FROM THE ORTHOPEDIC DEPARTMENT OF THE UNIVERSITY OF UPPSALA, SWEDEN

METHODS OF STUDYING SOME MECHANICAL PROPERTIES OF BONE TISSUE

By

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PURPOSE OF THE INVESTIGATION

In the past the architectural structure of bone tissue has been discussed with regard to its mechanical value. Ward 1838, Humphrey 1888, Wolff 1869, Keith 1919, and recently Evans and Tobin have made important contributions.

The technological research of recent years has produced increasingly accurate methods of measuring the changes that occur when a material is exposed to mechanical load. We therefore decided to apply these methods to biologic tissue. In the present paper we shall report on the instruments and methods used to study deflection in bone exposed to loads. The neck of the human femur was the material chosen for the experiments.

When a bone, is subjected to increasing loads it will be deflected successively until the strain becomes so great that fracture occurs. We have attempted to observe the deformations of the surface of the bone that result from the application of loads until fracture occurs.

TECHNIQUE OF MEASUREMENTS

The following equipment is required for these measurements.

1) A loading apparatus providing a steadily increasing load which can be measured continuously.
2) A device that can be placed directly on the bone whose deflections are to be studied. This device must be able to reflect the reaction of the bone surface.

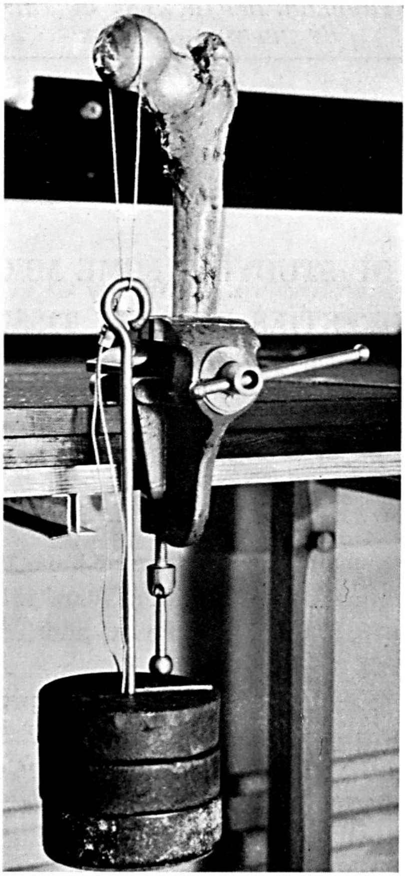


Fig. 1.
Arrangement for loading between 0 and 20 kg.

3) A system that permits either direct or relative numerical recording of the magnitude of the deflection.

LOADING APPARATUS

We used two types of loads, as follows: (1) The specimens were loaded directly with weights according to Figure 1. This however, did not permit the application of any great load. Under the experimental conditions illustrated in Figure 1, we applied loads up to 20 kg. (2) For heavier loads we used Amsler's hydraulic machine for testing materials (Fig. 2), which allows for loading up to 5,000 kg.

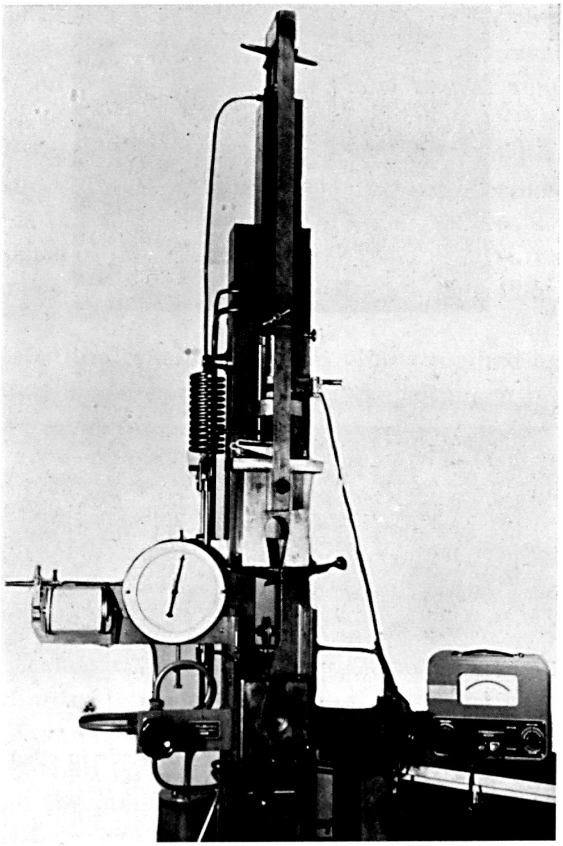


Fig. 2.
Amsler Compression Machine for loading between 0 and 5000 kg.

REGISTRATION OF THE MECHANICAL REACTION OF BONE

Several methods can be used for this purpose. A stress-coat technique has been described in earlier biologic studies, including a paper by Haboush in 1952. A displacement pick-up may also be used (Hirsch). Neither method is entirely reliable, and we therefore preferred to use strain-gauges.

The drawback of strain-gauges is the difficulty of attaching them to fresh bone specimens. We tried different gluing procedures, and since the methods we finally evolved proved practicable in serial experiments we would like to make a preliminary report.

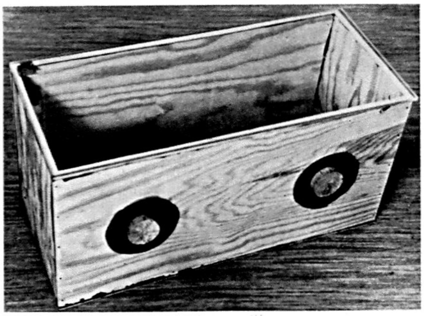


Fig. 3 a.

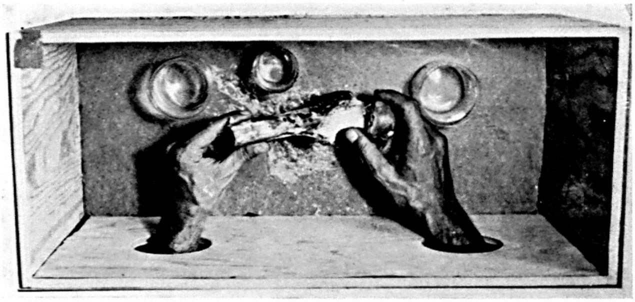


Fig. 3 b.

a) The glueing box; b) View of how the glueing is made in ether-atmosphere.

METHODS OF GLUING STRAIN-GAUGES TO FRESH BONE

It is essential that the entire strain-gauge be applied uniformly to the bone surface whose mechanical reaction is to be recorded. Since fresh bone is moist and covered by fatty substances, both moisture and fat must be removed without altering the physical qualities of the bone. In other words, moisture and fat must only be removed superficially, and from a very small area adequate to take a strain-gauge. If the gluing time can be restricted to a minute or two, during which the surface is kept dry while the strain-gauge is properly fixed in place, then there is little chance of harming the bone.

We constructed special equipment for our purpose (Figure 3). The specimen is denuded of soft tissue and placed in a small, hermetically sealed box, into which the operator can put his hands. The box has at least one glass wall through which the specimen is visible.

Ether vapor is blown into the box. A small area of the bone is then cleaned with ether on a brush. The surface of the cleaned specimen should be of sufficient size to accommodate the smallest type of strain-gauge (5 × 5 mm). We used Paste Collodion VF Bofors Sweden as glue. It is estersoluble and as long as it is kept in the ether atmosphere it remains fluid and can be applied to the specimen. As soon as the specimen is taken out of the box the glue hardens and the strain-gauge is attached to the bone without the latter suffering any appreciable damage. The whole gluing process only takes one or two minutes.

We have tested the reliability of this gluing method and found that the strain-gauge does not loosen even if the specimen is kept in refrigeration or at room temperature for one or two days, which of course is considerably longer than the time required for our experiments. By sectioning the specimen we confirmed that we had achieved firm contact in every part of the glued area.

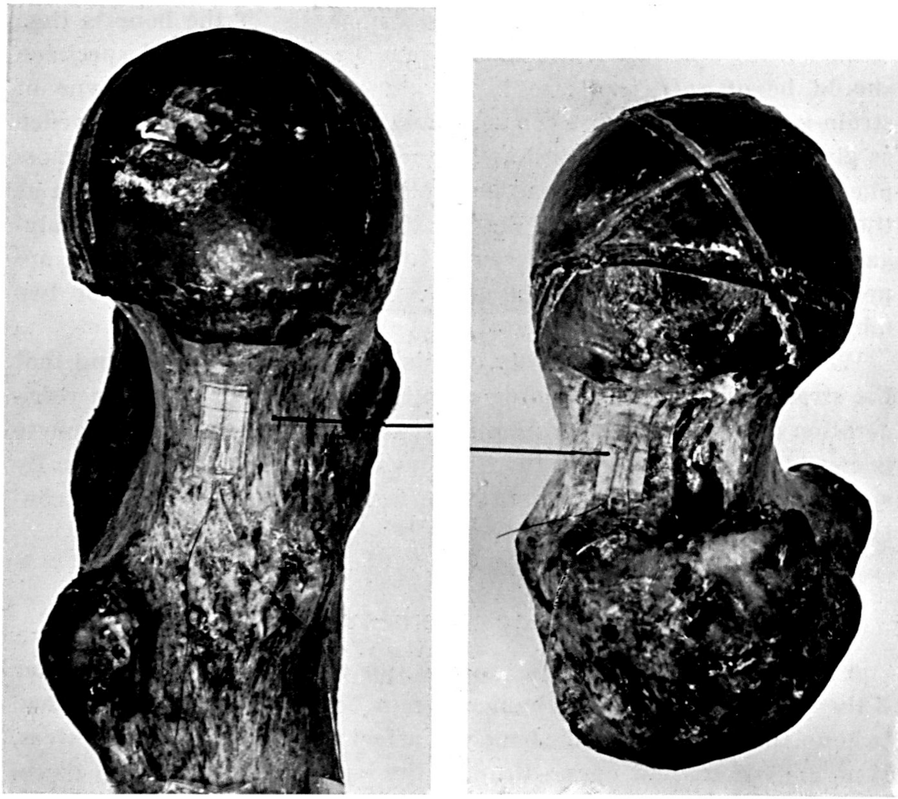
THE RECORDING SYSTEM

A strain-gauge consists of a series of fine wires, whose diameter alter if they are submitted to mechanical strain. Since the wires are attached to bone, the deflection of the bone will affect the dimension of the wires. If an electric current passes through the wires this current will therefore vary when the mould of the bone varies. In other words the deflection of the bone can be observed by the variations of the electric current. The strain-gauge must be connected with a meter, which will permit readings of the variations which succeed different loads applied to the bone specimen. The measuring instrument used is a direct reading measuring bridge (Philips No. G M 5536).

ERRORS IN THE TECHNIQUE

Stability of the electric system is required for measurements of this kind. We paid special attention to the following factors:

1. The room in which we worked was electrostatically shielded.
2. The temperature of the room was constant throughout the experiments.
3. The measuring instruments were checked and were electrically stable.
4. All cables were of fixed dimensions and of the same type.



a b

Fig. 4.

a) Strain-gauges placed on the under surface of the femoral neck; b) Strain gauges on the superior surface of the femoral neck.

5. Only one type of strain-gauge was used (Philips Type P.R. 9214–R 121.0–0.5. Gauge factor K: 1.88–1.5 per cent).
6. Fresh specimens only were used. Two similar pieces of bone were always taken, e.g. one from the right and one from the left femur of the same individual; one piece of bone served as a stabilizer, while the other was subjected to loading experiments.

THE EXPERIMENTS

We shall now report on the measurements made with the instruments described above.

The strain-gauge was applied to the neck of the femur according to

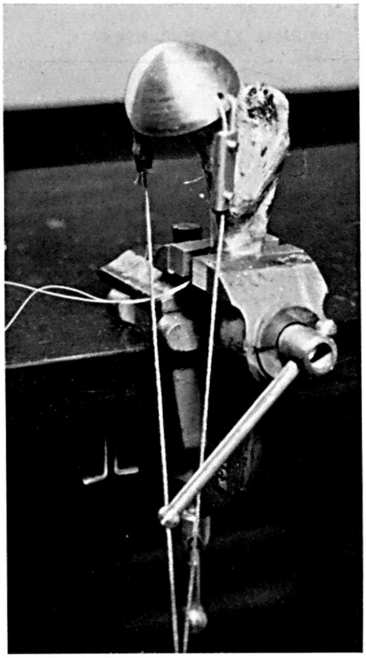


Fig. 5.

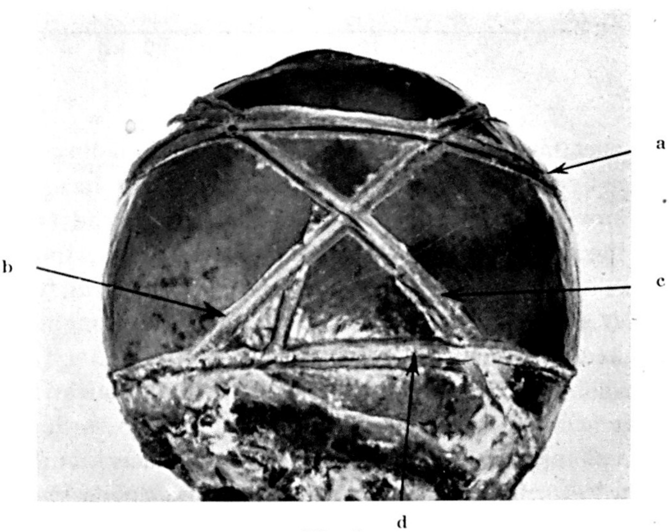


Fig. 6.

Lines made on the femoral head to allow different directions of loading.
a, b, c, d are according the diagram showed in fig. 8.

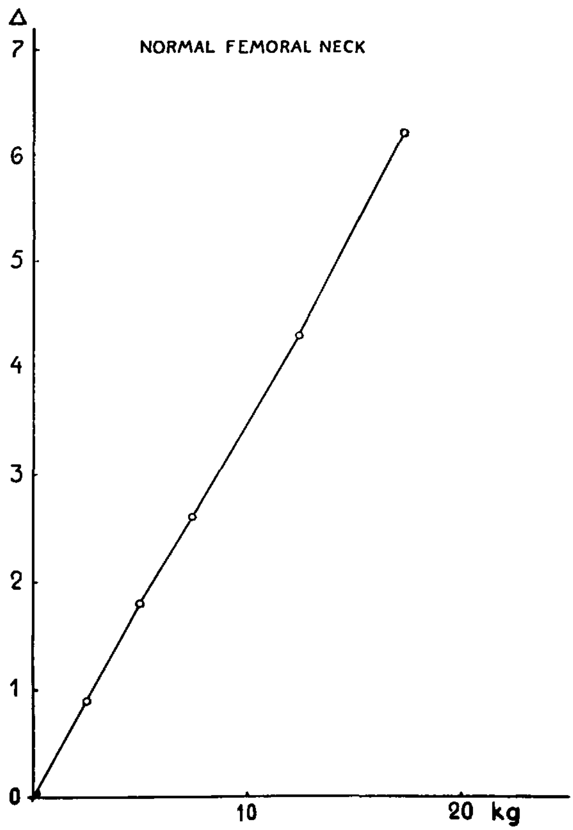


Fig. 7 a.

Fig. 4. The specimens were placed in a vice and loading forces were applied either by weights suspended from the femoral head on wires or via a metal bowl of the same shape as the femoral head (Fig. 5). The direction of the acting force was varied in different experimental series, either by having the wire cross the femoral head in different places (Fig. 6) or by changing the surface of contact of the metal bowl with the femoral head. The loads ranged from 2.5 to 20 kg.

When the head of the femur was exposed to pressure in a vertical direction, the neck of the femur was displaced downward. This movement led to a change on the surface of the femoral neck and the strain-gauge responded with a change in current, which was shown on the measuring bridge.

The diagram in Figure 7 a shows the values which we were able to read on the measuring bridge when loads of 2.5 to 17.5 kg were applied

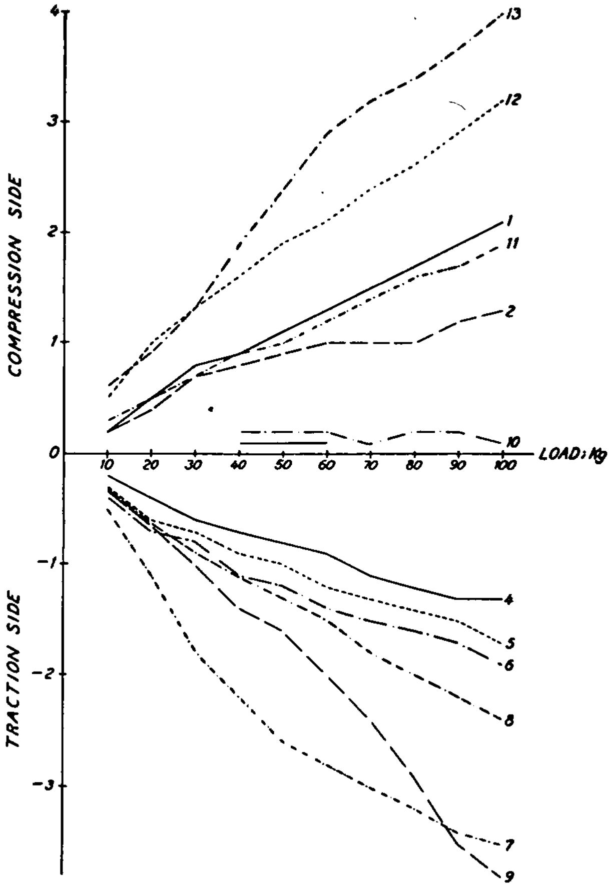


Fig. 7 b.
Measurements taken by strain-gauges, surrounding the femoral neck. The stress varies in different parts of a small vertical section.

to a certain area of the femoral head (sensitivity of the measuring bridge: 3/1000 mm.). The strain-gauge was placed on the under surface of the bone cortex, according to Fig. 4. Within the area tested, the relation between the deflection recorded and the load was a straight line in all our experiments. We have made over 300 diagrams, all of which show the same tendency.

In order to choose where to put the strain gauge a number of tests were made with strain gauges placed closed to each other round the neck. Fig. 7 b illustrates the various deflection curves obtained. The compression side is represented by the cortex inferior, the traction

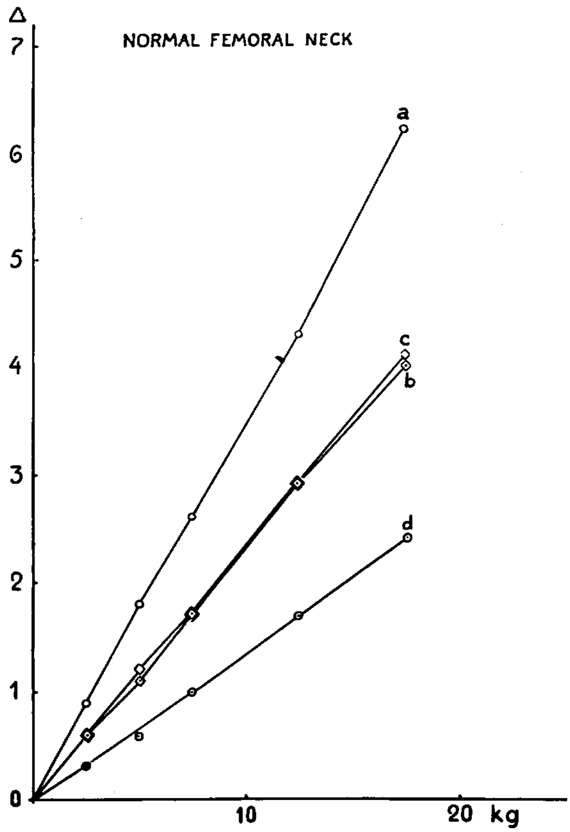


Fig. 8.

side by the upper cortex. In the following by the upper and the lower cortex are meant those places where the greatest deflection occurred.

The magnitude of the deflection on the measuring bridge also varied with the extent to which the direct load rested on different parts of the femoral head, owing to the variation of the moment. Fig. 8 illustrates a few diagrams obtained when the wire over the head was crossing in different directions. The longer the axis of the moment, the more the femoral head was displaced downward under the same load.

The experiments did not permit the real stress that developed in the femoral neck. Since the structure of the bone is heterogeneous, calibration for the type of loading in question is so far not practicable. We are therefore restricted to a relative evaluation. One and the same specimen with the same strain-gauge was loaded with increasing weights. The values so obtained were then compared with each other. In this

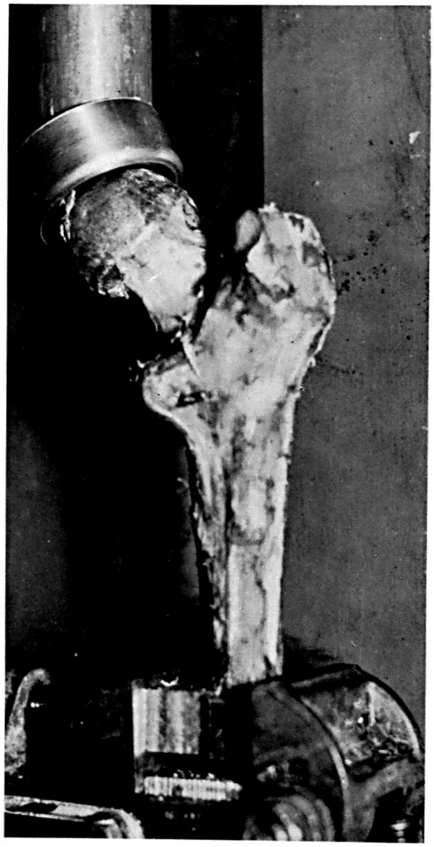


Fig. 9 b.

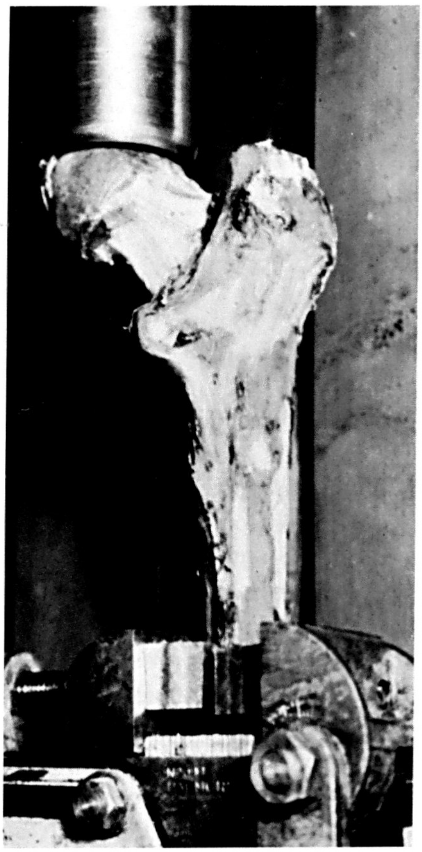


Fig. 9 a.

Specimen in the Amsler Compression Machine. a) perpendicular loading; b) oblique loading.

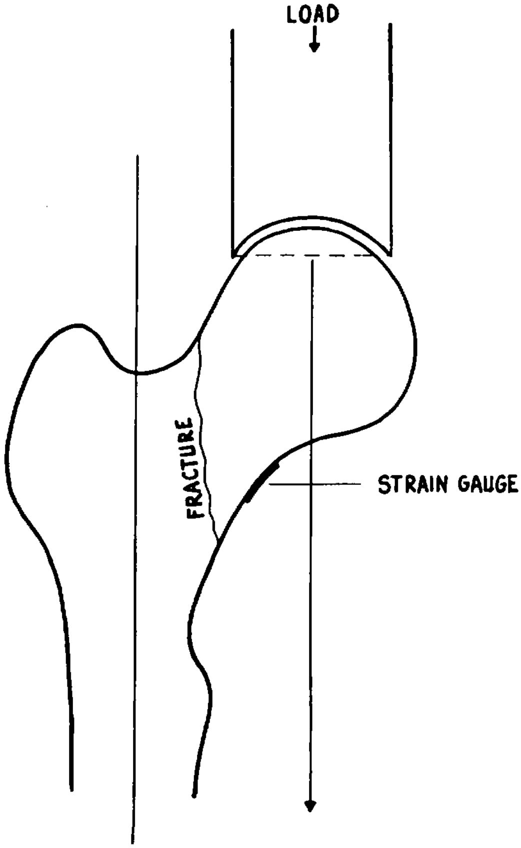


Fig. 10.
Drawing of a compression experiment.

way we arrived at a relative measurement of the weight-bearing capacity of a specific specimen, i.e. the ratio between load and deflection.

Femoral heads were loaded to the point of neck fracture in the Amsler machine (Fig. 9). The pressure was transmitted via a bowl applied to the femoral head. The contact between the bowl and the head could be varied, i.e. different parts of the head could be pressed down. The mounting in this machine is firm, resulting in considerable accuracy of the diagrams. A certain type of pressure on the femoral head invariably gave the same type of fracture of the neck.

If the direction of the load was parallel to the axis of the femoral shaft, the neck of the femur fractured as in Fig. 10. The diagram of the ratio between load and deflection in this type of experiment is

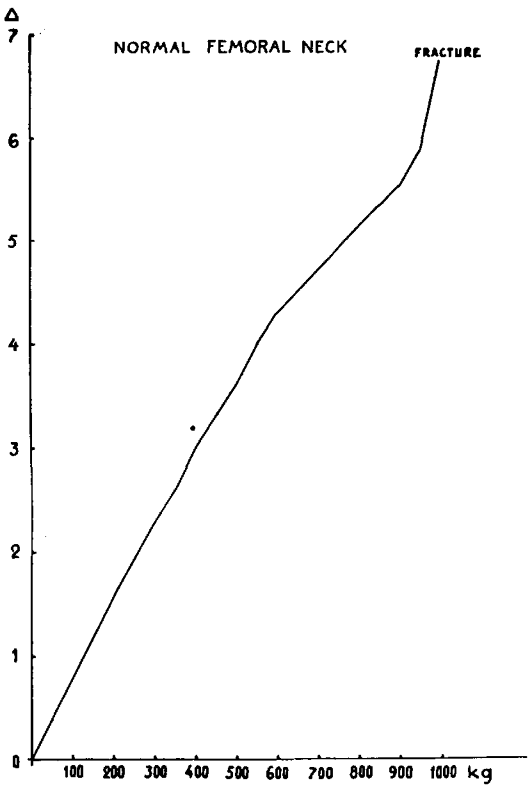


Fig. 11.

shown in Fig. 11. The curve is almost straight to the point of fracture. Fracture occurred at loads between 400 and 1100 kg. The angle between the neck and the shaft of the femur was of importance, varus showed lower resistance than valgus. The age and sex of the patient and the dimensions of the specimen were also highly significant factors. Elderly patients and, especially, females had a lower loading tolerance. Altogether 36 specimens have been studied hitherto.

SUMMARY

1. A technique is described by which some mechanical properties of bone tissue can be studied.
2. The method was applied to femoral necks.
3. Deflections of the femoral neck caused by increasing loads were recorded and diagrams are presented.

RESUME

1. Description d'une technique permettant d'étudier certaines propriétés mécaniques du tissu osseux.
2. La méthode a été appliquée à des cols fémoraux.
3. La déflexion du col fémoral causée par des poids progressivement plus lourds a été enregistrée et les diagrammes en sont présentés.

ZUSAMMENFASSUNG

1. Eine Technik mittels welcher gewisse mechanische Eigenschaften von Knochengewebe untersucht werden können, wird beschrieben.
2. Die Methode wurde an Oberschenkelhälsen verwendet.
3. Ablenkungen des Schenkelhalses, die unter zunehmender Belastung entstanden, wurden registriert und die Diagramme werden vorgelegt.

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