reflect functional adaptation, the femur being subjected to compression more than the humerus.

In contrast to the values for the tensile strength, for the compression there was a small difference between the sexes, the ultimate compressive strength of the femur being significantly greater for men than women. It is difficult to judge whether this difference is due to a real difference between the sexes or to the composition of the material. The differences between the femur and humerus have another significance, since the comparisons are made on the same subjects.

As in the case of the tensile strength, the compressive strength showed extremely large individual variations. The means are in close agreement with those reported in the literature.

SUMMARY

A study has been made of compressive strength, compression at rupture, limit of proportionality and modulus of elasticity of cortical bone of the femur and humerus. The specimens were obtained from autopsy subjects of both sexes and a wide range of ages. There was a qualitative change in the cortical bone with age, reflected in a reduction in all the properties except the modulus of elasticity.

RESUME

It a été procédé à une étude sur la force de compression, la compression à la rupture, la limite de la proportionnalité et le module d'élasticité de

l'os cortical du fémur et de l'humérus. Les spécimens ont été prélevés à l'autopsie de sujets des deux sexes représentant une gamme d'âges variés. On a observé des modifications qualitatives de l'os cortical avec l'âge reflétant une réduction de toutes les propriétés excepté le module de l'élasticit.

ZUSAMMENFASSUNG

Ein Studie der Kompressionsstärke, der Kompression bei der Sprengung, der Grenze der Proportionalitet und des Modulus der Elastizitet von kortikalem Knochen des Femurs und Humerus wurde ausgeführt. Die Proben wurden von Autopsiesubjekten beiderlei Geschlechtes und weit verschiedenen Altersklassen erhalten. Man fandt eine qualitative Veränderung des kortikalen Knochens entsprechend dem Alter, die sich in einer Verminderung aller Eigenschaften mit Ausnahme der Elastizitet zeigte.

REFERENCES

1. Lindahl, O. (1961) Experimental skin pain induced by injection of water-soluble substances in humans. *Acta physiol. scand.* **51**, Suppl. 179.
2. Lindahl, O. & Lindgren, A. (1967) Cortical bone in man. I. Variation of the amount and density with age and sex. *Acta orthop. scand.* **38**, 133–140.
3. Lindahl, O. & Lindgren, A. (1967) Cortical bone in man. II. Variation in tensile strength with age and sex. *Acta orthop. scand.* **38**, 141–147.