ORTHOPEDIC DEPARTMENT, UNIVERSITY OF UPPSALA, SWEDEN

THE WEIGHT-BEARING CAPACITY OF STRUCTURAL ELEMENTS IN FEMORAL NECKS

Second Report

By

CARL HIRSCH and ALFREDO BRODETTI

MATERIALS AND METHODS

The measuring technique was described in the first report. The material consisted of fresh autopsy specimens from both femurs in each patient (only the upper end of the femur). Altogether 36 specimens were examined. A strain gauge was glued to the upper and the lower surface of the femoral neck. The deflection curve was determined for each case (Fig. 1–a_1). Cancellous tissue was then removed, under roentgenologic supervision, from within the inferior layer of the femoral neck through a hole immediately below the greater trochanter. After once again having determined the deflection curve, the cancellous tissue in the upper layer of the femoral neck was removed through the same hole, and new measurements were made (Fig. 1–a_2). Finally we sawed through the upper layer of the compact tissue and made the last series of measurements (Fig. 2).

TECHNIQUE OF ANALYSIS

We refer to the various structural elements as follows: *Ss* = Spongiosa superior, superior cancellous tissue; *Si* = Spongiosa inferior, inferior cancellous tissue. *Cc* = Corticals superior, superior compact layer; *Ci* = Corticalis inferior, inferior compact tissue (Fig. 3).

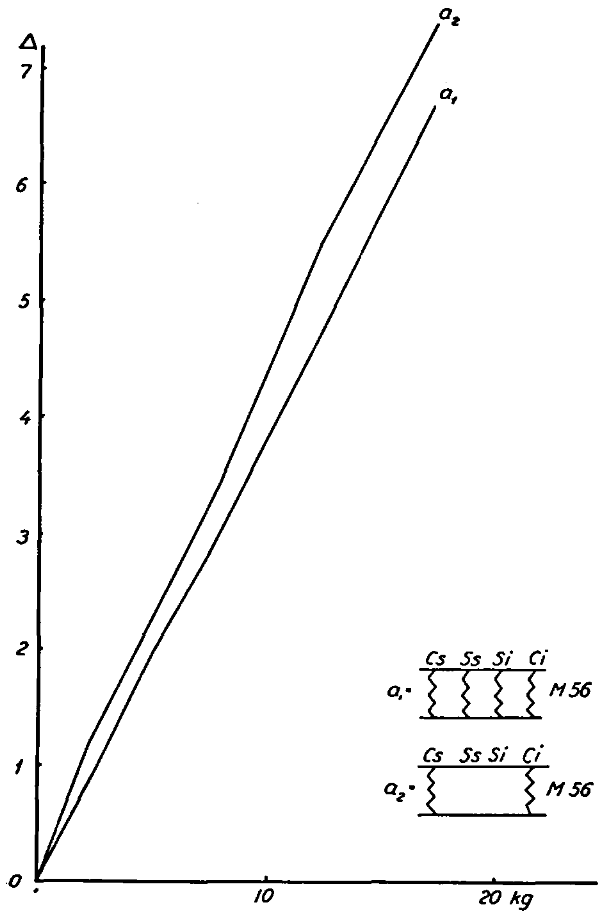


Fig. 1.

Graph to illustrate the deflection of the femoral neck when the femoral head is increasingly loaded employing a specimen containing all the structural elements, a_1 and when the trabecular system (the cancellous bone) is removed a_2.

The location and orientation of the strain gauge was the same in all experiments. Since a strain gauge only measures the strain present on the surface of the small area where it is attached the significance of the results obtained depends upon the proper positioning of the gauge. Stress analysis indicating the suitable attachment of the gauge was reported in the first paper.

Tests were made in order to avoid large concentrations of stress when parts of the cortex were removed. Stress concentration did not

Fig. 2.
Specimen prepared for testing. The upper part of the cortical layer is partly removed. The cancellous structural and the inferior cortical bone are left. At the cortex inferior a strain gauge is glued on to the bone.

seem to influence the results. Furthermore the measurements taken by strain-gauge and those obtained by fracturing the specimens gave approximately the same figures.

In the first report it was said that the relation between load and deflection on the whole ran a straight course. Consequently it could be assumed that the determinations would give the same percentile valuese regardless of the weights used in the loading experiments. We made our measurements with weights up to 20 Kg. We also took measurements at the level where the femoral neck *fractured*, i.e. with loads between 400 and 1000 Kg.

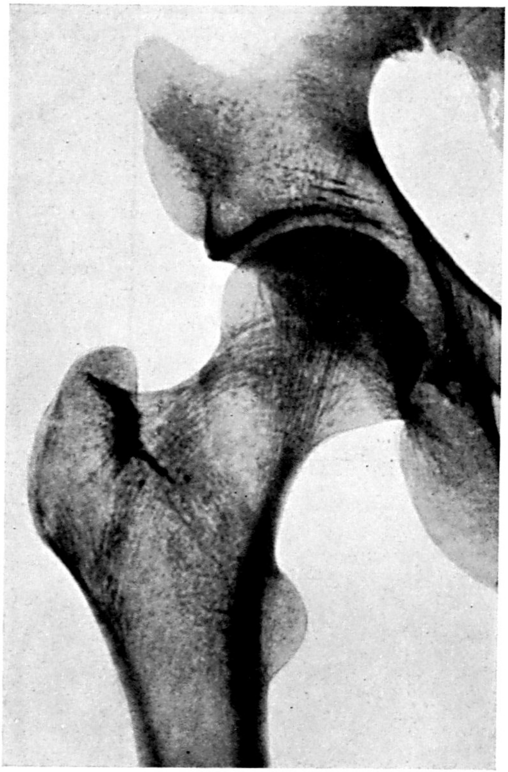


Fig. 3 a.
A normal X-ray picture showing the trabecular system.

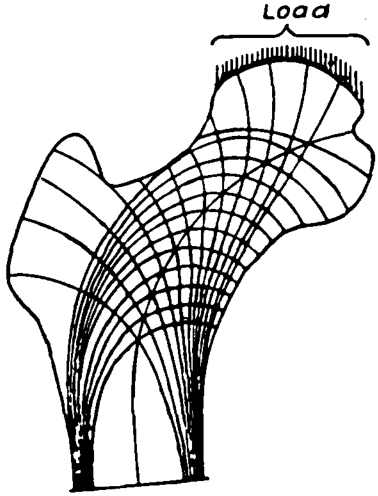


Fig. 3 b.
Many theoretical analyses have led to various explanations of the geometrical arrangements of the trabecular system. Attempts have also been made to find the lines of stress in the upper femur. This graph illustrates stress lines according to John C. Koch.

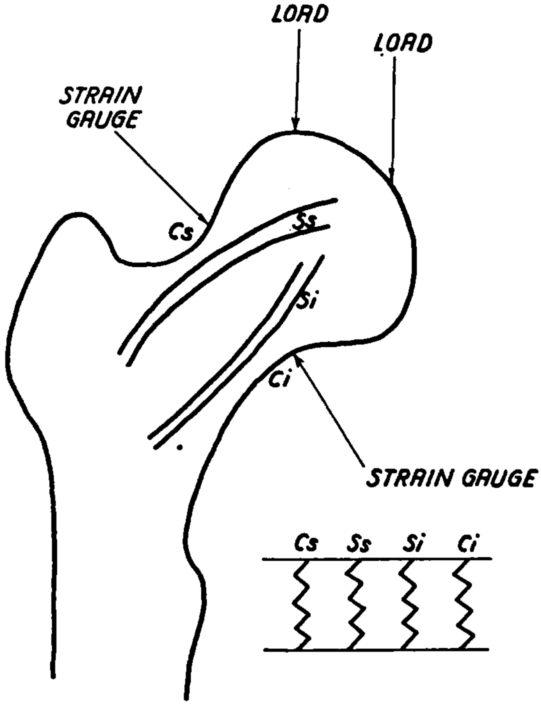
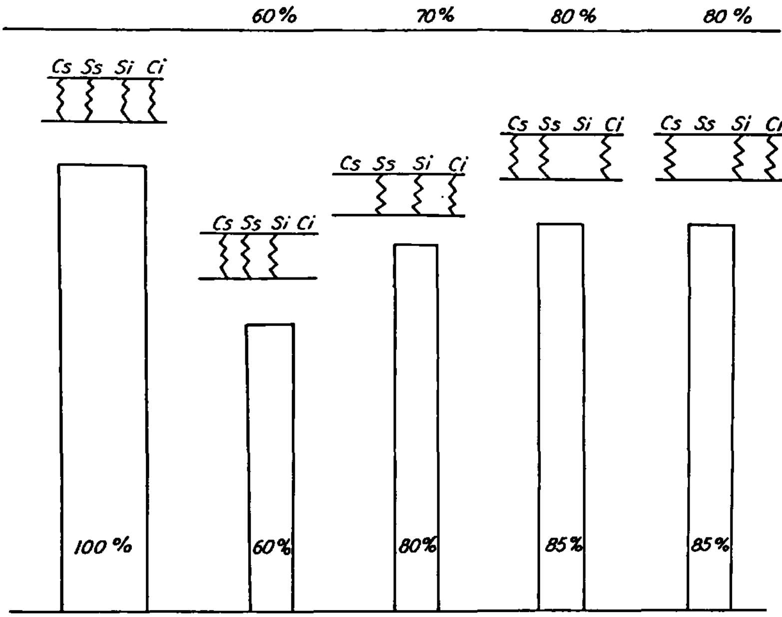


Fig. 3 c.
Author's system of dividing the structural elements in the upper femur.
Cs= corticalis superior
Ci= corticalis inferior
Ss= spongiosa superior
Si= spongiosa inferior

We determined from our diagrams the relation between deflection and load. We found out the magnitude of the load required to produce a specific deflection recorded on the measuring bridge. When the measurements were repeated after structural elements were removed, the load causing the same deflection as before was ascertained. This load we called the *weight-bearing capacity*. We further determined the magnitude of the load required to cause fracture of the neck of the specimen.

During the course of our experiments it was found that the right and the left hip joint from the same patient up to the age of 60 years reacted to compression in the same way. After the age of 60 the upper end of the femur frequently varied in its capacity to resist mechanical stress, and in these cases the right and the left femurs could not be

Measurements taken by Amsler compression apparatus.
Amount of load necessary for femoral neck fracture.
Load above 400 Kg.



Measurements taken by strain-gauge. Load below 20 kg.

Fig. 4.

When one of the structural elements in fig. 3 c is removed the bearing capacity decreases according to the diagram. The inferior cortex is the strongest part the bearing capacity of which is 40 %. The weakest part is represented by the cancellous tissue, by the trabeculae. Approximately the same condition is found with small loading and heavy loading.

Figures illustrate the remaining bearing capacity.

compared. As long as we worked with subjects under a certain age, the "normal curve" could be determined in one of the specimens up to the point of fracture, while the pre-fracture significance of the structural elements could be studied in the other specimen. We could then establish how much less stress was required before a specimen where some tissue had been removed would break.

Measurements taken by Amsler compression apparatus.
Amount of load necessary for femoral neck fracture.
Load above 400 Kg.

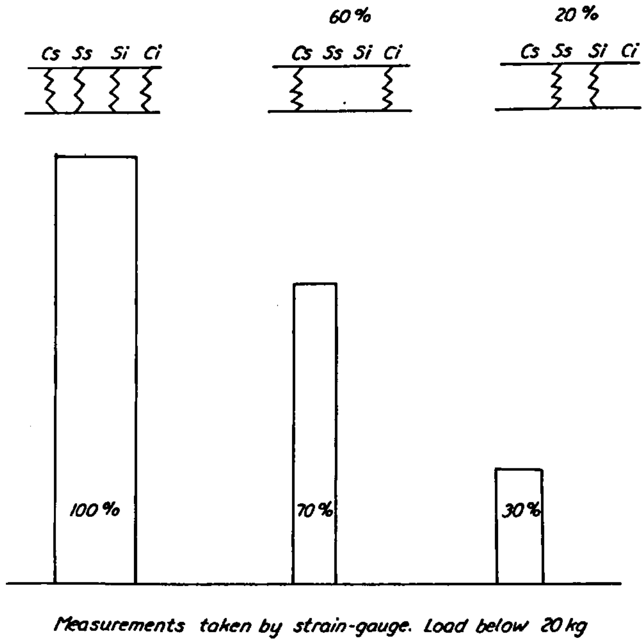


Fig. 5.

The cortical bone has a bearing capacity of 70 %, the cancellous tissue 30 %.

RESULTS OF MEASUREMENTS

Figure 4 reveals the decrease in bearing capacity following removal of one of the four structural elements. The greatest decrease, 40 %, occurred when *Ci* was eliminated, the least when either *Ss* or *Si* was put out of function. In the latter case the carrying power decreased by 15 per cent for each element. *Cs* was responsible for 20 %.

It is noteworthy that the loads producing fractures showed almost the same relative interrelationship.

Fig. 5 shows that if both *Ss* and *Si were* eliminated at the same time, the bearing capacity dropped to 70 per cent, i.e., these two elements together represented 30 per cent of the strength of the femoral neck.

If *C* and *S* were combined in accordance with figure 6 in such a way as to eliminate one compact and one cancellous area, the carrying power *and* the resistance to fracture decreased considerably.

Measurements taken by Amsler compression apparatus.
Amount of load necessary for femoral neck fracture.
Load above 400 Kg.

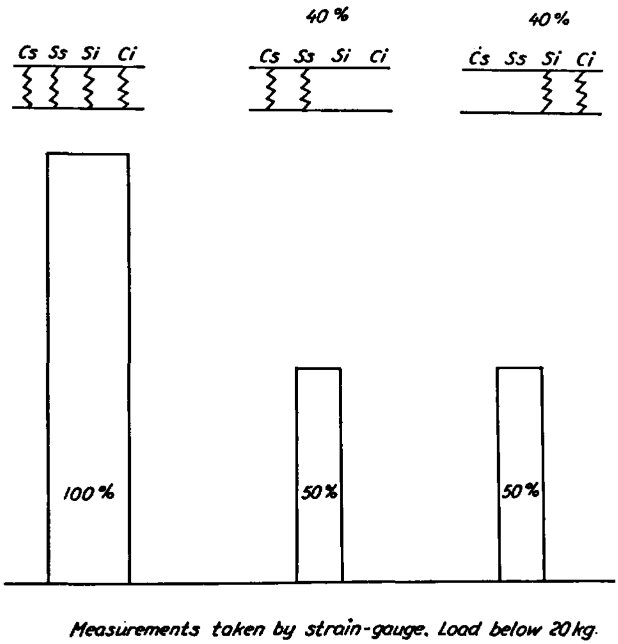


Fig. 6.

When one cortical and one cancellous layer are removed at the same time the weight-bearing capacity drops down to 50 %.

SUMMARY

1. Up to the age about 60 the resistance of the femoral neck to compression forces is the same on the left and the right side. After that age the mechanical resistance may decrease considerably on one side. This might be of clinical significance in the explanation of neck fractures.
2. The inferior cortical layer of the femoral neck has a weight-bearing capacity of 40 per cent in adults.
3. The superior cortical layer has a weight-bearing capacity of 20 per cent.
4. The superior and inferior cancellous tissue are of approximately equal value and each takes care of 15 per cent of the weight-bearing function.

5. If both cancellous layers are destroyed at the same time, the weight-bearing capacity is reduced by 30 per cent.
6. If the inferior compact layer and the inferior cancellous layer are eliminated or the superior cortical and trabecular system are removed, the weight-bearing capacity will be 50 per cent of normal.
7. The measurements sem to indicate that the trabecular tissue corresponds to a reinforcing system which helps to increase stability. It might be compared with çables in a bridge construction, the actual foundation of which is represented by the compact tissue.

RESUME

1. Jusqu'à près de 60 ans, la résistance du col fémoral aux forces de la compression est la même du côté gauche que du côté droit. Passé cet âge, la résistance mécanique peut diminuer considérablement d'un côté. Cela peut présenter une importance clinique pour l'explication des fractures du col.
2. La couche corticale inférieure du col fémoral a une capacité portative de 40 % chez les adultes.
3. La couche corticale supérieurs a une capacité portative de 20 %.
4. Les tissus cancellés supérieur et inférieur sont d'une valeur relativement égale et se chargent de 15 % de la fonction portative.
5. Si les deux couches cancellées sont détruites simultanément, la capacité portative est réduite de 30 %.
6. Si la couche compacte inférieure et la couche cancellée inférieure sont éliminées ou que le système cortical supérieur et trabéculaire soient enlevés, la capacité portative n'atteint plus que 50 % de la normale.
7. Ces données semblent indiquer que le tissu trabéculaire correspond à un système de renforcement qui contribue à l'accroissement de la stabilité. Il peut être comparé aux câbles de construction d'un pont dont les fondements seraient alors représentés par le tissu compact.

ZUSAMMENFASSUNG

1. Bis zum Alter von ungefähr 60 Jahren ist die Widerstandskraft des Oberschenkelhalses gegenüber Druckbelastung die gleiche auf der rechten und linken Seite. Im späteren Alter kann die mechanische Widerstandskraft auf einer Seite ganz wesentlich abnehmen. Dieser Umstand kann von klinischer Bedeutung für die Erklärung von Schenkelhalsbrüchen sein.

2. Die kaudale, kortikale Schichte des Schenkelhalses vermag 40 % des Gewichtes von Erwachsenen zu tragen.
3. Die kraniale, kortikale Schichte vermag 20 % zu tragen.
4. Die kraniale und kaudale Spongiosa sind von ungefähr gleichem Werte und vermögen ungefähr 15 % des Gewichtes auf sich zu nehmen.
5. Wenn beide Spongiosaschichten gleichzeitig zerstört werden, dann wird die Tragfähigkeit 30 % herabgesetzt.
6. Wenn die kaudale Compacta und die angrenzende Spongiosa oder die kraniale Corticalis und das trabekuläre System ausgeschaltet werden dann wird die Tragfähigkeit auf 50 % des Normalen herabgesetzt.
7. Diese Messungen scheinen darauf hinzuweisen, dass das trabekuläre Gewebe einem Verstärkungssystem entspricht, welches die Widerstandskraft erhöht. Es kann mit den Trossen einer Brückenkonstruktion verglichen werden, deren eigentlisches Fundament vom kompakten Gewebe dargestellt wird.