The Effects of Age and Strain Rate on the Mechanical Properties of Bone

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The increased incidence of bone fractures in persons over 35 years of age (Knowelden et al, 1964) could be attributed to a decrease in bone strength after the fourth decade of life. There have been several attempts to show how the strength of bone varies with age. ASCENZI AND BONUCCI (1965,1968), SEDLIN, and HIRSCH (1966) and EVANS and LEBOW (1951) could not show a trend of variation of bone strength with age, although HIRSCH and EVANS (1965) did show that the average Ultimate Tensile Strength (UTS) of specimens from infants was greater than that shown by other investigators for specimens from adult femora. The work of VOSE et al (1961) tends to indicate that the intrinsic strength of bone increases with age. MELICK and MILLER (1966) on the other hand, show a decrease in the UTS with increasing age. A decrease in both the tensile and compressive strengths with age is demonstrated by LINDAHL and LINDGREN (1967, 1968). The results obtained by YAMADA (1970) indicate that the UTS of bone increases up to the third decade of life and thereafter decreases.

The disagreement shown by these workers would indicate that some systematic study, in which all the variables are standardised, should be undertaken to determine whether age is a determinant of bone strength - a view also expressed by SEDLIN (1965). It was this that prompted the study of age related changes in bone strength. The initial work described here was undertaken at Birkbeck College, London, in collaboration with Dr. S Chatterji and Professor J. W. Jeffery.

Since bone is known to be weaker in tension than in compression, it is more likely to fail when tensile forces are applied to it. Most accidental fractures of bone are tension fractures, even the spiral fractures associated with torsion, EVANS et al (1951). For this reason, it was decided to measure the tensile strength of small samples of bone and to see how the results varied with age.

The central 10 cm or so of the femoral diaphysis were removed at post-mortem and stored in sealed plastic bags at -20°C. As far as possible, bone from persons known to have had skeletal disorders or who had been bed-ridden for a considerable period prior to death was not used in this study. All bones had been frozen prior to testing, none being tested fresh.

Parallel strips of bone were removed from the lateral quadrant. These strips were lapped to remove any cancellous bone or adherant tissue including the periosteum, so that only cortical bone remained. Between four and six strips were obtained from each bone.

After determining the density of these strips of bone by a simple water displacement technique, they were shaped into tensile test-pieces using two hardened-steel jigs. The resulting samples were flat, dumbell shaped test-pieces, 50mm long, with a central waisted section 29 mm in length having a cross-sectional area of 4mm^2, WALL et al (1972).

Tensile strength determination was carried out using a Hounsfield Tensometer, modified to operate in the vertical position. The bone samples were held in specially designed mould-type grips, WALL & CHATTERJI (in press). Two linear displacement transducers were used to measure load and displacement and these were recorded on an X-Y plotter. An extension rate of 1mm per minute was selected for this work.

The results obtained for the UTS are shown in fig.1. The short horizontal lines indicate the mean value and the limits of the vertical lines indicate $\pm$1 SD about the mean. It can be seen that the strength increases up to the fourth decade of life and thereafter decreases. This trend is evident again in fig.2 which shows the mean values of the mechanical properties measured for each decade age-group plotted against age. All the properties measured, UTS, Elasticity (E) and Percentage Elongation (PE) show the same trend. - increasing in value up to the fourth decade of life and thereafter decreasing.

The graph in fig.2 also shows the results from two other studies of age-changes in the UTS of femoral cortical bone. The common feature of all three studies shown is that there is a decrease in UTS after the third or fouth decade of life. The results of LINDAHL and LINDGREN (1967) differ from the other two studies in that there is no peak simply a gradual decrease in strength from the second to the fifth decade of life and thereafter a more noticeable decrease. The differences in values for UTS obtained in the three studies may possibly be explained by differences in moisture content of the samples and in strain rate.

These three studies are lacking in data from the lower age range of 0-10 years and to a lesser extent from the 10-20 years age group. Thus they shed no light on the findings of HIRSCH and EVANS (1965) and their work on infant bone. They tested very small, flat, dumbell shaped pieces of cortical bone in tension. It was found that there was a tendancy towards an increase in UTS with advancing age. However, the average value of UTS obtained from infants was greater than that reported by other investigators for fresh adult femurs. The trend demonstrated would fit the findings of the present study and those of YAMADA (1970), ie. an increase in UTS with age up to the fourth decade of life. However, the higher average value of UTS for infant bone with respect to adult bone might better fit the findings of LINDAHL and LINDGREN (1967). Although as HIRSCH and EVANS (1965) point out, these differences in value might be due to differences in sampling site and testing technique.

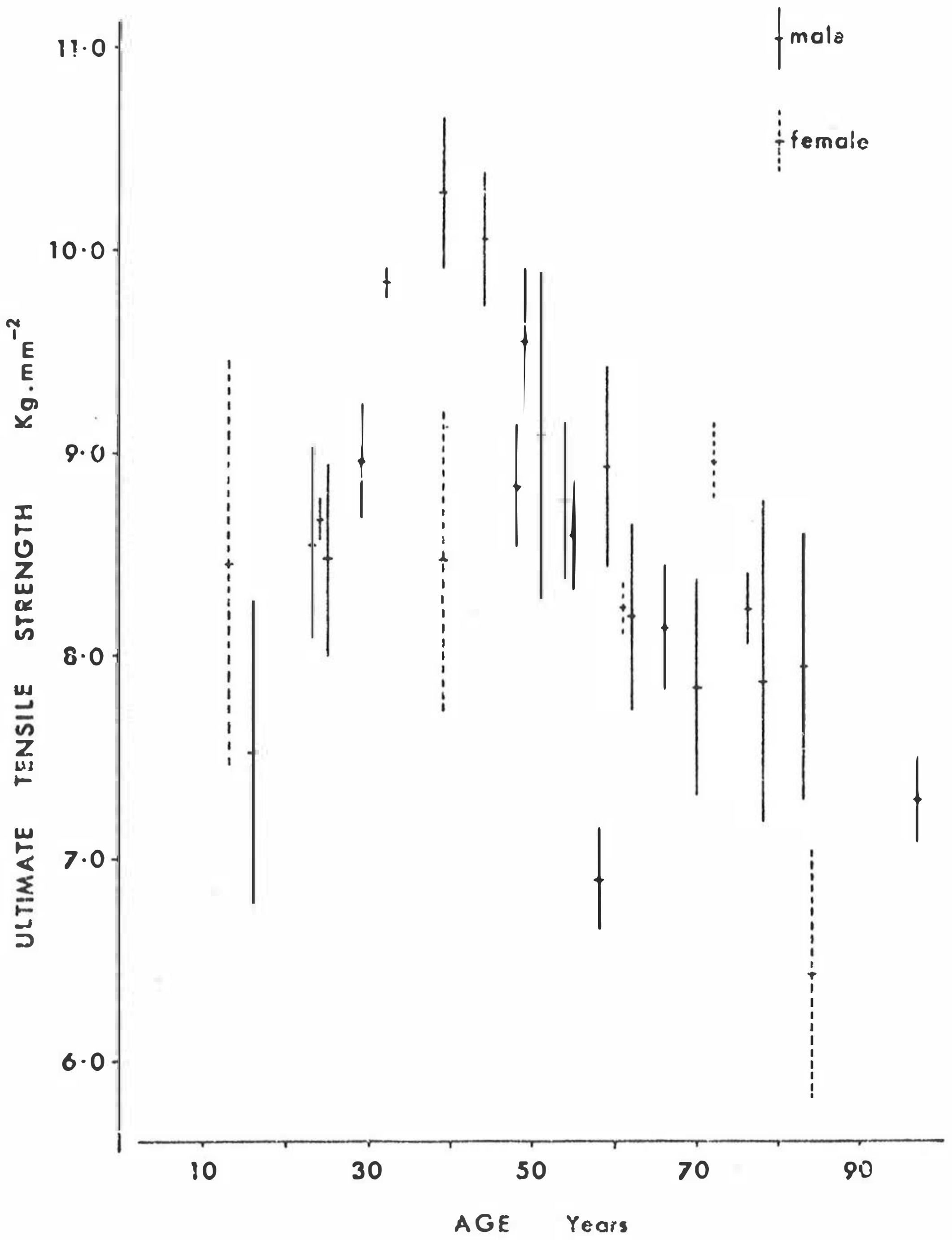
The situation does need clarification and for this reason we are continuing the work and concentrating our efforts on the younger age groups. However, material is difficult to obtain and the sizes involved make the present method of testing unsuitable. We are at present working on methods for obtaining the mechanical properties of small bone samples. These include miniaturising the tensile test procedure described above and a penetration type test.

It has already been stated that the earlier work was carried out at the comparatively slow extension rate of 1mm/min. Bone strength is known to vary with strain rate (PIEKARSKI 1968). It was suggested by CURREY (1959) that the rate of loading should be as high as possible, consistent with accurate reading; this he reasons is more likely to simulate the sequence of events which occurs when bone fractures in nature. We have decided therefore to study the effects of strain rate on the tensile properties of bone in the hope of predicting the values that can be expected when bone is fractured in vivo under trauma conditions.

Strips of bone were removed as previously described but this time from both the lateral and anterior quadrants. The study was limited to males from the 70-80 age group. The test pieces were fractures at rates varying from 3mm/min to 3,000 mm/min on a Mayes Universal Hydraulic testing machine. The latter rate is the maximum that can be achieved with this particular machine. Samples tested at this rate will fracture in about 20 milliseconds. At the slowest rate used samples are fractured in about 30 seconds.

The results obtained are shown in fig.3, in which the various mechanical properties tested plotted against the extension rate, the rate of extension being plotted on a logarithmic scale. From this graph it can be seen that the UTS does increase with increasing rate of extension in the range from 30 to 3,000 mm per min. The Elasticity and Percentage Elongation do not vary linearly with the log of extension rate. The Maximum Modulus of Elasticity appears at a rate of 300mm/min, which coincides with the minimum percentage elongation.

These preliminary results do indicate the importance of strain rate in the mechanical testing of bone and also the need for further work in this area. At present we are carrying out tests varying the extension rates from 10 to 3,000 mm/min. The tests are being done for bone samples from each decade age group. It is hoped that these results will be available for presentation at the conference where they will be discussed further.



male
female
11·0
10·0
9·0
8·0
7·0
6·0
ULTIMATE TENSILE STRENGTH Kg.mm^{-2}
10
30
50
70
90
AGE Years

FIG. 1.

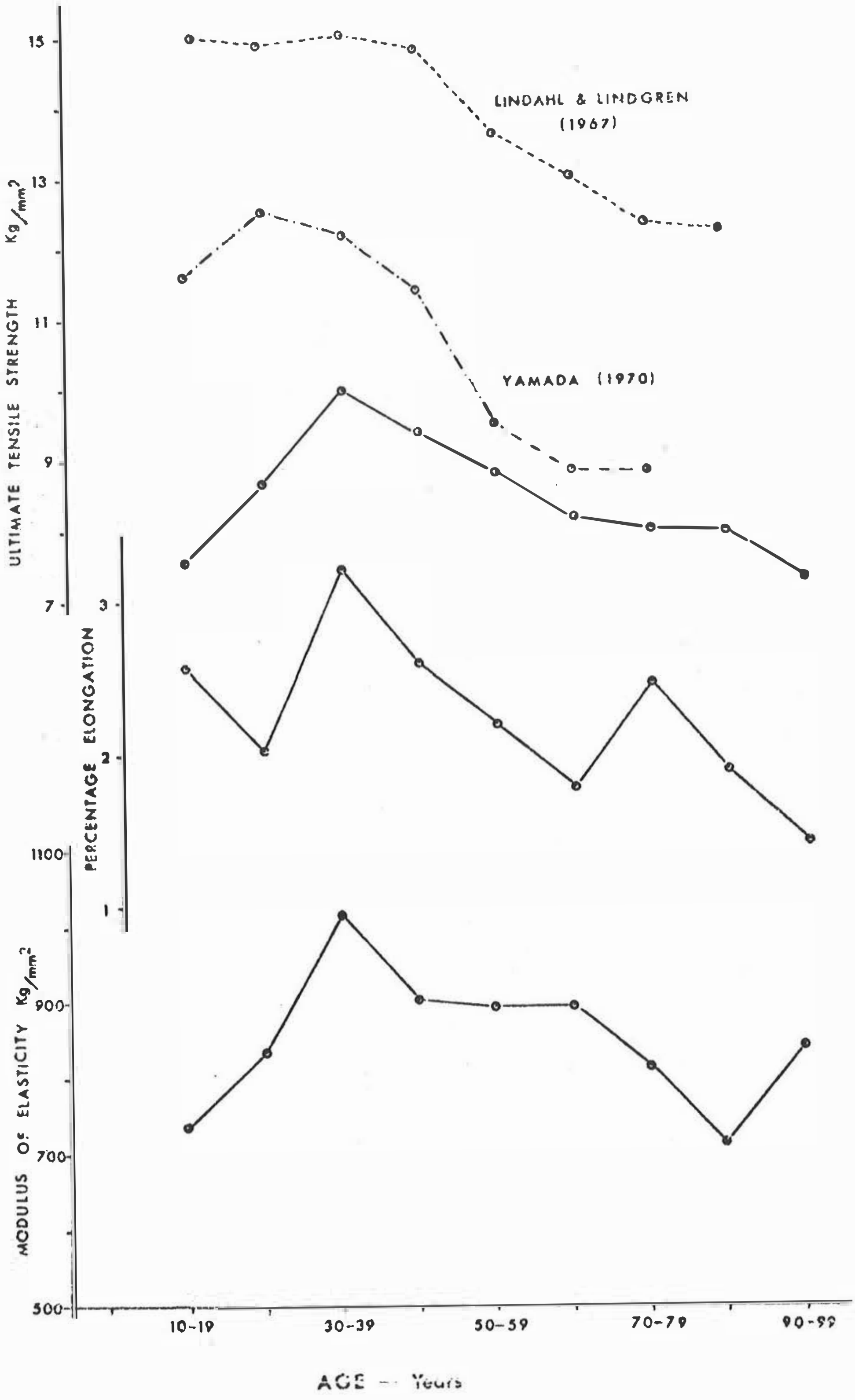

LINDAHL & LINDGREN (1967)
YAMADA (1970)
ULTIMATE TENSILE STRENGTH Kg/mm²
15
13
11
9
7
PERCENTAGE ELONGATION
3
2
1
MODULUS OF ELASTICITY Kg/mm²
1100
900
700
500
10-19
30-39
50-59
70-79
90-99
AGE — Years

FIG. 2.

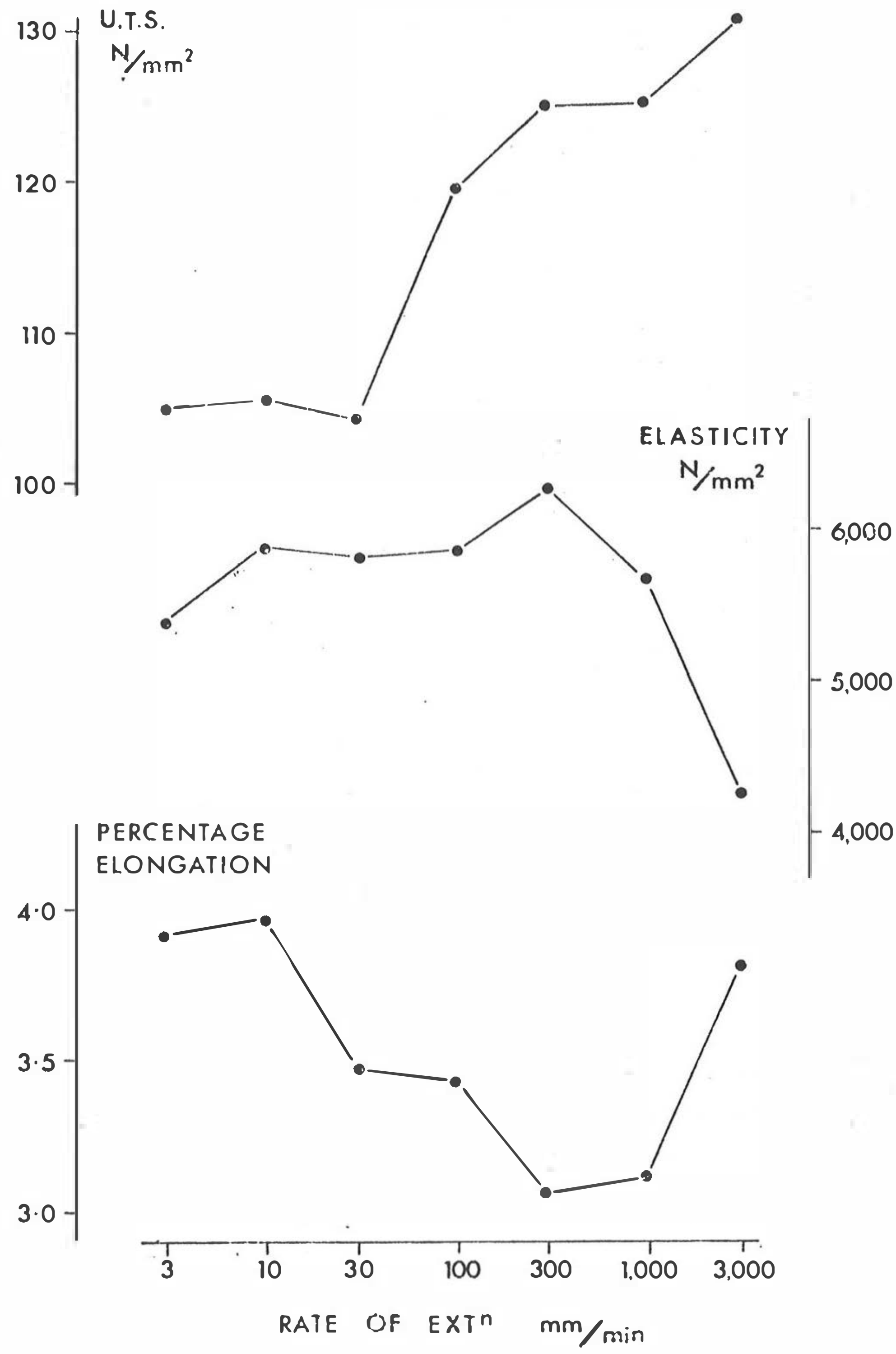

U.T.S.
N/mm²
130
120
110
100
ELASTICITY
N/mm²
6,000
5,000
4,000
PERCENTAGE
ELONGATION
4·0
3·5
3·0
3
10
30
100
300
1,000
3,000
RATE OF EXTⁿ mm/min

FIG. 3.

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