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AN EXPERIMENTAL STUDY ON THE USE OF NAILS AND BOLT SCREWS IN THE FIXATION OF FRACTURES OF THE FEMORAL NECK

By

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The great variety of nail and screw-like appliances that are now available for use in the fixation of fractures of the femoral neck indicate that confusion still exists when a choice is to be made of the most suitable internal splint to maintain the reduction of the fracture until the healing process is completed.

The literature on both the clinical and surgical aspects of this subject is large, but there are relatively few papers devoted to the experimental investigation of the effects of internal fixation in fractures of the femoral neck. The work of *Kotrnetz* (13) is the first in this field. His study was carried out in only ten femoral necks, which after division, were fixed with Smith-Petersen nails. *Lehman* (14) also using Smith-Petersen nails analysed the angle of inclination of the fracture line, and the wedging of the fragments in four specimens. Both these studies were rather unconclusive due to the small number of experiments on which they were based. Experimental studies were also reported on the Putti screw (3) and on the Compere pins (5). *Harmor, Baker & Reno* (9) published the first extensive investigation on the subject. They tested 12 different types of appliance in the fixation of fractures in 242 femoral necks. However, in their experiments the loading forces were applied to the femoral heads in such a way that the fracture surfaces were impacted rather than distracted.

In almost all the experiments reported in these papers the weight-bearing capacity (W.B.C.) of the particular metallic device used to obtain fixation of the specimens was stressed. In the present work emphasis has been shifted from the strength of the device to that of the

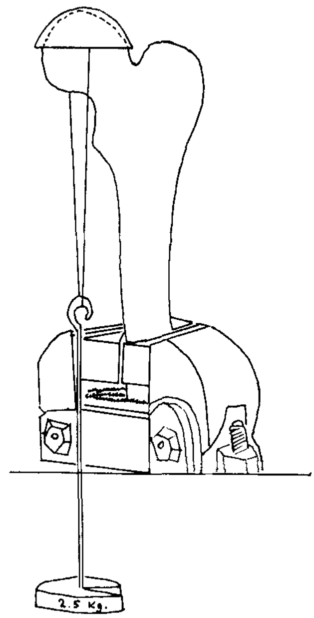


Fig. 1.
Loading arrangement used for the first series of experiments. Via a metal bowl, weights of 2.5 kg. each, to a maximum of 20 kg. were suspended from the femoral head.

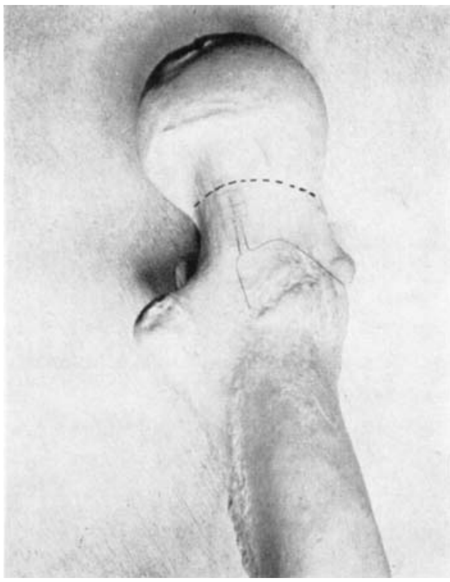


Fig. 2.
The strain-gauge applied on the medial aspect of the femoral neck. The dotted line indicates the location of the experimental "fracture".

experimental fracture in terms of its W.B.C. (i.e. the relation between deflection and load) when fixed with a given type of appliance.

While admitting that experimental techniques do not reproduce exactly the conditions of the living human, it was felt that some evidence could be presented in favour of the superiority of one or other of these devices in maintaining the reduction of experimental fractures of the femoral neck.

METHODS AND MATERIALS

The equipment used in the experiments (11) included the following:

1. A loading apparatus giving an increasing load which can be measured continuously. Weights of 2.5 kg. each, suspended from the femoral head via a metal bowl (Fig. 1), until a maximum of 20 kg. was reached, were used. An Amsler Hydraulic Machine was used for heavier loads. This machine is provided with a dial, the indicator of which

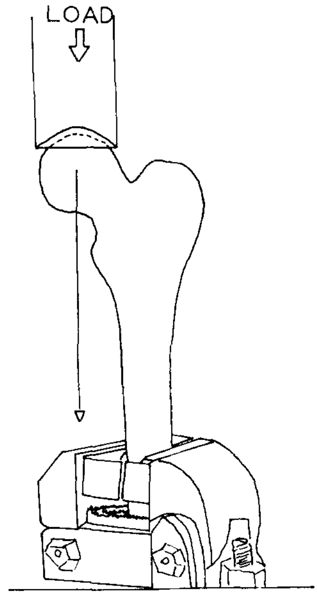


Fig. 3.
Loading arrangement for the second series of experiments, in which the Amsler Machine was used. The lower end of the specimen, firmly fixed in the vice, rests on a steel "tooth edged" surface to ensure a better grip.

moves clockwise giving the amount of progressive load being applied to the material under test. When the load applied reaches the point of breaking stress of the material the indicator stops its movement to return to zero, following the anti-clock-wise direction. A marker remains on the reached point.

2. Strain-gauges (Philips, Type P.R. 9214-R 121. 0–0.5. Gauge factor K: 1.88–1.5 %) applied on the medial aspect of the femoral neck, below the line of the experimental fracture (Fig. 2).

3. Direct Reading Measuring Bridges (Philips No. GM 5536) giving readings of the deflection caused by the increasing load on the specimen.

The specimens consisted of the upper third of the femur from which the surrounding soft tissue had been dissected away. The length of the femoral shaft, 25 cm. from the top of the great trochanter to the distal end, was kept constant. The distal end of the specimen during the tests, was placed in a specially adapted vice (Figs. 1 and 3) permitting a very firm fixation and accuracy to obtain the same position for each experiment. The specimens were radiographed before and after the experiments.

Vertical loading was used, with its direction parallel to the femoral shaft. This type of loading was chosen for the following reasons:

a. It is the easiest to reproduce experimentally and the experimental

TABLE I

Experimental details of the 22 specimens of the first series.

R. = Right. L. = Left. S.G. = Strain-gauges H.M. = Hydraulic Machine.

Case No.	Age	Sex	Side Type of appliance	Type of measurement	Site of the appliance Additional comments	W. B. C. in %
1/1	70	F	R. Nail	S.G.	Nail in valgus.	30 %
2/45	72	F	L. Nail	S.G.	"Fracture" reduced in valgus.	22 %
3/2	81	F	R. Nail	S.G.	"Fracture" reduced in valgus.	28 %
4/3	77	M	R. Nail	S.G.	Nail in the Neutral Zone.	24 %
5/3	77	M	L. Nail	S.G.	Nail in the Neutral Zone.	29.5 %
6/4	65	M	R. Nail	S.G.	Nail in the Neutral Zone.	23 %
7/5	78	M	L. Bolt screw	S.G.	Screw in the Neutral Zone.	39 %
8/7	66	M	R. Bolt screw	S.G.	Screw in the Neutral Zone.	41 %
9/8	81	F	R. Nail and Bolt screw	S.G. + H.M.	Specimen with severe osteoarthritic changes; tested with both a nail and a screw.	6 %
					1st Exp.: Nail fixation.	19 %
					2nd Exp.: Screw fixation.	
					This specimen is not included in the results.	
10/9	28	M	R. Bolt screw	S.G.	"Fracture" reduced in valgus.	38 %
11/9	28	M	L. Bolt screw	S.G.	Screw in valgus.	37 %
12/50	68	M	R. Nail	S.G.	"Fracture" reduced in valgus.	30 %

13/11	50	M	R. Bolt screw	S.G.	"Fracture" reduced in valgus by placing the screw slightly eccentric in the femoral head and exaggerating the tightness of the bolt.	36 %
14/11	50	M	L. Bolt screw	S.G.	The screw in the same position as specimen 13/11. No valgus deformity resulted for the tightness of the bolt was not extreme. This specimen is not included in the results.	34.5 %
15/12	82	F	R. Bolt screw	S.G.	Screw in the Neutral Zone.	44 %
16/12	82	F	L. Two bolt screws	S.G.	Three types of experiments:	
					A) The superior screw in varus only.	34 %
					B) Two screws: the superior in varus, the inferior in valgus.	40.5 %
					C) The inferior screw in valgus only.	37 %
17/13	79	F	R. Two bolt screws	S.G.	Same as the preceding specimen.	
					A)	33 %
					B)	42 %
					C)	36 %
18/13	79	F	L. Two bolt screws	S.G.	Same as the preceding specimen.	
					A)	31 %
					B)	39.5 %
					C)	36.5 %
19/53	73	M	R. Two bolt screws	S.G.	Three types of experiments:	
					A) The inferior screw in valgus only.	35 %
					B) Two screws: the superior in varus, the inferior in valgus.	40 %
					C) The superior screw in varus only.	34 %
20/14	33	M	L. Bolt screw	S.G.	Screw in the Neutral Zone. Increasing tightness of the bolt the W.B.C. values increase too.	A 47 % B 50 % C 52 %
21/15	69	F	R. Nail	S.G.	Nail in valgus.	33 %
22/15	69	F	L. Nail	S.G.	"Fracture" reduced in valgus.	29 %

TABLE II

Experimental details of the 48 specimens of the second series.

R. = Right. L. = Left. H.M. = Hydraulic Machine. S.G. = Strain-gauges.

Case No.	Age	Sex	Side Type of appliance	Type of measurement	Site of the appliance Additional comments	W. B. C. in %
23/16	54	F	R.	H.M.	Breaking point: 800 kg.	
24/16	54	F	L. Nail	H.M.	Nail in the Neutral Zone. "Fracture" discontinued at 265 kg.	33 %
25/17	77	F	R.	H.M.	Breaking point: 880 kg.	
26/17	77	F	L. Bolt screw	H.M.	Screw in the Neutral Zone. "Fracture" discontinued at 385 kg.	43.5 %
27/18	68	F	R.	H.M.	Breaking point: 710 kg.	
28/18	68	F	L. Nail	H.M.	"Fracture" reduced in valgus, discontinued at 190 kg.	26.5 %
29/19	73	M	R.	H.M.	Breaking point: 1000 kg.	
30/19	73	M	L. Bolt screw	H.M.	Screw in valgus. "Fracture" discontinued at 365 kg.	36.5 %
31/20	66	F	R.	H.M.	Breaking point: 920 kg.	
32/20	66	F	L. Bolt screw	H.M.	Screw in valgus. "Fracture" discontinued at 350 kg.	38 %
33/20	70	F	R.	H.M. + S.G.	Breaking point: 370 kg.	
34/22	70	F	L. Bolt screw	H.M. + S.G.	Screw in the Neutral Zone. "Fracture" discontinued at 170 kg.	46 %
35/23	71	F	R.	H.M.	Breaking point: 680 kg.	
36/23	71	F	L. Nail	H.M.	Nail in the Neutral Zone. "Fracture" discontinued at 165 kg.	24 %
37/24	83	F	R.	H.M.	Breaking point: 710 kg.	
38/24	83	F	L. Bolt screw	H.M.	Screw in the Neutral Zone. "Fracture" discontinued at 365 kg.	51 %
39/25	71	F	R.	H.M.	Breaking point: 870 kg.	
40/25	71	F	L. Bolt screw	H.M.	Screw in the Neutral Zone. "Fracture" discontinued at 380 kg.	44 %
41/26	76	F	R.	H.M. + S.G.	Breaking point: 630 kg.	
42/26	76	F	L. Nail	H.M. + S.G.	Nail in the Neutral Zone. "Fracture" discontinued at 215 kg.	34 %

43/27	70	M	R.	H.M.	Breaking point: 850 kg.	
44/27	70	M	L. Bolt screw	H.M.	Screw in varus. "Fracture" discontinued at 305 kg.	36 %
45/28	72	F	R.	H.M.	Breaking point: 720 kg.	
46/28	72	F	L. Bolt screw	H.M.	Screw in varus. "Fracture" discontinued at 225 kg.	31 %
47/29	79	F	R.	H.M. + S.G.	Breaking point: 880 kg.	
48/29	79	F	L. Nail	H.M. + S.G.	Nail in valgus. "Fracture" discontinued at 285 kg.	32.5 %
49/30	76	F	R.	H.M.	Breaking point: 920 kg.	
50/30	76	F	L. Nail	H.M.	Nail in valgus. "Fracture" discontinued at 285 kg.	31 %
51/31	73	M	R.	H.M.	Breaking point: 800 kg.	
52/31	73	M	L. Nail	H.M.	Nail in valgus. "Fracture" discontinued at 210 kg.	26 %
53/32	71	F	R.	H.M. + S.G.	Breaking point: 680 kg.	
54/32	71	F	L. Bolt screw	H.M. + S.G.	Screw in varus. "Fracture" discontinued at 215 kg.	31.5 %
55/33	80	F	R.	H.M. + S.G.	Breaking point: 910 kg.	
56/33	80	F	L. Nail	H.M. + S.G.	Nail in varus. "Fracture" discontinued at 210 kg.	23 %
57/34	68	M	R.	H.M.	Breaking point: 470 kg.	
58/34	68	M	L. Bolt screw	H.M.	Screw in varus. "Fracture" discontinued at 160 kg.	34 %
59/35	62	F	R.	H.M.	Breaking point: 780 kg.	
60/35	62	F	L. Nail	H.M.	Nail in varus. "Fracture" discontinued at 195 kg.	25 %
61/36	70	F	R.	H.M.	Breaking point: 690 kg.	
62/36	70	F	L. Bolt screw	H.M.	"Fracture" reduced in valgus, discontinued at 255 kg.	37 %
63/37	69	M	R.	H.M. + S.G.	Breaking point: 840 kg.	
64/37	69	M	L. Bolt screw	H.M. + S.G.	"Fracture" reduced in valgus, discontinued at 295 kg.	35 %
65/38	59	M	R.	H.M. + S.G.	Breaking point: 950 kg.	
66/38	59	M	L. Nail	H.M. + S.G.	"Fracture" reduced in valgus, discontinued at 295 kg.	32 %
67/39	69	F	R.	H.M.	Breaking point: 580 kg.	
68/39	69	F	L. Bolt screw	H.M.	"Fracture" reduced in valgus, discontinued at 225 kg.	39 %
69/59	66	F	R.	H.M. + S.G.	Breaking point: 675 kg.	
70/59	66	F	L. Bolt screw	H.M. + S.G.	Screw in valgus. "Fracture" discontinued at 250 kg.	37 %

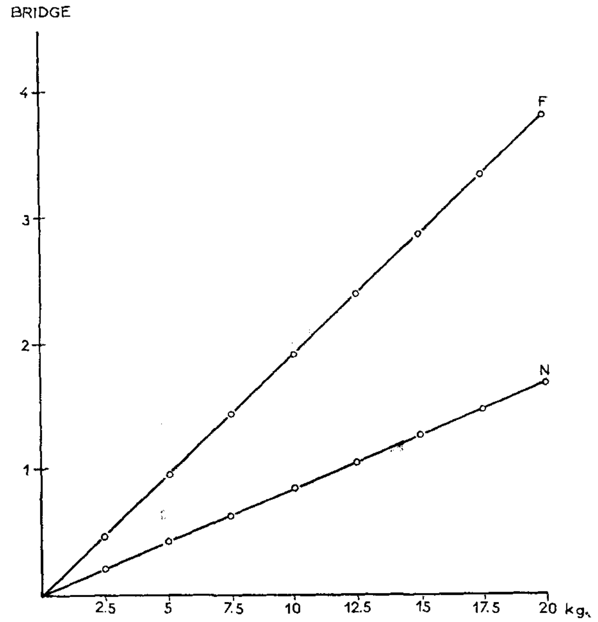


Fig. 4.
W.B.C. diagram of specimen 15/12, recorded by means of a straingauge. N = the normal W.B.C. of the specimen. F = the W.B.C. of the specimen "fractured" and fixed with a screw. F is 44 % of N.

type of loading most similar to living conditions. The individual standing on both legs, with the help of the "locking" of the knees, of the hips and of the lumbar spine joints, requires little muscle power to maintain his balance (2). And so, using a vertical loading the complex and important role played by the muscles in the mechanics of the hip joint is partially reduced.

b. Vertical loading through the calcar femoralis is transmitted to the medial cortical bone of the femoral neck (2, 12, 15) thus permitting better detection, by means of strain gauges, of the magnitude of deformation occurring.

For the purpose of comparison in this study, experimental "fractures" were produced with a hand saw (throughout this paper "fracture" refers to the artificial division of the femoral neck). Subcapital "fractures" with a direction perpendicular to the axis of the femoral neck were obtained. A radiographic control assured that they were identical. Moreover, variations of the cervical angle of the femoral neck were taken into consideration and the limits were set within 124° and 131°.

Specimens that at the radiographic control were found above or below the limit were eliminated.

Fresh specimens removed at autopsy were used. The results obtained in 70 specimens will be reported here. Those used for testing the experimental arrangements, or eliminated because they did not meet the experimental requirements, are not considered.

The 70 femora were obtained from 40 cadavera. Of these, 25 were females and 15 malees. Their ages ranged from 28 to 83 years, the average being 70 years.

Two types of experiments were undertaken:

1. The normal W.B.C. of a group of 22 specimens (Table I), loaded between 2.5 and 20 kg., was recorded by means of strain gauges (Fig. 4, N). These femoral necks were then "fractured" as described above. The fragments of the head and neck were aligned and fixed with either a nail (10 cases) or a bolt screw (13 cases)[1]. The specimens then were again subjected to loading with the same technique used for the first test. Deflections were recorded (Fig. 4, F) and the values from this second test were expressed as a percentage of the normal W.B.C. derived from the first experiment.

2. In a second group of 48 specimens (Table II), the 24 right femoral necks were submitted to vertical loading in the hydraulic machine until fracture occurred. In Fig. 5 is shown the curve of deflection of a normal femoral neck, recorded througt strain gauges applied on its medial aspect. This specimen was subjected to vertical loading in the hydraulic machine until fracture occurred at 950 kg. This amount of laod indicated by the arrest of the marker on the dial of the Amsler Machine is the point of breaking stress, which corresponds to the W.B.C. of this femoral neck. On this basis, the figures obtained at the breaking point of the right sided specimeens were assumed as the normal W.B.C. for the particular pair of femoral necks under investigation.

The 24 left sided femoral necks were prepared with a "fracture" fixed with one or other of the devices under consideration (10 nails and 14 bolt screws). These were then tested in the hydraulic machine, the load being increased until discontinuity of the "fracture" occurred. By discontinuity here is meant the end point of the test given by the arrest of the marker of the dial of the Amsler Machine (Fig. 5). The amount of load required to discontinue the "fractures" of the left sided specimens was recorded as the W.B.C. of the fixed "fractured" femoral neck.

[1] Specimen 9/8 was tested with both the nail and the bolt screw.

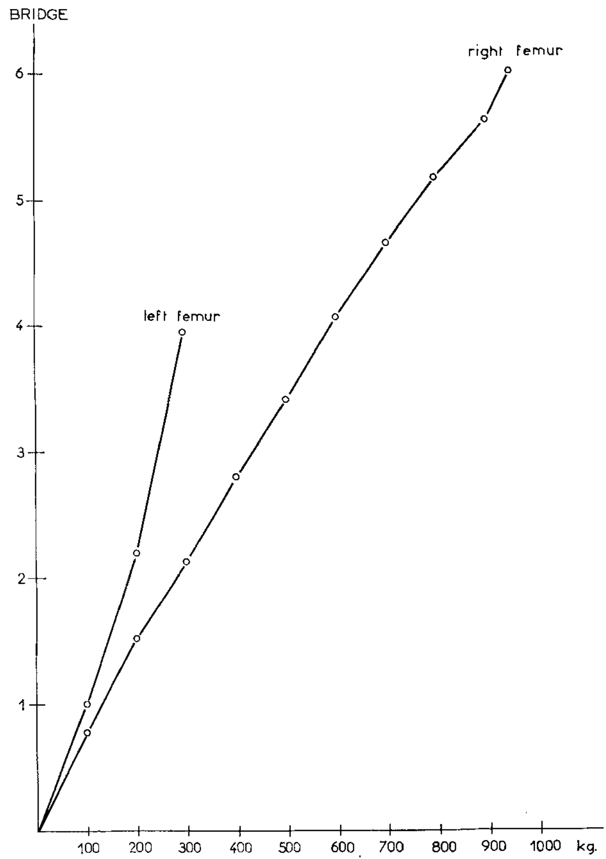


Fig. 5.

W.B.C. diagrams of specimens 65/38 and 66/38, recorded by strain-gauges. The right femur (65/38) was loaded under the hydraulic machine until fracture occurred at 950 kg. This amount of load was assumed as the normal W.B.C. of this pair of femoral necks. The left femur was "fractured" and fixed with a nail. Loaded under the hydraulic machine, the "fracture" was discontinued at 295 kg. This amount of load representing the W.B.C. of the "fractured" and fixed femur, is 32 % of the normal W.B.C.

These values were then estimated as to percentage of the normal W.B.C. of the right femoral neck.

According to Hooke's law the relation between deflection (strain) and load (stress) on the whole ran a straight line (11, 2). Therefore the determinations would give the same percentage values regardless of the weights used in loading the specimens. In Chart 1 is shown that

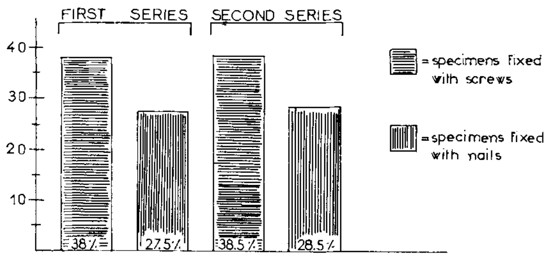


Chart 1.
The comparison between the average W.B.C. values obtained by means of strain-gauges in the first series of experiments (11 specimens fixed with bolt screws, 9 with nails) and the average W.B.C. values obtained in the second series of experiments (14 specimens fixed with bolt screws, 10 with nails) using the hydraulic machine.

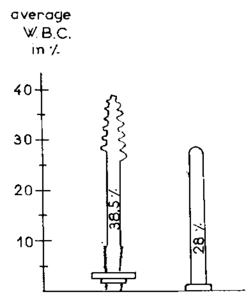
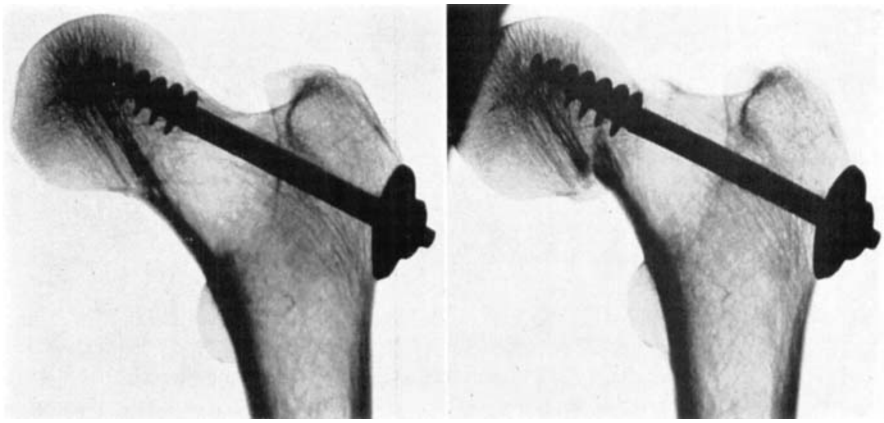


Chart 2.
The comparison between the average W.B.C. of 25 "fractured" femoral necks fixed with bolt screws and the average W.B.C. of 19 "fractured" femoral necks, fixed with nails.

Chart 3.
The differences among the average W.B.C. values according to the various positions of the appliances and to the reduction of the "fractures". From left to right: varus position, valgus, appliance in the neutral zone, "fractures" reduced and fixed in valgus.



a b

Fig. 6.

Specimen 58/34. Breaking point of the right femur at 470 kg. Bolt screw in varus in the left femur (a). "Fracture" discontinued at 160 kg. (b). W.B.C. 34 %.

the average values obtained by means of strain gauges in the first series of experiments and those obtained by loading the specimens in the hydraulic machine in the second series are approximately the same. Moreover, in some of the experiments of the second series strain gauges were used too (Table II).

25 specimens were tested with a bolt screw and 19 with a nail. These were placed in different positions and sites in the specimens; viz. in varus, valgus and along the centre of the neck and femoral head. This last position is referred to as the "neutral zone" of the femoral neck and its significance will be discussed later. In addition, a group of the "fractures" were reduced and fixed in valgus.

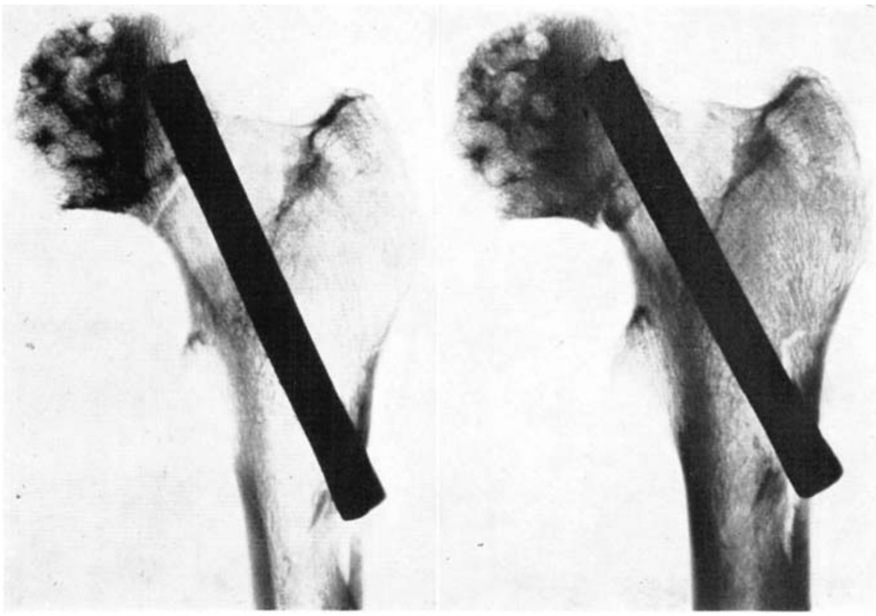
On specimens 9/8, 16/12, 17/13, 18/13, 19/53, 20/14 of the first series of experiments, more than one test was conducted. However, one test only was considered in the results, the test performed first.

Specimens 9/8 and 13/11 (Table I) being only indicative were not included in any of the groups of the results.

RESULTS

The average W.B.C. for the 25 "fractures" fixed with bolt screws was 38.5 %, with a maximum value of 51 % and a minimum value of 31 %.

The average W.B.C. for the 19 "fractures" fixed with nails was 28 % (maximum value 34 %, minimum value 22 %). (Chart 2).



a b

Fig. 7.

Specimen 50/30. Breaking point of the right femur at 920 kg. Nail in valgus (a). "Fracture" discontinued (b) at 285 kg. W.B.C. 31 %. In this specimen the obliquity of the nail results in an eccentricity of its medial end, thus lowering the holding power.

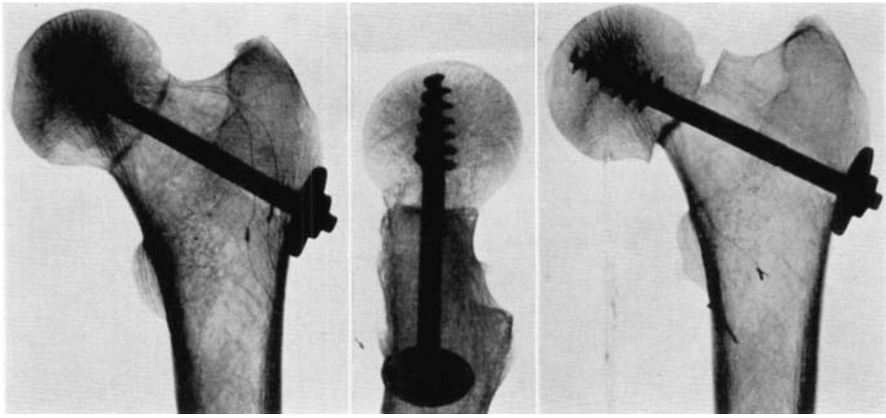
The following results are grouped according to the different positions in which the fixing devices were placed in the specimens (Chart 3). The identifying number of the specimens reported for each group corresponds to Tables I and II.

VARUS

In this group the appliance was placed in a varus position. 7 specimens (16/12A, 17/13A, 18/13A, 44/27, 46/28, 54/32, 58/34) were fixed with bolt screws (Fig. 6). 2 specimens (56/33, 60/35) were fixed with nails. The average W.B.C. was 31 %. Maximum value 36 %, minimum value 23 %.

VALGUS

Five specimens (11/9, 19/53A, 28/19, 30/20, 70/59) were fixed with bolt screws and 5 specimens (1/1, 21/15, 48/29, 50/30, 52/31) were fixed



a b c

Fig. 8.
Specimen 34/33. Breaking point of the right femur at 370 kg. Bolt-screw in the neutral zone (a and b). "Fracture" discontinued at 170 kg. (c). W.B.C. 46 %.

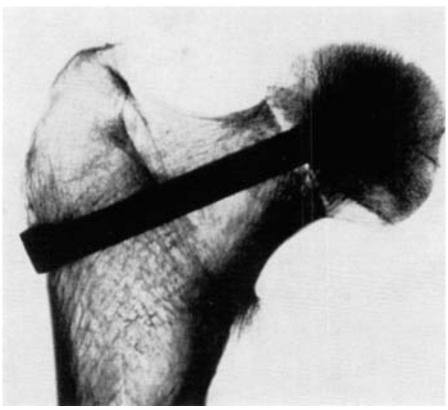


Fig. 9.
Specimen 5/3, tested with a strain-gauge. Nail in the neutral zone. W.B.C. 29.5 %.

with nails (Fig. 7). The appliances were placed in contact with the inferior cortex of the femoral neck. The average W.B.C. was 33.5 %. Maximum value 38 %, minimum value 26 %.

NEUTRAL ZONE

Eight specimens (7/5, 8/7, 15/12, 20/14A, 26/17, 34/22, 38/24, 40/25) were fixed with bolt screws (Fig. 8). Six specimens (4/3, 5/3, 6/4, 23/16, 36/23, 42/26) were fixed with nails (Fig. 9). The average W.B.C. of the group was 37.5 %. Maximum value 51 %, minimum value 22 %.

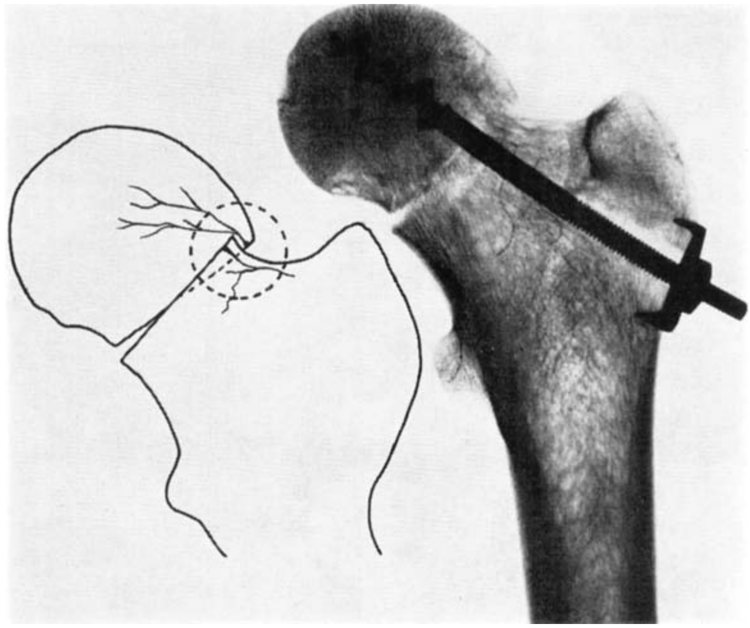


Fig. 10.
Specimen 64/37. "Fracture" of the left femur reduced in valgus. Breaking point of the right femur at 840 kg. "Fracture" discontinued at 295 kg. W.B.C. 32 %. The drawing shows how the reduction in valgus and the impaction can interfere with the lateral epiphyseal vessels.

"FRACTURES" REDUCED AND FIXED IN A VALGUS POSITION

Five specimens (10/9, 13/11, 62/36, 64/37, 68/39) were fixed with bolt screws (Figs. 10 and 11). Six specimens (2/45, 12/50, 3/2, 22/15, 28/18, 66/38) were fixed with nails. The average W.B.C. was 32 %. Maximum value 38 %, minimum value 22 %.

DISCUSSION

The average W.B.C. of the "fractures" fixed with bolt screws (38.5 %) compared with that of those fixed with nails (28 %) leaves little doubt that the bolt screw is mechanically more efficient in fixing and holding these "fractures" reduced under the conditions of the experiments. These values, however, are only a comparison between the two devices, and do not consider the position occupied by them.

The tests conducted on specimen 9/8 (Table I) give a further de-

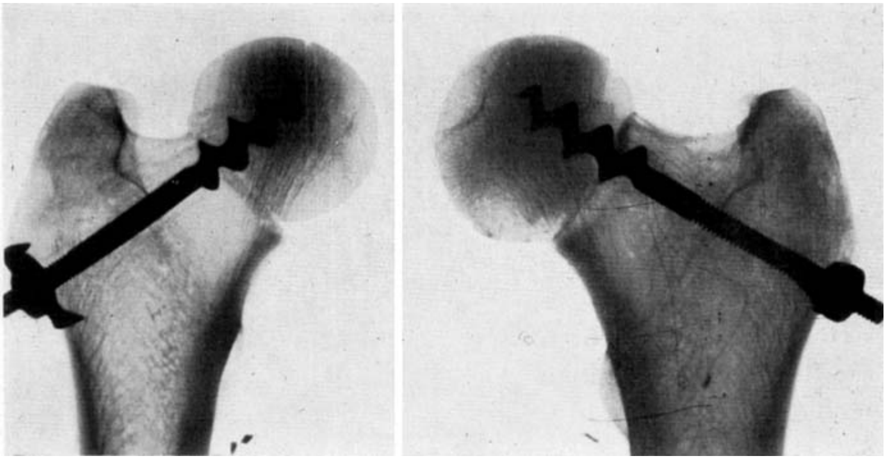


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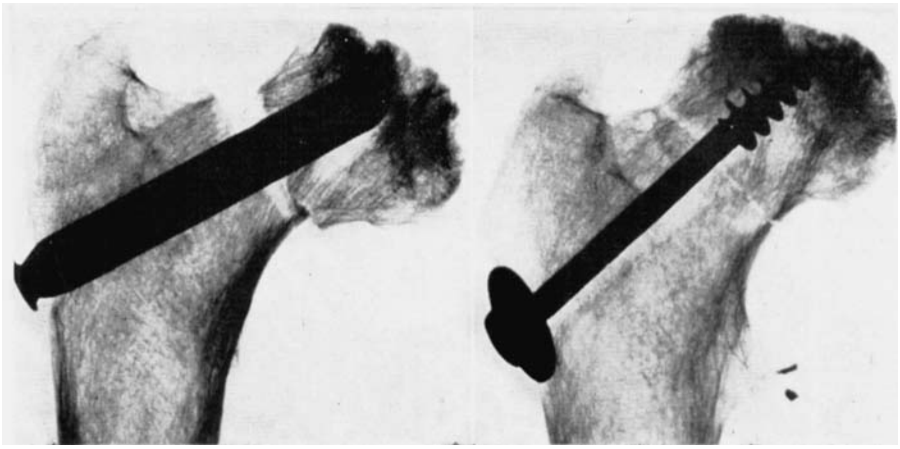
Fig. 11.

In (a) specimen 13/11, tested with a strain gauge. The reduction in valgus of the "fracture" was obtained by exaggerating the tightness of the bolt with the screw placed slightly eccentric in the head. W.B.C. 36 %. In (b) specimen 14/11. The screw in the same position as in specimen 13/11. No valgus reduction resulted, for the tightness of the bolt was not extreme.

monstration of the better experimental W.B.C. of a "fractured" femoral neck fixed with a bolt screw. The specimen, with severe osteoarthritic changes, was preleved from the cadavera of an 81 year old female. According to the technique described for the first series of experiments the normal W.B.C. was recorded. Then a "fracture" was produced and was fixed with a nail. The specimen was loaded again and 12.5 kg. were sufficient to discontinue the "fracture" as shown in Fig. 12 a. The W.B.C. of the nailed "fracture" was 6 %. After removing the nail, a bolt screw was replaced to fix the "fracture". The specimen remained connected to the measuring bridge through the strain gauges, was reloaded under the hydraulic machine, in order to tave a possibility of higher loading. This time discontinuity of the "fracture" (Fig. 12 b) occurred at 85 kg. and the W.B.C. deduced from the diagram was 19 %. These two W.B.C. values are the lowest of all, and the severity of the osteoarthritic changes are responsible for this considerable difference.

When either the nails or the bolt screws were inserted in a varus position, the resultant average W.B.C. (31 %) of the fixed "fractures" was among the lowest. At any rate, this value is higher than one would expect considering that this is an unsound position from a mechanical



a b

Fig. 12.

Case 9/8. Right femur with severe osteoarthritis. The "fracture" was firstly fixed with a nail (a) and a strain-gauge was applied. Discontinuity occurred at 12.5 kg. W.B.C. 6 %. The nail was replaced by a bolt screw (b) and the specimen, still connected through the strain-gauge to a measuring bridge, was loaded under the hydraulic machine. Discontinuity of the fracture occurred at 85 kg. W.B.C. 19 %.

point of view. Very likely, the high average W.B.C. obtained was due to the fact that more bolt screws (7 specimens) than nails (2 specimens) were used. Therefore, the average value obtained in this group may indicate trends, but is not statistically significant. Besides the mechanical disadvantage, a device entering the femoral neck and head in varus is very likely to damage the important lateral epiphyseal vessels (4, 17). This would increase, in the living, the risk of aseptic necrosis of the femoral head.

The results obtained when the fixative devices were inserted in a valgus position confirmed the findings of *Compere, Wallace & Lee* (5). These authors compared the differences in the fixation of fractures when wires were inserted parallel to the axis of the neck of the femur on one side and in a very oblique direction on the other side. On the average, they found that the wires inserted parallel to the neck axis would resist a load of 338.2 kg. but only 205 kg. if they had been inserted obliquely, that is in a valgus position.

If a device is inserted into femoral neck in a valgus position, the tip may well fail to meet the femoral head's central point. This has been shown to be its hardest point (8, 18), (Fig. 15 b). Should the tip of the

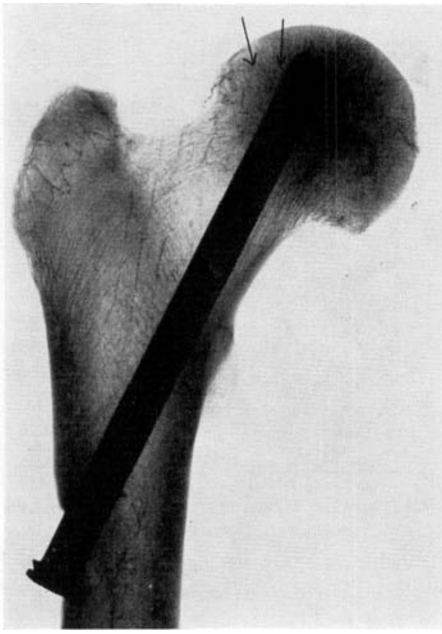


Fig. 13.
Injected specimen showing how the tip of the valgus appliance ends in the area of femoral head occupied by the lateral epiphyseal vessels (arrows).

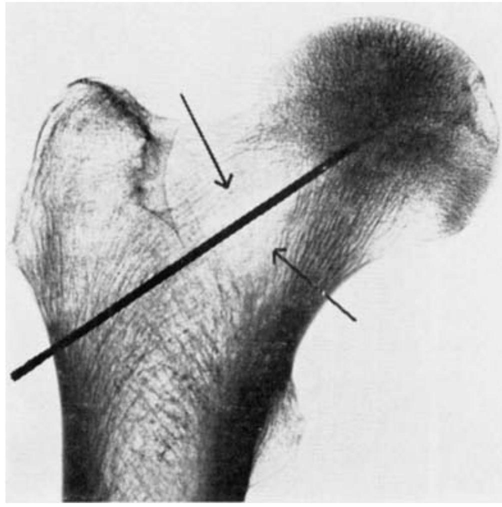
device enter the periphery of the sphere of the head it is in a bad position for the following reasons:

1. It can no longer prevent eccentric rotation of the head fragment.
2. The holding power of the bone at the periphery of the femoral head is low.
3. The lateral epiphyseal vessels are likely to be damaged (Fig. 13).
4. An appliance taking a very oblique course, because of the normal anteversion of the femoral neck will be prone to be posterior in the neck, thus damaging one of the main supporting systems arising from the calcar femoralis (10).

The best figure for W.B.C. (37.5 %) was obtained with the appliance in the neutral zone. This corresponds to the median of the Ward's triangle (Fig. 14), between the two trabecular arches which are the internal weight bearing system of the femoral neck.

In an intact femoral neck under vertical load, these two trabecular systems provide the 30 % of the W.B.C. of the whole femoral neck (12). If the reduction of the "fracture" is anatomical, the weight bearing system of the femoral neck is restored almost in its entirety. A fixative device inserted in the neutral zone, well anchored in the strong centre

Fig. 14.
The Ward's triangle, limited by the internal weight-bearing system (arrows) of the femoral neck. Its median corresponds to the neutral zone, which is the weak point to be reinforced by an appliance when a fracture occurs.



of the head and on the subtrochanteric cortical bone, adds some strength reinforcing a natural weak point. Moreover, it does not destroy either of the two trabecular systems, neither are important vascular channels in the central zone of the femoral neck and head (4) (Fig. 15).

There seemed to be no advantage in reducing the "fracture" in valgus position and fixing it there. The W.B.C. of fixed "fractures" was found to be low (33.5 %) under these conditions. The reduction in valgus of the "fracture" in specimen 13/11 (Fig. 11 a) was obtained by placing the screw eccentric in the head and tightening the bolt more than necessary. This resulted in rotation of the head fragment. An anatomical reduction was obtained in specimen 14/11 (Fig. 11 b) although the screw was placed in the identical position as in specimen 13/11, because the tightness of the bolt was not exaggerated.

Excessive tightness of the bolt does not produce any damage when the screw is placed in the neutral zone, but increases the W.B.C. as shown in case 20/14 (Table I). This specimen was tested many times and each time the tightness of the bolt was previously augmented. The result was an increase of the W.B.C. up to a point at which the fixation reached a stabilization and no further increase was obtained.

It is beyond the purpose of this paper to apply to the living bone conclusions obtained from specimens, but a theoretical discussion of certain important biological considerations may be of interest.

Thise considerations all stand against the possible advantages of fixing fractures in valgus position. First of all, not only from a me-

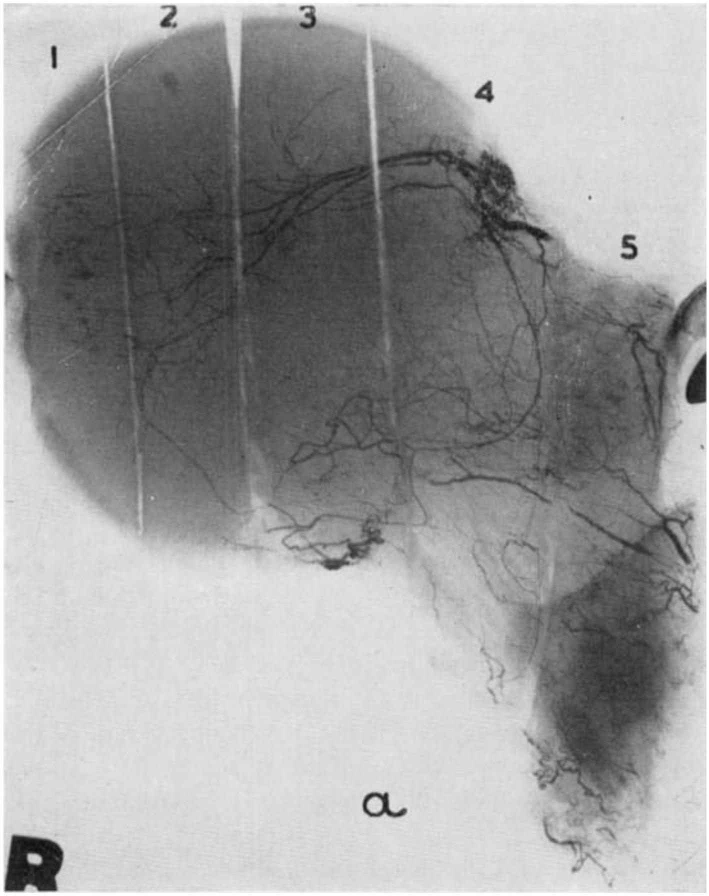


Fig. 15.

In (a) decalcified left femoral head of subject aged 68, after vascular injection with barium, divided into slab sections. Section 4 includes the point of entry of the lateral ep:physeal vessels (uppart part) and section 3 that of the inferior metaphyseal vessels (lower part). Two parallel rows demonstrate the sections of the femoral head and neck in succession from 1 to 5, prior to decalcification (b) and after decalcification (c). The trabecular arrangement can be followed in (b): in section 3 b, corresponding to the centre of the femoral head, the trabecular concentration is greatest. Medially (sect:ons 2 b and 1 b) and laterally (sections 4 b and 5 b) the number of trabeculae decreases. The vascular pattern can be followed in (c): starting from the femoral neck (section 5 c) it can be seen that the pattern is peripheral. The only artery met by a central appliance is the superior metaphyseal artery, which in section 4 c crosses the bone longitudinally. Note the r:ch anastomoses at the periphery of the section. Section 3 c shows the lateral epiphyseal vessels (above) and the inferior metaphyseal vessels. No important vascular formation occupies the centre of the section. The rich network of the anastomoses between the

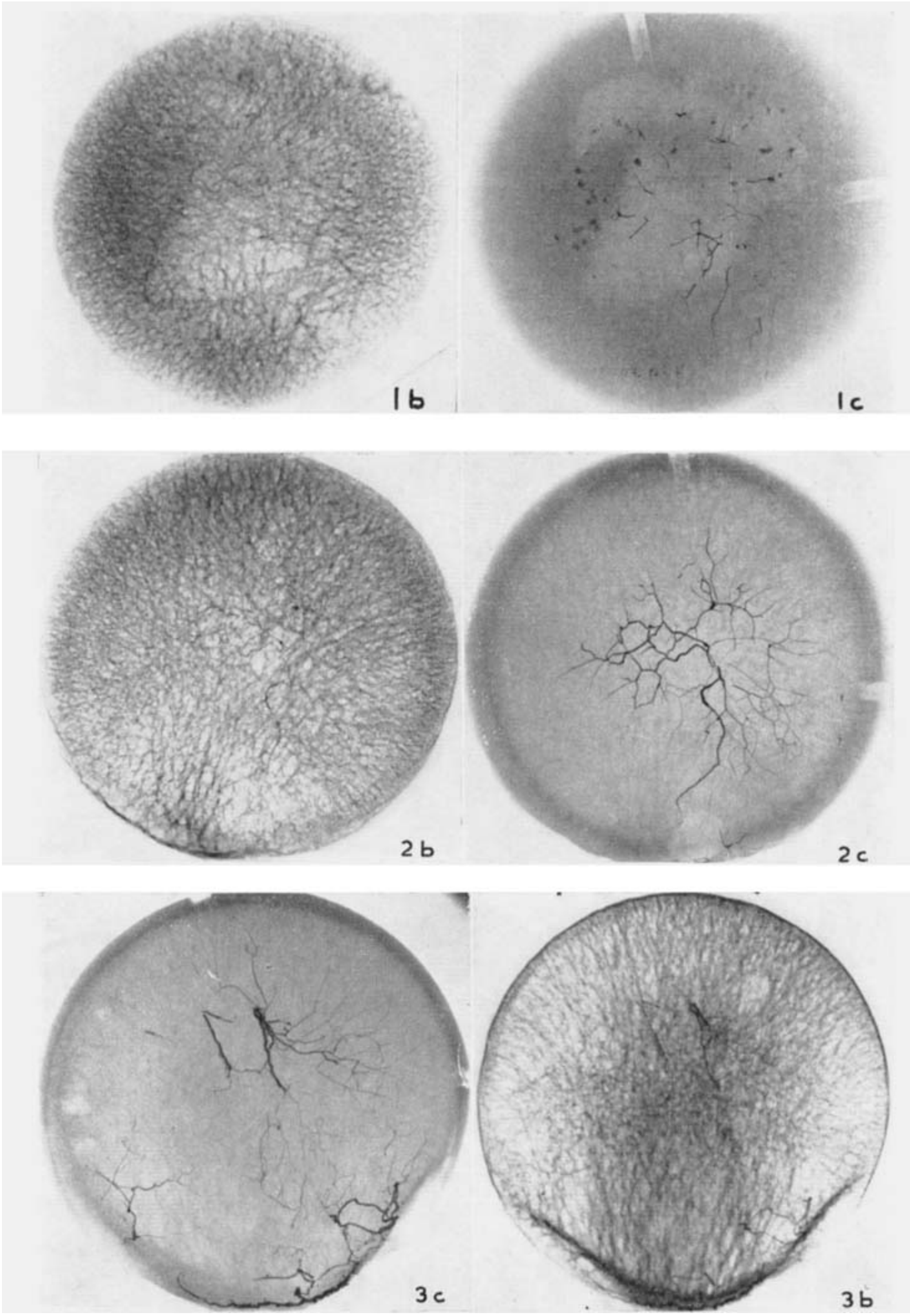


Fig. 15.

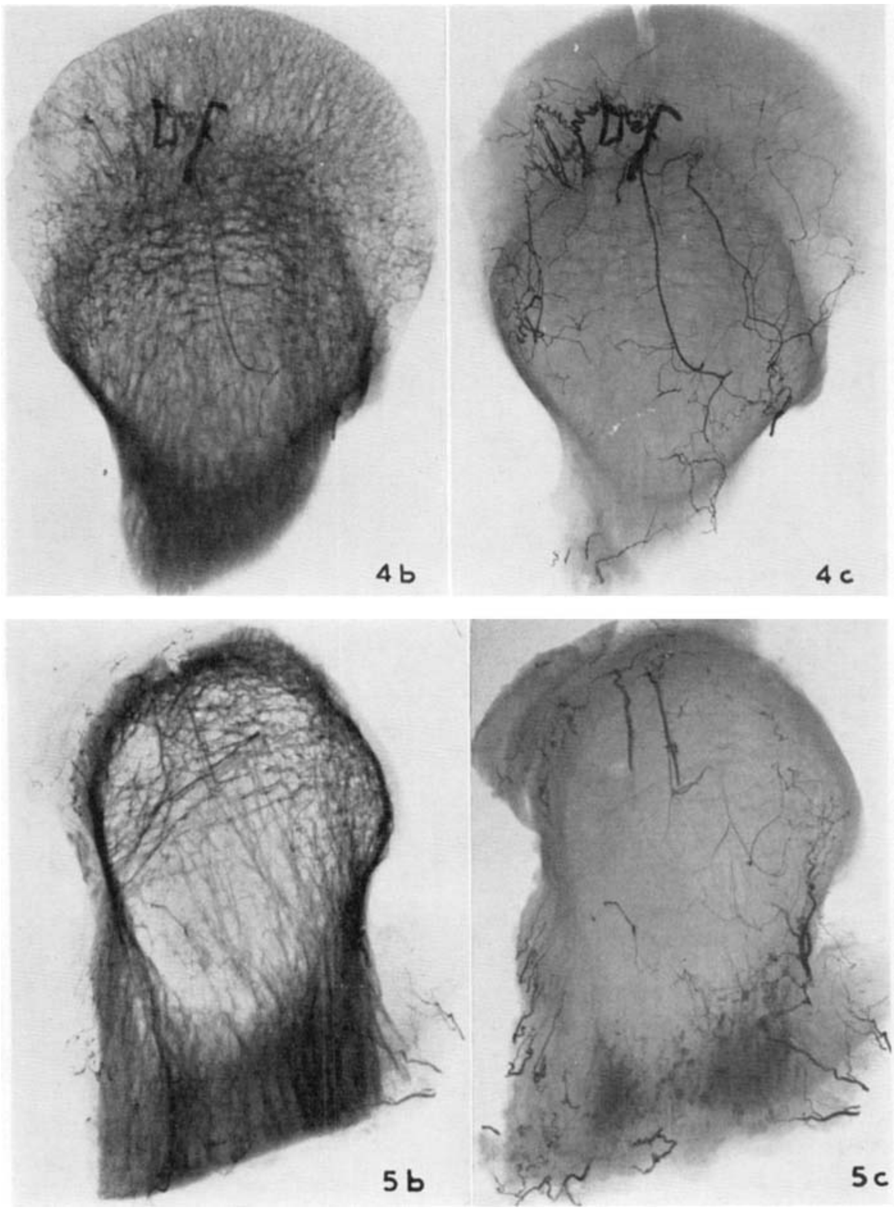


Fig. 15.

arteries coming from the round ligament and the lateral epiphyseal vessels are shown in 2 c. Due to their richness, the eventual severing of some of these anastomoses by the appliance, is of secondary importance.

chanical point of view it is important to replace the architectural elements of the femoral neck in order to have the trabeculae orientated according to their normal lines of stress. Any deviation in direction or change in power acts upon the bone tending to readapt it's structure (1). These efforts in the case of a fractured femoral neck would greatly retard the healing process. Conversely, the forces within the limits of tolerance' will stimulate the bone formation, if they are applied as intensified normal forces (6). This in the living corresponds to the impact established by the bolt screw in an anatomically reduced fracture of the femoral neck.

Secondly, the formation of the healing callus in fractures of the femoral neck speaks for itself in favour of an anatomical reduction. No periosteal callus has been found or demonstrated in the healing fracture of the femoral neck. *Farkas, Wilson & Hayner* (7), studying a specimen of a healed fracture, observed that the new bone formation due to the healing process arose from the existing trabecular structure of the internal weight bearing system.

Such a reparative process could be facilitated by replacing the components involved in their anatomical relationship and by avoiding the presence of a foreign body in the area where new bone formation is known, and expected, to occurr.

SUMMARY AND CONCLUSIONS

1. Seventy fresh specimens of human femoral heads and necks have been examined under defined conditions of experiments.
2. The tests showed that a bolt screw is a more satisfactory device than a nail in the fixation of experimental "fractures" of the femoral neck.
3. The best experimental position for insertion of the fixative device is in the "neutral zone" of the femoral neck, following near perfect anatomical reduction of the "fracture".
4. With emphasis on the limitations implied in the fact that conditions of experimental mechanical tests on specimens are far from those in the living human, some theoretical advantages of the findings have also been discussed.

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My thanks are also due to the Stilles Werner Company of Stockholm, who kindly provided the different appliances to be tested.

RESUME

1. Soixante-dix specimens frais de têtes et de cols de fémur humain ont été examinés dans des conditions d'expérimentation définie.
2. Les épreuves montrèrent que le boulon à vis est une formule plus satisfaisante que le clou pour la fixation des "fractures" expérimentales du col fémoral.
3. La meilleure position expérimentale pour l'insertion du moyen fixatif est la "zone neutre" du col fémoral, en suivant de très près la réduction anatomique de la "fracture".
4. En soulignant les limites dues au fait que les conditions des épreuves mécaniques expérimentales sur des specimens sont loin de celles que l'on peut pratiquer sur des êtres humains, il est discuté des avantages théoriques de ces trouvailles.

ZUSAMMENFASSUNG

1. Siebzig frische Exemplare von menschlichen Schenkelhälsen und Köpfen wurden unter bestimmte experimentellen Bedingungen untersucht.
2. Die Versuche zeigten, dass zur Feststellung von experimentellen Brüchen des Femurhalses eine Bolzenschraube eine zufriedenstellendere Vorrichtung ist als ein Nagel.
3. Die beste experimentelle Position für die Einführung der fixierenden Vorrichtung liegt in der "neutralen Zone" des Schenkelhalses, nach beinahe perfekter Reposition der "Fraktur".
4. Unter Betonung der Begrenzungen, die sich aus der Tatsache ergeben, dass Bedingungen in experimentellen mechanischen Untersuchungen an Präparaten wesentlich verschieden von denen beim lebenden Menschen sind, werden einige theoretische Vorteile der Befunde besprochen.

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