THE UPPER END OF THE FEMUR —
ITS STRUCTURE AND FRACTURES

A Thesis Submitted for the Degree of Doctor of Philosophy
in the Faculty of Engineering at the University of Surrey

by

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SUMMARY

With the aim of reducing the period of hospitalisation of patients with fractures of the upper end of the femur and giving them serviceable hips, certain studies have been carried out.

A number of mechanical features of the upper end of the femur and the mechanics of internal fixation of fractures affecting this bone end are investigated.

A new sliding pin together with a series of cervical and trochanteric fractures is reported.

Study of the anatomy of the upper end of the femur has revealed that the so-called trajectorial theory is ill founded.

The effect of osteoporosis on the proximal end of the femur, the diagnosis of this condition and the feasibility of determining the calcium content of a given femoral head with the aid of an image intensifier or oscilloscope are examined.

The blood supply of the upper end of the femur, revascularisation and the significance of increased radiological density of the femoral head after injury are discussed.

Avascular necrosis of the head of the femur is analysed.

The importance of the histology and specific gravity of femoral head biopsy specimens is considered.

The fixing moments of trifin nails in femoral heads are determined.

The aetiology and treatment of traumatic, stress and pathological fractures of the upper end of the femur are presented. Special attention is paid to the solution of difficult cases.
ACKNOWLEDGEMENTS

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SOME MECHANICAL PROPERTIES OF THE FRAGMENTS OF

FEMORAL NECK FRACTURES AND OF THE IMPLANTS

USED FOR THEIR INTERNAL FIXATION

It was felt that without knowledge of a number of basic facts there could be no solution to the problem of the fractured femoral neck, the unsolved fracture, and no improvement in the treatment of trochanteric fractures. With these ends in view the forces acting on the head of the femur are briefly reviewed and a number of experiments dealing with previously uninvestigated properties of the proximal and distal fragments of femoral neck fractures are described.

1.1 FORCES ACTING ON THE HEAD OF THE FEMUR

At this stage it is convenient to summarize the forces acting on the hip. The centre of the head of the femur may be regarded as the origin of an orthogonal cartesian frame of reference with one axis passing through the centre of the opposite femoral head and the other two lying respectively in the sagittal and horizontal planes. The forces presented below make angles with these three axes and are in fact vectors which vary with activity. They have been culled from the literature dealing with this subject and have been confirmed by direct calculation as well as clinical and experimental observations.

(a) In standing on two legs each hip supports 1/3rd of the total body weight.

(b) In standing on one leg the hip supports 5/6ths of the total body weight, but according to McLeish and Charnley (1970) the joint forces range from 1.8 to 2.7 times body weight and make an angle of 7° - 10° with the vertical.

(c) Lying on one side and abducting the leg on the side that is uppermost...
against gravity produces a reaction of 9/10ths of the total body weight on the femoral head.

(d) Straight leg raising in the supine position produces a reaction of 2/3rds of the body weight on the femoral head.

(e) In walking both static and dynamic forces act on the femoral head. It can be shown that at a rate of walking corresponding to a stance phase of .5 secs. the vertical force on the femoral head reaches a maximum value of 570 lbs. in an individual weighing 140 lbs. In theory this force can be lessened by the use of crutches, sticks, a caliper or by leaning towards the weightbearing hip. In practice, however, these precautions are forgotten sooner or later so that a damaged hip may be subjected to the full force produced by locomotion.

(f) Muscular tone also produces a force acting on the hip. The magnitude of this force is unknown but it can reasonably be assumed to be of the same order as the force produced by the muscles of the thigh, which according to Küntscher (1935) amounts to 30.7 kg. or 67.5 lbs. in an adult.

In this thesis the values given in (a - f) have been used, although it is realised that some of these are higher than those found by Rydell (1966) and lower than those found by Williams and Svensson (1968).

1.2 MECHANICAL PROPERTIES OF FEMORAL HEADS

Success in the treatment of femoral neck fractures depends to a large extent on the mechanical strength of the femoral head. Yet in this study of the relevant literature the writer has come across only two publications dealing with this subject. Putti (1940) discovered that the screws that bear his name could be pulled out of femoral heads by forces ranging from 125 to 475 kgs. Hardinge (1949) determined the force necessary to crush the cancellous bone in the head and subcapital region of the femur. The greatest resistance of 382 lbs., corresponding to a pressure of 7800 lbs/sq.in.,
## TABLE I

### STRENGTH OF FIXATION OF PINS IN FOUR FEMORAL HEADS

<table>
<thead>
<tr>
<th>Experiment</th>
<th>Age</th>
<th>Sex</th>
<th>Cause of Fracture</th>
<th>Local Pathology</th>
<th>Moment Resisted (lb. ins)</th>
<th>Force Resisted (lbs)</th>
<th>Pin Used</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>85</td>
<td>F</td>
<td>Experiment</td>
<td>Nil</td>
<td>382</td>
<td>306</td>
<td>Trifin-nail</td>
<td>Pin bent. Fixation not disturbed.</td>
</tr>
<tr>
<td>2</td>
<td>73</td>
<td>M</td>
<td>Experiment</td>
<td>Nil</td>
<td>432</td>
<td>432</td>
<td>As above</td>
<td>As above</td>
</tr>
<tr>
<td>3</td>
<td>74</td>
<td>F</td>
<td>Experiment</td>
<td>Nil</td>
<td>432</td>
<td>432</td>
<td>As above</td>
<td>As above</td>
</tr>
<tr>
<td>4a</td>
<td>70</td>
<td>F</td>
<td>Fall</td>
<td>Rheumatoid arthritis</td>
<td>189</td>
<td>252</td>
<td>3/8 diameter screw bolt.</td>
<td>Pin completely loosened.</td>
</tr>
<tr>
<td>4b</td>
<td>70</td>
<td>F</td>
<td>As above</td>
<td>As above</td>
<td>Not calculated</td>
<td>Finger pressure</td>
<td>As above</td>
<td>As above</td>
</tr>
<tr>
<td>Experiment</td>
<td>Age</td>
<td>Sex</td>
<td>Local Pathology</td>
<td>Cause of Fracture</td>
<td>Fixation</td>
<td>Load Withstood (lbs)</td>
<td>Result</td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>-----</td>
<td>-----</td>
<td>-----------------</td>
<td>------------------</td>
<td>----------</td>
<td>---------------------</td>
<td>--------</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>77</td>
<td>F</td>
<td>Nil</td>
<td>Experiment</td>
<td>Near vertical Kuntscher nail.</td>
<td>896</td>
<td>Firm impaction. Loosening of nail in lateral cortex.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>73</td>
<td>F</td>
<td>Nil</td>
<td>As above</td>
<td>As above</td>
<td>123</td>
<td>Head partially crushed over nail.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>79</td>
<td>F</td>
<td>Nil</td>
<td>As above</td>
<td>Honey nail-plate.</td>
<td>336</td>
<td>Head descended ( \frac{3}{4} )&quot;. Pin protruded medially ( \frac{1}{4} )&quot;. Anterior half of head dropped off.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>84</td>
<td>F</td>
<td>Nil</td>
<td>Fall</td>
<td>McLaughlin's nail-plate.</td>
<td>560</td>
<td>Head split.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Not known</td>
<td>Not known</td>
<td>Nil</td>
<td>Fall</td>
<td>As above</td>
<td>282</td>
<td>Head split. (Fig. 6)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>78</td>
<td>F</td>
<td>Nil</td>
<td>Fall</td>
<td>Pin-tube-plate.</td>
<td>246</td>
<td>Head crushed over pin.</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>48</td>
<td>M</td>
<td>Nil</td>
<td>Experiment</td>
<td>Pin-tube-plate.</td>
<td>627</td>
<td>Pin cut out. Deep hole in femoral head. (Fig. 7)</td>
<td></td>
</tr>
</tbody>
</table>
was offered at the intersection of the medial and lateral trabecular systems in the femoral head. (Fig. 1) The smallest value of 105 lbs., corresponding to a pressure of 2140 lbs/sq.in., was found in the inferior marginal area of the greatest sagittal diameter of the femoral head.

Neither of these authors dealt with the forces and moments which loosen pins in femoral heads, the force with which implants are gripped by the femoral head, the co-efficient of friction for stainless steel and Vitallium on femoral head cancellous bone and the effect of nailing on femoral heads. These features were investigated and the results are reported below.

1.2.1 Forces and Moments which loosen pins in Femoral Heads

Every Orthopaedic Surgeon, who has pinned femoral neck fractures, must at some stage in his career, have felt dismayed by radiographs showing that the pin he had so carefully inserted into the centre of the femoral head a few days previously was now somewhere else. The magnitude of the forces causing this displacement was investigated experimentally.

1.2.1.1 Experiments

Two sets of experiments were performed.

In the first the bending moments which loosened pins in femoral heads were determined. In the second, loads were applied directly to femoral heads.

(A) In the set-up shown in Fig. 2 the bending moment resisted by the femoral head was found by multiplying the force applied by means of a rod to the right of the fulcrum by its distance from the fulcrum. This moment divided by the distance between the centre of the adjustable bolt steadying the femoral head and the fulcrum, equalled the force which the femoral head had withstood. In the first three experiments trifin nails were driven into femoral heads. For the last experiment an excised femoral head belonging to a patient suffering from rheumatoid arthritis was used. She had sustained a subcapital fracture which was treated with a sliding
pin placed above the medial trabecular system. (Fig. 3) Three weeks after her operation, while she was doing straight leg lifting exercises for the first time, the pin cut out. (Fig. 4) In experiment 4a the pin was re-inserted passing this time through the undamaged intersection of the medial and lateral trabecular systems. After experimental loosening the pin was inserted into the sole intact portion of the femoral head for experiment 4b. All relevant data for these experiments is shown in Table I.

(B) Loading of pinned femoral heads - Vertical loads were applied to the heads of seven femora with pinned cervical fractures. (Fig. 5) In each case the shaft of the femur was vertically orientated and securely fixed in a special clamp. All relevant data is given in Table II.

1.2.1.2 Analysis

Eleven experimental results are available for study. In the first three experiments in Table I the femoral heads tested were relatively stronger than the trifin nails used. The fourth femoral head tested in Table I conveys a threefold message:

(a) A pin driven into an osteoporotic femoral head can become dislodged by straight leg raising. In this particular case the pin did not traverse the strongest portion of the head, the intersection of the two trabecular systems. (Hardinge, 1949).

(b) For the loosening of a pin passing through the strongest portion of a soft femoral head, as in experiment 4a, a force of the order of only 250 lbs suffices. Such a force is only developed by weightbearing and not by physiotherapy while resting in bed.

(c) Experiment 4b clearly shows that the practice of withdrawing a badly placed pin and re-inserting it into a neighbouring portion of the femoral head is dangerous.

The results presented in Table II show that with the sole exception of the first specimen, all the femoral heads containing pins were either split
(Fig. 6) or crushed (Fig. 7) by forces ranging from 123 lbs to 627 lbs. A force of 123 lbs is easily exceeded by walking, whereas a force of 627 lbs is of the same order as the maximum reached in normal locomotion. In this connection the result depicted in Figs. 8 and 9 showing how a pin may cut through the femoral head is of special interest. Normally the forces produced by weightbearing are transmitted to the femoral neck and shaft by the intact cortical and cancellous bone of the head and neck. If, owing to the presence of a fracture, these forces act chiefly on the femoral head, the cancellous bone above the pin may be crushed causing the pin to cut out. Here then is experimental support for the recommendation by Compere and Lee (1940) that weightbearing should be deferred until the fracture is united.

1.2.2 Force exerted on Trifin Nails by Femoral Heads and the Co-Efficient of Friction between Femoral Head Cancellous Bone and Stainless Steel or Vitallium

As far as the writer is aware the above tribological problems concerning the femoral head and pins inserted into it have never been investigated.

1.2.2.1 Experiments

Three necropsy specimens, two female and one male, belonging to patients over 70, who had all died from coronary disease were used. After experimental decapitation the femoral heads were nailed with trifin steel nails. On gross examination these bones were of normal consistency. The specimens were then inserted into a testing machine. They were placed over a circular hole in a steel plate allowing free descent of the nail after perforation of the articular cartilage. (Fig. 10) When loads were applied to the heads of the vertically orientated nails, the specimens became stable and did not move. In each case the loads recorded by the machine increased rapidly, but fell after perforation of the articular
cartilage and remained constant whilst the nail was being pushed through the femoral head. This constant force represented the kinetic frictional resistance $R$ offered by the femoral head to the movement of the nail. In the two female specimens, $R$ amounted to 0.03 tons and in the larger male specimen to 0.06 tons.

The angle of kinetic friction $\lambda$ was next determined. For this purpose the pins were loosened by pushing them backwards and forwards repeatedly until they would slide freely. The femoral heads were then fixed in a vice and gradually tilted until the pins slid out of the femoral heads. The angle $\lambda$ between the pins and the horizontal top of the vice was the angle of friction. (Fig. 11) It was found to be 35° for stainless steel pins. When Vitallium nails were substituted the angle amounted to 42°. These experiments were repeated with several other specimens and yielded identical results for the co-efficient of friction.

1.2.2.2 Interpretation of Results

Since $\tan \lambda = \mu$ ........................................ (1)

$(\mu =$ kinetic co-efficient of friction)$

$\mu$ stainless steel on femoral head cancellous bone = 0.7

$\mu$ Vitallium on femoral head cancellous bone = 0.9

These two high values of $\mu$ are of the same order as the co-efficient of kinetic friction for a rubber tyre moving slowly on dry concrete.

Let $F$ be the force normal to the surfaces of the pin.

Then $F = \frac{R}{\mu}$ ........................................ (2)

The total force $P$ is greater than $F$ and makes an angle $\lambda$ with the normal to the pin. The relation between $P$ and $F$ is expressed by $P = F \sec \lambda$ (Fig. 12) The direction of $P$ is such that it always resists the movement of the pin. If in Fig. 12 the movement of the pin is reversed $P$ will be above $F$ and its inclination downwards.
By substituting numerical values in Equation 2 the forces normal to the pin were found to be 96 lbs for the two female specimens and 192 lbs for the male specimen. These values divided by the total surface area, the circumferential measurement of the cross section of the nails multiplied by the depth of insertion, gave the intensity of these forces: 34.2 lbs and 28.5 lbs per sq. inch respectively for the two female specimens and 41 lbs per sq. inch for the male specimen.

Depending on the degree of osteoporosis present these pressures obviously vary, but the arithmetic mean of the above three values was 35 lbs per sq. inch. Using the formula $P = F \times \sec 35^\circ$ it can be shown that $P$ the total average force on one square inch of a moving stainless steel nail equals 42.8 lbs and makes an angle of 35° with the normal to the implant. In markedly osteoporotic specimens $F$ and $P$ will be smaller. In specimens with very dense cancellous bone these forces will be greater.

This frictional resistance to movement is of practical importance. A Vitallium nail is slightly more apt to keep the fragments of a fracture apart than an implant made of stainless steel. Further more energy is required to drive a Vitallium nail into the femoral head than a stainless steel one.

1.2.3 Effect of Nailing on the Femoral Head

It came as a complete surprise to the writer that the effects of driving a nail into the femoral head should never have been examined. The brief study presented here is based on two post-mortem specimens, experimental nailings and two clinical disasters.

1.2.3.1 Two Post-Mortem Specimens

Neither of the two patients who provided the post-mortem specimens was suffering from a bleeding disease. The first specimen was removed from the hip of a woman of 76 years after a trifin nail had cut out of her femoral head four weeks after insertion. There was fairly extensive
It is, however, known that the patient was an elderly woman who died within two to three weeks after the insertion of her pin. The head of the bone was removed with the pin still in situ. In this case the damage was more widespread. Several bruises were present and adjacent to the fovea, there was a dark area of cartilaginous softening. (Fig. 14)

1.2.3.2 Experimental Nailing

Radiographs of a femoral head nailed experimentally are shown in Fig. 15. The nail has been perfectly placed and the femoral head appears undamaged. Yet on gross examination there is a fairly extensive fracture of the articular cartilage. (Fig. 16) These cartilaginous fractures were observed in ten specimens under 50 years old nailed under laboratory conditions whenever the tip of the nail was inserted to within 1/2" - 3/4" of the articular cartilage.

A few years later these experiments were repeated with spongy femoral heads belonging to elderly people. The nails could now be driven right up to the articular cartilage without doing any noticeable damage.

In all these experiments a teak block from which two hemispherical holes with diameters of 1/2" and 2" had been excavated with special reamers was used. The holes were lined with corrugated rubber to provide an energy absorbing mechanism similar to that of articular cartilage. (Zarek and Edwards, 1964.) It would have been preferable to test complete hip joints, but it proved impossible to obtain such specimens.

1.2.3.3 Clinical Evidence

Minor fractures of the articular cartilage of the femoral head cannot be detected radiologically as Fig. 15 clearly demonstrates. Major damage is exceptional, but does occur. Two such cases are illustrated in Figs. 17 - 20.
Case Report 1 - The first patient was a man aged 85 years with a subcapital femoral fracture. His hip was pinned (Fig. 17). Two days later the head of his femur was split in two. (Fig. 18)

Case Report 2 - The second patient was a woman aged 78 years with a trochanteric fracture. Internal fixation was performed (Fig. 19). Within six days her right hip became painful. Her leg was in external rotation. Radiographs showed that the pin had gone through the head of the femur (Fig. 20).

1.2.3.4 CONCLUSIONS

The bruising and cartilaginous fractures sometimes caused by nailing can be assumed to contribute to the degenerative changes which sometimes occur many years after nailing, as the following case shows.

Case Report 3 - The 71 year old patient whose hip is depicted in Fig. 21 had her cervical femoral fracture pinned when she was 51 years old. Union occurred uneventfully. Eighteen years later she experienced pain in her left hip and another two years later marked unilateral changes were present.

When femoral neck fractures are treated by immediate prosthetic replacement the removed femoral heads are invariably undamaged. The bruising of the femoral heads here reported can therefore reasonably be attributed to nailing and not to the violence which caused the patient's fracture.

Fortunately major disasters after nailing are very rare. In a personal series of more than 300 consecutive hip nailings, no other cases in which the femoral head was split were encountered. But in view of the fact that nailing can undoubtedly damage the femoral head it is clearly desirable to use a less noxious method of internal fixation. A screw is, therefore, to be preferred to a nail.
1.3 MECHANICAL PROPERTIES OF THE DISTAL FRAGMENT

In most elderly patients with femoral neck fractures the cancellous bone in the neck and trochanteric region is largely replaced by fatty marrow and the lateral cortex is soft and thin from senile osteoporosis. That such bone cannot adequately support a pin used for the internal fixation of femoral neck fractures was recognised by Putti (1940), Eaton (1956) and Charnley, Blockey and Purser (1957). Yet the vast majority of orthopaedic surgeons are not aware of this fundamental fact.

To demonstrate convincingly that in elderly patients suffering from femoral neck fractures the lateral fragment does not provide support for a pin, clinical and experimental evidence will be provided.

1.3.1 Clinical Evidence

Three case histories are presented.

Case Report 4 - A man aged 68 years was operated on. Films taken in the operating theatre showed that the fracture was well reduced when it was pinned. (Fig. 22) Several days post-operatively, during which period he was confined to bed, the distal fragment was found to be externally rotated round the nail. (Fig. 23)

Case Report 5 - The fracture of a man aged 70 years was well reduced and pinned. (Fig. 24) Check X-Rays 32 days later showed that the pin was coming out of the femoral head and that the inferior cervical cortex was abutting against the pin. (Fig. 25) Three days later the pin was hammered back into the femoral head. Ten days after the second operation the femoral shaft started to move upwards and 3½ months later the head was in full varus, the pin resting on the inferior cervical cortex. (Fig. 26) At no time had this patient borne any weight on his injured limb. He was allowed to get up 6½ weeks after his second operation using crutches and bearing weight only on his sound limb.
Case Report 6 - A woman aged 77 years died 36 days after pinning of her trochanteric fracture with an implant fixed to the femoral shaft. (Fig. 27) Post-operatively she was confined to bed. A radiograph taken one day after the operation showed that the pin had only just entered the cancellous bone of the femoral head. When the post-mortem specimen was X-Rayed it was found that the head had travelled downwards so that the pin rested on the superior cervical cortex. (Fig. 28)

1.3.1.1 CONCLUSIONS

These three cases demonstrate that in elderly patients the distal fragment of a nailed femoral neck fracture can rotate round the nail (Cases 4 and 5) and that a pin with femoral shaft fixation which has not been deeply driven into the femoral head can move inside the femoral neck.

In addition the first two cases explain the most likely mechanism of the extrusion of a nail from the femoral head. Because the distal fragment can move freely round the nail, adduction of the thigh causes the inferior cervical cortex to strike the nail. Repeated impingements of the cortex on the nail work the nail loose and eventually wrench it out of the femoral head.

1.3.2 Experimental Evidence

Examination of a number of pinned post-mortem specimens of elderly patients showed that with very little force applied to the femoral heads the nails could be circumducted quite easily inside the distal fragments. Some of these hips had been pinned while the patients were still alive, others were pinned in the laboratory. In all these cases the cancellous bone inside the distal fragment had largely disappeared and had been replaced by fatty marrow. No useful purpose would have been served to investigate the very low compressive strength of this tissue.

However, in the majority of young specimens and occasionally in elderly specimens the trochanteric region is occupied by tough cancellous
bone. Six such specimens, including two belonging to elderly patients, were tested. The two elderly specimens had been specially picked for the hardness of the cancellous bone in the distal fragment on gross and radiographic examination. (Fig. 29)

The shafts of the specimens were vertically clamped. Loads were then applied to the end of the nail driven through the distal fragment in the bull's eye position as in Fig. 30. In experiments 2 and 3, the loads were applied to the nailed femoral heads leaving a gap between the fragments. The load at which the nail started to descend and crush the cancellous bone was recorded in each case. All relevant data are shown in Table III.

1.3.2.1 Interpretation of Results

The following calculations were carried out. In all cases the force normal to the end of the nail was determined from the equation:

\[ F' = F \times (\cos \theta - 90) \]  \hspace{1cm} (3)

\( F' \) = vertical force acting on end of pin applied by testing machine.
\( \theta \) = nail-shaft angle) See Fig. 30

It was decided to disregard any possible visco-elastic behaviour of the specimen and to assume that the strength of the cancellous bone in the distal fragment was uniform and that the resistance offered to the descent of the nail increased linearly with the distance from the lateral cortex owing to compaction. The total reactive force \( T \) produced by the cancellous bone has its centre of gravity at a distance \( 2/3s \) from the cortex. (\( s \) = length of pin in bone.) By taking moments about the mid-point of the thin lateral cortex where it is pierced by the pin, \( T \) can be calculated from the equation:

\[ F' \times \ell = T \times 2/3s \]  \hspace{1cm} (4)

(\( \ell \) = length of nail)

Once \( T \) has been found, \( f \) (the reaction by the cancellous bone on 1" of the pin) can be determined from the relationship

\[ T = \frac{f \times s^2}{2} \]  \hspace{1cm} (5)
### TABLE III

**Experimental Work on the Mechanical Properties of the Distal Fragment**

<table>
<thead>
<tr>
<th>Experiment</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>73</td>
<td>Over 70</td>
<td>32</td>
<td>32</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>Sex</td>
<td>F</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Side</td>
<td>Not Recorded</td>
<td>Not Recorded</td>
<td>L</td>
<td>R</td>
<td>L</td>
<td>R</td>
</tr>
<tr>
<td>Local Pathology</td>
<td>Perthes' disease</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
</tr>
<tr>
<td>General Pathology</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
<td>Nil</td>
<td>Polycystic kidneys</td>
<td>Polycystic kidneys</td>
</tr>
<tr>
<td>Length of lever arm (ins)</td>
<td>3(\frac{3}{4})</td>
<td>3(\frac{3}{4})</td>
<td>5(\frac{1}{3})</td>
<td>4(\frac{1}{2})</td>
<td>4</td>
<td>3(\frac{3}{4})</td>
</tr>
<tr>
<td>Length of pin in bone (ins)</td>
<td>2</td>
<td>2(\frac{5}{8})</td>
<td>2(\frac{5}{8})</td>
<td>2(\frac{5}{8})</td>
<td>2(\frac{5}{8})</td>
<td>2(\frac{5}{8})</td>
</tr>
<tr>
<td>Free portion of pin (ins)</td>
<td>1(\frac{1}{2})</td>
<td>1(\frac{1}{2})</td>
<td>2(\frac{1}{4})</td>
<td>1(\frac{3}{8})</td>
<td>1(\frac{3}{8})</td>
<td>1(\frac{3}{8})</td>
</tr>
<tr>
<td>Angle of pin with vertical</td>
<td>112°</td>
<td>125°</td>
<td>125°</td>
<td>127°</td>
<td>120°</td>
<td>120°</td>
</tr>
<tr>
<td>Vertical force (lbs)</td>
<td>100</td>
<td>89.6</td>
<td>134.4</td>
<td>112</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Force normal to pin (lbs)</td>
<td>92.6</td>
<td>63.3</td>
<td>77</td>
<td>67.4</td>
<td>86.6</td>
<td>86.6</td>
</tr>
<tr>
<td>Moment resisted by cancellous bone (lb ins)</td>
<td>324</td>
<td>246</td>
<td>395</td>
<td>286</td>
<td>346</td>
<td>324</td>
</tr>
<tr>
<td>Total force resisted by cancellous bone (lbs)</td>
<td>244</td>
<td>155</td>
<td>216</td>
<td>164</td>
<td>198</td>
<td>205</td>
</tr>
<tr>
<td>Force per inch run (lbs)</td>
<td>122</td>
<td>55</td>
<td>57</td>
<td>47.5</td>
<td>57.5</td>
<td>72.7</td>
</tr>
<tr>
<td>Intensity of force (lbs per sq inch)</td>
<td>325</td>
<td>147</td>
<td>152</td>
<td>127</td>
<td>153</td>
<td>194</td>
</tr>
<tr>
<td>Cortical reaction (lbs)</td>
<td>151.4</td>
<td>92.7</td>
<td>139.0</td>
<td>96.6</td>
<td>111.4</td>
<td>118.4</td>
</tr>
<tr>
<td>Orientation of pin</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
<td>□</td>
</tr>
<tr>
<td>Frictional resistance (lbs)</td>
<td>-</td>
<td>67.2</td>
<td>179.2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
By dividing $f$ by the distance between 2 fins (3/8") the compressive strength of the cancellous bone of the distal fragment can be computed in lbs/sq. in. The cortical reaction $R$ is calculated from the equation:

$$F' + R = T \quad \ldots \ldots \ldots (6)$$

The results of these calculations are presented in Table III. There was no significant difference between right and left femora belonging to the same individual. (Experiments 3 & 4 and 5 & 6.) Orientation of the pin also made no difference to the force required to depress the pin a certain distance. (Experiments 5 & 6.) This is not surprising because in each case the same amount of bone had to be crushed. (Figs. 31 & 32.) The average force per inch run amounted to 68.6 lbs and the average cortical reaction was 118 lbs. Specimen 1 belonged to a woman aged 73 years suffering from healed Perthes disease and turned out to be the strongest of the six specimens tested. The compressive strength of its cancellous bone amounted to 325 lbs/sq. in exceeding 2.5 times the lowest value, found in Specimen 4. The average compressive strength in the six experiments was 183 lbs/sq. in. The greatest value for the compressive strength of femoral head cancellous bone found by Hardinge (1949) was 7,800 lbs/sq. in. Therefore, the experiments presented here, show that using resistance to compression as a yardstick, the closely knit cancellous bone in the femoral head can be 24 to 60 times stronger than the loosely woven cancellous bone of the distal fragment of specimens specially picked for their hardness.

In the six specimens tested the average reactive force acting on one inch of nail was 68.6 lbs and this value will be used for the calculations to be presented later. Of special interest was the fact that trifin nails of average length were loosened by loads of the order of 100 lbs. Since the forces produced by straight leg raising and abduction have the same magnitude, it is easy to understand why simple nails sometimes fail to immobilise
the distal fragment even if the patient does not walk, as has already been demonstrated in the previous section.

Two methods of overcoming this difficulty are:
(a) Fixing the nail to a plate screwed to the femoral shaft. (= shaft fixation.)
(b) Firmly compressing the fragments so that frictional forces augment the limited mechanical strength of the distal fragment.

1.4 FRICITIONAL RESISTANCE OFFERED BY THE SURFACES OF FEMORAL NECK FRACTURES

In the absence of published data on this subject it was decided to carry out an experimental investigation.

1.4.1 Experiments
A subcapital cervical fracture was produced by a saw cut. The shaft was then so held that the plane of the fracture was horizontal and the capital fragment was laid on the cervical. By slowly altering the position of the shaft, the angle made by the plane of the fracture with the horizontal was gradually increased. When it reached 50° the head just started to slide. (Fig. 33)

Three irregular cervical fractures were next examined. In Experiment 2 in Table III, a near vertical fracture was pinned with the pin placed in the cervical axis. The fragments were then distracted and the cancellous bone in the distal fragment was crushed by applying a vertical load to the femoral head and increasing this load until the pin just touched the inferior cervical cortex. (Fig. 34) The fragments were then firmly impacted manually and by again applying a load to the femoral head and increasing it until the capital fragment started to slide across the cervical, the frictional resistance was found to be 67.2 lbs. (Fig. 35) In Experiment 3 in Table III, the frictional resistance, determined by the same method,
amounted to 179.2 lbs. In a third experiment, not recorded in Table III, a force of only 8 lbs caused the femoral head to slide downwards.

1.4.2 Analysis of Results

The first experiment showed that the angle of friction $\lambda$ for cervical femoral bone on cervical femoral bone was $50^\circ$. From the equation $\tan \lambda = \mu$ the value for the co-efficient of friction is found to be 1.19. This relatively high value for a co-efficient of friction means that if a force of 100 lbs acts on the femoral head at right angles to the surface of a femoral neck fracture, a tangential force of 119 lbs will be necessary to displace the femoral head. (Fig. 36)

In theory then, any fracture making an angle of more than $50^\circ$ with the horizontal or less than $40^\circ$ with the vertical would tend to be unstable.

In practice, however, even vertically disposed fractures may offer frictional resistance. The second set of experiments was designed to determine its magnitude. Although only three experiments were performed, they showed that the forces necessary to push the femoral head downwards across the face of the fracture ranged from a few pounds to 179.2 lbs. In view of this wide variation, no further experiments were performed. But in the calculations to be presented later, the arithmetic mean of the three values, namely 85 lbs, will be employed. Although the term frictional resistance has been used, what was actually measured was the force which fractured interlocking bony spicules across their bases. It is obvious that this force must vary from case to case. In some instances the fragments can be disimpacted by small forces when, as often happens in elderly patients, the fracture is comminuted and some of the larger spicules are already fractured across their bases. However, it is obvious that firm impaction maintained throughout the healing period must be beneficial.

The experiments here reported also have a bearing on the classification of femoral neck fractures. Pauwels (1935) based his well-known classification
on assumed values of 0.3 and 0.6 for the co-efficient of friction. He then showed by calculation that fractures with an inclination to the horizontal not exceeding 25° were stable. If the inclination was between 25° and 70° the fracture was unstable because shear acting parallel to the surfaces of the fracture was in excess of axial compression and could move the fragments. He further concluded that if the angle of the fracture with the horizontal was greater than 70° the forces normally acting on the hip passed medial to the line of the fracture, thereby tilting the femoral head and subjecting the fracture to both shearing and tensile forces.

Apart from the fact that the values for the co-efficient of friction assumed by Pauwels (1935) were too low, these fractures do not lend themselves readily to mathematical analysis. As a rule they do not have flat surfaces, but are irregularly shaped. Moreover, Pauwels did not take into consideration the fact that impaction of the fragments can make even vertically disposed fractures relatively stable. For these reasons any classification based on the obliquity of these fractures must be inaccurate. But this does not mean that there should be no anatomical classification at all and that the distinction between adduction and abduction fractures should be given up as suggested by Linton (1949) and Watson-Jones (1952). According to the relationship between fragments, two main groups can be distinguished:

(a) Vertically disposed, adduction or varus fractures. The proximal fragment includes a portion of the inferior cervical cortex. The fragments are in shear and can ride over each other. (Fig. 37a, a tracing of a radiograph) Initially incomplete fractures of the superior cortex can progress to this type which comprises more than 90% of all femoral neck fractures. If the distal fragment is impacted into the femoral head the term abduction or valgus fracture is frequently applied.
(b) Horizontally disposed fractures. The proximal fragment includes a portion of the superior cervical cortex. The femoral neck supports the femoral head. The fragments are in compression and become impacted into each other. (Fig. 37b, again a tracing of a radiograph) Less than 10% of all cases belong to this group.

All intermediate degrees of obliquity are, of course, seen clinically, but comminution of the inferior cervical cortex followed by absorption can convert a fracture which was originally mainly horizontal into a mainly vertical one. Impaction may occur with both vertical and horizontal fractures, although impacted vertical fractures tend to be unstable as expected.

1.5 SUMMARY

The forces acting on the hip are considerable. They may reach a value of four times the individual's body weight.

Experiments here presented have shown that normal femoral heads can easily withstand bending moments of the order of 300 - 400 lb ins but if there is osteoporosis, e.g. from rheumatoid arthritis, pins can be loosened by much smaller bending moments. Loads varying from 123 - 627 lbs can crush or split the heads of suitably supported experimentally pinned cervical femoral fractures.

The average force acting on 1 sq in of nail moving through a femoral head is 42.8 lbs and makes an angle of 35° with the normal to the implant. The co-efficient of friction between stainless steel and femoral head cancellous bone is high, 0.7. If Vitallium is used instead, the co-efficient is 0.9.

Nails pile-driven into the femoral head may cause bruising and fractures of articular cartilage. Two cases are presented where the femoral head was split in two by nailing.

The distal fragment of a femoral neck fracture cannot adequately
support a nail in an elderly patient.

The apparent co-efficient of friction for cervical femoral bone on cervical bone is 1.19. Re-examination of the classification of femoral neck fractures showed that it is only necessary to distinguish between vertically and horizontally disposed fractures.
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CHAPTER II
THE MECHANICS OF INTERNAL FIXATION OF FRACTURES
OF THE UPPER END OF THE FEMUR

With the aid of the data in Chapter I the internal fixation of cervical and trochanteric fractures will now be analysed. Special attention will be paid to the problem of early ambulation.

2.1 CERVICAL FRACTURES

2.1.1 The Analysis of Haboush

Haboush (1953) analysed four methods of pinning the neck of the femur:
1. Nail placed in bull's eye position.
2. Nail in so-called optimum position placed almost vertically resting on the inferior cervical cortex.
3. Nail in bull's eye position attached to a plate. (= shaft fixation)
4. Nail in optimum position attached to a plate.

He assumed that in all cases a load of 100 lbs acted on the femoral head and did not consider any frictional resistance at the fracture nor the reaction of the cancellous bone in the distal fragment.

The account presented below differs from the analysis of Haboush (1953) in that six methods are examined, and that whenever necessary the frictional resistance at the fracture and the reaction of the cancellous bone in the distal fragment are studied, and that the maximum sagittal load a given osteosynthesis can withstand has been calculated. In order not to complicate the calculations unduly it is assumed that in each situation the pin has been inserted centrally and is firmly gripped by the femoral head. Only antero-posterior projections will be investigated.
2.1.2 **Frictional Resistance at the Fracture Site**

How to deal with the frictional resistance acting on the surfaces of these fractures poses a difficult problem. The interlocking bony spicules which produce this resistance must be fractured across their bases before movement of the head can occur. As has already been shown to overcome this resistance in vertically disposed fractures a vertical force on the femoral head averaging 85 lbs is necessary. This force is not friction in its true sense. However, it adds to the stability of any of the osteosyntheses considered. In some of the diagrams which follow the component of this force normal to the pin at the centre of the fracture has been shown. Of course, if the fragments are firmly impacted the resistance to downward movement may exceed the force acting on the head of the femur. The osteosynthesis is then stable and the resistance to movement remains an internal force. In the worked examples it has been assumed that the frictional resistance is 85 lbs. In the writer's opinion this is the best method of dealing with this problem short of leaving it out altogether as was done in the analysis of positions 2, 4a, 5 and 6, where special conditions obtain.

Only vertically disposed fractures have been analysed in detail but horizontally disposed fractures are also examined. Fractures with intermediate obliquity have not been considered specially. It has already been explained that they tend to change to vertical fractures and they should be looked upon as possessing the same degree of stability.

The results will answer the often asked question whether a patient can walk on his pinned hip before his fracture has united. In the calculations which follow it has been assumed that the body weight is 140 lbs and that the maximum vertical force acting on the femoral head during the stance phase of walking equals 570 lbs. It would be futile to consider greater forces. They would only crush the head of the femur. For each of the six theoretically possible situations a worked example is presented. To do this
## TABLE IV

**Moments withstood by implants used for the internal fixation of femoral neck fractures**

<table>
<thead>
<tr>
<th>Implant Description</th>
<th>lb. ins.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vitallium, Watson-Jones nail, cannulated, three flanged</td>
<td>280</td>
</tr>
<tr>
<td>Vitallium, Smith-Petersen nail solid, three flanged</td>
<td>320</td>
</tr>
<tr>
<td>Vitallium, four flanged nail cannulated</td>
<td>345</td>
</tr>
<tr>
<td>F.M.B. round rod $\frac{1}{4}$&quot; diameter</td>
<td>61.7</td>
</tr>
<tr>
<td>F.M.B. round rod $\frac{3}{8}$&quot; diameter</td>
<td>208</td>
</tr>
<tr>
<td>F.M.B. round rod $\frac{1}{2}$&quot; diameter</td>
<td>495</td>
</tr>
</tbody>
</table>

F.M.B. steel is now known as EN 58 J
it was necessary to know the respective strength of nails and nail-plate junctions.

2.1.3 The Strength of Hip Nails and Nail-Plates

With reference to the strength of nails, the writer is indebted to the Austenal Company (1961) for the information presented in Table IV. For comparison, the moments which solid steel rods made of EN 58J steel can withstand are also given.

The strength of nail-plate junctions was determined by Foster (1958). He found that the new type MacLaughlin nail-plate made of Vitallium had the strongest junction of the implants available when he wrote his paper, withstanding a bending moment of 448 lb·ins. This value has been used in all the subsequent calculations.

2.1.4 Bull's Eye Position

In this position the nail is inserted in the cervical axis. Two types of case require consideration.

(a) The patient's hip is soft from osteoporosis. Mechanical analysis is difficult because the distal fragment cannot support a pin which is firmly gripped by the capital fragment. The leverage exerted by the patient's leg produces movement of the distal fragment round the point where the pin pierces the lateral cortex. If the plane of the fracture is mainly vertical the pin comes to rest on the inferior cervical cortex with the femoral head in varus. If the fracture line is mainly horizontal the distal fragment falls into lateral rotation when the patient tenses her psoas to lift her leg. (Fig. 38)

(b) The distal fragment is capable of giving some support to the nail. Since in this case there is no movement, shear force and bending moment diagrams can be constructed. For a vertically disposed fracture the forces acting on the pin (Fig. 39) are linked by three equations:
\[ F \cos \alpha \times z = D \cos \alpha \times s + T \times 2/3s \] .......... (7)
\[ F \cos \alpha + R = T + D \cos \alpha \] .......... (8)
\[ T = \frac{f \times s^2}{2} \] .......... (9)

Notation: \( F \) = vertical force acting on centre of femoral head.
\( F' \) = force normal to pin = \( F \cos \alpha \)
\( \alpha \) = angle between \( F \) and a line normal to pin passing through
centre of femoral head. \((43^0 \text{ in Fig. 39 allowing for the}
\text{inclination of the femur.})\)
\( z' \) = length of pin from centre of femoral head to lateral
cortex \((3\frac{1}{2}'' \text{ in Fig. 39}).\)
\( D \) = frictional resistance offered by fracture \((85 \text{ lbs from}
\text{previous experiments}).\)
\( D' \) = frictional resistance acting on a pin.
\( s \) = length of lateral fragment traversed by pin \((2\frac{5}{8}'' \text{ in Fig. 38}).\)
\( T \) = total reaction of cancellous bone on pin.
\( R \) = reaction of lateral cortex.
\( f \) = reaction of cancellous bone in lateral fragment on
\text{nail} \( = 68.6 \text{ lbs from previous experiments}).\)

From a consideration of the shear force diagram and equations (7),
(8) and (9) it becomes clear that the magnitude of \( F \), the maximum vertical
force which a femoral neck pinned under the conditions detailed above can
withstand depends on:

(a) The degree of compression of the fragments. The more firmly
the fragments are pressed together the larger \( D \) becomes.

(b) The size of the lateral fragment. If \( s \) increases \( T \) becomes
larger, for \( T = \frac{f \times s^2}{2} \) .......... (9)

(c) The density of bone in the lateral fragment. The more dense
the bone is, the larger \( f \) and thereby \( T \) become.
There is also a small negligible force along the axis of the nail, but this does not affect the above considerations.

Reference to Fig. 39 shows that the maximum sagittal load this osteosynthesis can withstand is 225 lbs. The maximum antero-posterior force it can withstand is of the same order. This means that exercises such as straight leg raising and abducting the leg against gravity as well as standing on two legs will not disturb the fracture. Standing on one leg and walking, however, produces forces in excess of 225 lbs owing to the lever action of the pelvis so that movement of the proximal fragment occurs and the head is forced into varus, making non-union a certainty unless the patient is young and the distal fragment contains firm cancellous bone which firmly grips the nail. Since it cannot be foretold whether a given femur is hard or soft, the treatment of a vertical femoral neck fracture by a nail in the bull's eye position seems to be of doubtful value.

The bending moment diagram shows that the maximum moment acting on the nail is only 176 lb ins which the nail can easily withstand.

Horizontally disposed fractures are stabilised by this method and usually unite. Early ambulation, however, can crush capital cancellous bone between the pin and the acetabulum, because the forces which weightbearing produces act mainly on the femoral head and are not transmitted by an intact femoral neck to the femoral shaft.

2.1.5 **Nail Parallel to the Cervical Axis**

Resting on Inferior Cervical Cortex

If the cortical resistance $R$ and the measurements of a given femur are known, $F$, the maximum vertical force which the osteosynthesis can withstand, is easily calculated. The average value for $R$ is 118 lbs in Table III. However, it was felt that an actual experiment might be more informative than a number of computations. For this purpose the neck of the femur of a man aged 48 years, who had died from coronary thrombosis,
was experimentally fractured and then pinned. When the femoral head of the specimen was loaded as in Fig. 40 the head became displaced downwards, the lateral cortex ploughed up (Fig. 41) and the nail bent by a vertical force of only 269 lbs. Of special interest was the fact that the fracture above the pin started to gape directly the specimen was loaded, and that a moment of only 206 lbf·ins caused bending of the pin. The bending moment and shear force diagrams presented in Fig. 42 are based on this experiment and derived from these three equations:

\[ F' \cos \alpha \times (l - s) = R \times s \]  
\[ F'' + R = L \]  
\[ F'' = F \cos (\alpha + \beta) \]

Notation:  
- \( F \) = vertical force acting on normally inclined femur.  
- \( F' \) = vertical force in experiment.  
- \( F'' \) = force normal to pin.  
- \( \beta \) = angle of inclination of femoral shaft. (11° in Fig. 39)  
- \( \alpha \) = angle between \( F' \) and \( F'' \) (40° in Fig. 41)  
- \( L \) = total load on pin.  

Other symbols as before.

\( l = 3.5'' \)  \( s = 2.5'' \) in Fig. 42

The disadvantages of this method can now be stated.

(a) The pin passes into the structurally weakest portion of the femoral neck (Hardinge 1949). Fixation of the pin in the head is therefore less secure than in the previous method.

(b) A vertical force acting on the femoral head causes slight bending of the pin subjecting the fracture above the pin to tensile stresses which delay union. (See arrows in Fig. 42)

(c) The inferior cervical cortex acts as a fulcrum for the nail. As a result the distal portion of the nail may plough up the lateral cortex causing the head to descend and the lateral end of the pin to migrate upwards.
(d) The substantial reactive force of nearly 300 lbs where the pin rests on the cortex may produce crumbling of bone. This in turn lengthens the medial lever arm of the pin unleashing even greater destructive forces at the lateral cortex.

A patient with a vertical fracture treated by this method may move about in bed, do straight leg lifting exercises and raise his injured leg against gravity; he may stand on two legs and possibly on one, but he must not walk. For walking generates a vertical force of the order of 500 - 600 lbs, considerably in excess of the 269 lbs which caused complete mechanical failure of the experimental osteosynthesis. If allowances are made for the low value for R in the experiment and the average value of 118 lbs in Table III is inserted in equations (10), (11) and (12), F, the total vertical force which such a specimen can withstand, becomes 468 lbs. This is still well below the force produced by walking but more than enough to bend the pin.

The above conclusions do not apply to mainly horizontal fractures. Provided the capital cancellous bone above the pin is not crushed a patient thus treated may experience no ill effects from immediate walking.

It is clear that a patient treated by this method is not significantly better off than one whose fracture has been pinned with a nail in the bull's eye position.

2.1.6 Multiple Small Pins

A variation of methods 2.1.4 and 2.1.5 can conveniently be mentioned at this stage, namely, fixation by three or four thin pins. If one fairly massive nail cannot hold a vertical cervical fracture, then four pins will also be inadequate as the following case history demonstrates.

Case Report 7 - A girl, aged 16, sustained multiple severe injuries of her left lower limb. One of these was the cervical fracture shown in Fig. 43. An open reduction was necessary. It was noted that the femoral
head was hard and even driving a guide wire into it required considerable physical effort. Because it was thought that hammering a nail into this femoral head might easily cause damage, it was decided to use four Austin-Moore pins. The operation was performed just before midnight and these pins could not be found. For this reason four guide wires were used, and their ends were trimmed towards the end of the operation. A reasonable reduction was obtained. Three months later the fracture was thought to be firm (Fig. 44) By then her concomitant femoral and tibial shaft fractures showed evidence of early union and weightbearing with the aid of a walking caliper was permitted. Nevertheless careful scrutiny of Fig. 44 shows that all is not well. With the aid of a straight ruler, bending of the bottom wire and possibly one of the more superiorly placed ones can be demonstrated. These wires are being bent and about to fail in tension. This duly happened six months after the operation. In Fig. 45 three wires have fractured, although at that time the hip was painless and had a reasonable range of movement. Failure in shear may also occur. Frankel and Burstein (1970) demonstrate this in their Fig. 2 - 37.

The writer is convinced that this simple, easily performed method recently advocated by Strange (1969) is essentially unsound for vertically disposed fractures, although it may enable patients with valgus or transverse fractures to walk immediately after insertion of the pins.

2.1.7 Near Vertical Placement of Nail

In this placement recommended chiefly by Kuntscher (1953) the pin rests on the inferior cervical cortex and passes through the centre of the femoral head. The pin, therefore, makes a fairly obtuse angle with the vertical.

The forces acting on a vertical fracture nailed by this method (Fig. 46) are linked by these two equations:
\[ F \cos \alpha \times a - D \cos \alpha \times b = R \times c \] 
\[ F \cos \alpha = D \cos \alpha + R = L \]

Notation:
- \( \alpha \) = angle between \( F \) and \( F' \) making allowance for the normal inclination of the femoral shaft (\( \alpha = 69^\circ \) in Fig. 43)
- \( a \) = lever arm of \( F' \) (1.5" in Fig. 46)
- \( b \) = lever arm of \( D' \) (13/16" in Fig. 46)
- \( c \) = lever arm of \( R \) (2 3/16" in Fig. 46)
- Other symbols as before.

The forces and moments acting on this system are all shown in Fig. 46 which is a tracing of an actual fracture with a near vertical fracture line. A force of 570 lbs acting on the femoral head is normally produced by walking. Provided this force does not crush the femoral head it causes a lateral cortical reaction of only 122.5 lbs, a total load on the inferior cervical cortex of only 292 lbs and a maximum bending moment of only 268 lb ins on the pin. Cortical bone can withstand these forces and the pin recommended by Kuntscher (1953) is not bent by this moment. Only shock loading the femoral head by jumping and running would wreck such an osteosynthesis. Loads in excess of 570 lbs would be produced, the bone between the acetabulum and the pin would be crushed and the pin would cut out of the femoral head.

Since the pin tends to lie in a gutter inferiorly the osteosynthesis can also resist antero-posterior forces. Rotation of the distal fragment round the pin does not occur because contraction of the abductors firmly impact the fragments. Of special interest is the relatively high axial thrust of 532 lbs firmly compressing the fragments. This osteosynthesis would, therefore, appear to be stable in all directions and must be regarded as the best of the simple pinnings. Irrespective of whether the fracture line is vertical or horizontal, early ambulation is permissible.
in theory if the risk of crushing capital cancellous bone thereby is accepted.

In practice, however, there are the following disadvantages:

(a) The nail cannot always be ideally placed especially in cases of coxa vara. If an attempt is made to insert it near-vertically, it will enter the head marginally and will eventually cut out. It must, therefore, be inserted more horizontally which means reverting to the insecure method (2).

(b) If the inferior cortex is comminuted or the lateral cortex damaged by the insertion of the nail, the fracture is not properly immobilised.

(c) In cases of retroversion or excessive anteversion of the neck, it may be impossible to insert the nail centrally into the head in the lateral view so that it will later cut out.

2.1.8 Nail in Bull's Eye Position Attached to a Plate

Two types of case require consideration.

(a) There is no frictional resistance at the fracture site and the support of the pin by the distal fragment is negligible. The bending moments and shear force diagrams of this situation are shown in Fig. 47. Using the same notation as before let \( M \) be the moment the pin-plate junction can resist and \( P \) be the reaction at the junction, then:

\[
M = F \times \cos \alpha \times l
\]

\[
P = F'
\]

According to Foster (1958) \( M \) may reach a value of 448 lb ins. In Fig. 47, \( \alpha = 47^\circ \) and \( \ell = 3" \). By inserting numerical values in the above equations, it can be shown that if \( F \) exceeds 219 lbs there will be mechanical failure of the nail-plate junction. Moreover, this load would bend most pins in common use with the sole exception of a \( \frac{1}{2}" \) diameter circular steel or colbalt-chrome rod as used by Holt (1963). This means that if the fracture line is vertical the patient cannot stand on the
injured leg or walk until the fracture is united. However, there can be no objection to standing on both legs, to sitting and activities in bed such as straight leg raising and abduction exercises before union has occurred. But if the fracture line is horizontal and there is no comminution the patient can walk, because the forces produced by weight-bearing firmly impact the fragments, always provided the cancellous bone of the femoral head is not crushed between the acetabulum and the pin.

(b) The frictional resistance at the fracture site and the support of the pin by the lateral fragment are substantial. If the notation already described is used again, bending moment and shear force diagrams can be constructed from the following three equations:

(Fig. 48)

\[ F \cos \alpha \times \ell - D \cos \alpha \times s - T \times 2/3s = M \] .......... (17)

\[ F \cos \alpha = D \cos \alpha + T + P \] .......... (18)

\[ T = \frac{f \times s^2}{2} \] .......... (19)

By inserting numerical values in these equations, \( \alpha = 47^\circ, s = 2^{1/4}" , \ell = 3" , M = 448 \text{ lb ins} \) these forces can be calculated, and are shown in Fig. 48. \( F \), the maximum vertical force which this osteosynthesis can resist, is 410 lbs. As has already been demonstrated, a simple nail identically placed is loosened by a force of 225 lbs. The addition of shaft fixation has, therefore, nearly doubled the stability of the osteosynthesis.

It is worth repeating that the moment of 448 lb·ins acting on the outer end of the pin can only be resisted by a \( \frac{3}{4}" \) diameter round stainless steel rod.

Although an osteosynthesis performed under these conditions is stronger than the last example considered, walking must still be prohibited, for this procedure forces considerably in excess of 410 lbs. Horizontal cervical fractures, however, should be quite stable on walking and harm
will only result if the forces of weightbearing crush capital cancellous bone above the pin.

2.1.9 **Nail Parallel to Cervical Axis Resting on Inferior Cervical Cortex and Attached to a Plate**

In this situation, the statically indeterminate case, the pin may be regarded as a cantilever propped by the inferior cervical cortex at point 0 in Fig. 49 just distal to the fracture. The maximum vertical thrust on the femoral head this osteosynthesis can withstand is governed by the strength of the pin used. In Fig. 49 $a = 42^\circ$, $\ell = 3\frac{3}{4}''$, $s = 2\frac{1}{2}''$. Assuming that a four flanged Vitallium nail which can withstand a moment $M_y = 345$ lb ins is used then:

$$M_v = F\cos 42 \times (\ell - s)$$  \hspace{1cm} (20)

from which $F = 372$ lbs, $F' = 276$ lbs, $L = 276$ lbs.

As in position 2 there is no frictional resistance at the site of the fracture owing to the existence of tensile forces. Remembering that the moment on the nail must not exceed 345 lb ins anywhere, shear force and bending moment diagrams can be constructed. Over the lateral fragment, where $M_y$ is constant, the shear force is zero. (Fig. 49) It can be shown that walking produces a maximum bending moment of 530 lb ins at the fracture which then gradually reduces to 448 lb ins at the junction. Not even a $\frac{1}{2}''$ diameter EN 58J steel rod is equal to a moment of 530 lb ins. A patient with a vertical fracture thus treated must not walk before union has occurred and is fit only for non-weightbearing activities.

The above remarks do not apply to horizontally disposed fractures. Provided that the femoral head does not crumble on weightbearing causing the pin to cut out, such an osteosynthesis is perfectly stable.

2.1.10 **Near-vertical Nail Attached to a Plate**

In this method the nail is placed as recommended by Küntsch (1953)
and fixed to a plate. This is merely a special case of situation 2.1.9.

In Fig. 50 it is assumed that a force of 570 lbs acts on the femoral head. The osteosynthesis would withstand a greater force, but this would only squash the femoral head. The frictional resistance at the site of the fracture is not shown but will be considered later.

Using the same notation as in the previous situation and inserting numerical values \( \alpha = 60, \ \ell = 3.5" , \ s = 2.25" \) we obtain from the two equations below:

\[ F \cos 60 \times \ell - L \times s = M \quad \text{(21)} \]
\[ F \cos 60 = L - P \quad \text{(22)} \]

\[ L = 244 \text{ lbs and } P = 41 \text{ lbs.} \]

The relevant shear force and bending moment diagrams are shown in Fig. 50. The maximum shear force is 285 lbs. The reactive force produced by the inferior cervical cortex is 244 lbs. The bending moment at the fracture equals 357 lb ins. Subsequently the moment rises slowly to reach its maximum of 448 lb ins at the junction. In theory only a round stainless steel rod with a diameter of \( \frac{1}{8}" \) can withstand moments of this order. In practice, however, such an osteosynthesis can withstand forces of the order of 570 lbs and is, therefore, perfectly stable on walking, because the considerable axial thrust of 492 lbs much greater than in situations 2.1.8 and 2.1.9 firmly impacts the fragments and absorbs a substantial portion of the load on the femoral head. For instance it can be calculated that specimen 7 in Table II, secured with a sliding pin, offered on loading a frictional resistance of at least 380 lbs acting as an internal force. With ordinary nail-plates impaction is less, but probably greater than the average value of 86 lbs used in the previous examples.

Horizontally disposed fractures are more stable still and it would appear that of the six methods examined this placement of the nail fixed to a plate provides the best internal fixation. Immediate weightbearing is permissible for vertical and horizontal fractures alike, although it may
not be wise to give this permission for fear of crushing capital cancellous bone.

The chief disadvantage of nail-plates, including Deyerle's multiple pins (1965), and of this method in particular, is that the nail may enter the acetabulum post-operatively. The axial thrust, \( F \times \sin \alpha \) in Fig. 50 amounts to fully 492 lbs, which is considerably in excess of the average value of 0.12 tons or 269 lbs which in three experiments sufficed to push nails through normal femoral heads. This complication can only occur in ambulant patients treated with nail-plates whose femoral necks become absorbed. The more steeply the nail has been placed the more readily this phenomenon, sometimes referred to as overdrive, will occur. A sliding pin readily obviates this danger.

2.2 TROCHANTERIC FRACTURES

Adequate fixation can only be provided by nail plates. It is essential that the tip of the nail should enter the tough cancellous bone of the femoral head and preferably it should end in or pass slightly beyond the intersection of the two trabecular systems. If the nail stops short of the femoral head it will migrate upwards, a coxa vara deformity will develop and union will be delayed as demonstrated in Fig. 28. The cancellous bone in the distal fragment is usually very soft and only produces a negligible reaction on the nail. It is customary to insert the nail in the bull's eye position in order to cut through the vastus lateralis as high as possible when exposing the shaft of the femur. This muscle is aponeurotic in the trochanteric region, but its thickness then increases and may reach 1 1/2" to 3" half way down the thigh. If the nail is inserted near vertically and a five hole plate is used the incision may well extend into the lower half of the thigh, a large expanse of muscle is laid open and the risks of cardiac arrest and post-operative infection are increased.
The bending moment and shear force diagrams are easily constructed. (Fig. 51) Under a sagittal load the bending moment rises until it reaches the nail-plate junction. As already shown in Fig. 47 the moment is then transferred to the femoral shaft in stages, usually four or five depending on the number of screw holes provided on the plate used. The shear force remains constant over the nail.

Assuming that a nail of length \( l \) has been inserted in the bull's eye position making an angle of 125° with the femoral shaft and that the femoral shaft itself makes an angle of 10° with the vertical, the bending moment \( M \) produced by a sagittal load \( F \) is given by:

\[
M = F \times l \times \cos 45
\]

and the shear force by:

\[
S = F \times \cos 45
\]

Now Foster (1958) has shown that a moment of 448 lb ins usually causes mechanical failure at the nail-plate junction. Let the nail have a length of 3\( \frac{3}{8} \)". Inserting these two values in the first of the two equations and solving for \( F \) we have:

\[
F = \frac{448}{3.75 \times 0.7} = 171 \text{ lbs}
\]

This comparatively low value for \( F \) means that patients with pinned trochanteric fractures who stand or walk on the operation leg too early will suffer a disaster such as depicted in Figs. 52 and 53. Only if there is firm impaction of the fragments or the patient has merely sustained a hairline fracture so that the soft tissues keep the fragments together can early weightbearing be permitted unless an exceptionally strong implant, (e.g. the one described by Holt (1963) ) is used which can withstand a moment of approximately 1900 lb ins. From formula 23 we can calculate that the margin of safety of this device is of the order of 400 - 500 lb ins if the nail is 3\( \frac{3}{8} \)" long and a sagittal force of 570 lbs is assumed to act on the femoral head of an ambulant patient.
2.3 SUMMARY

Cervical fractures - Bending moment and shear force diagrams have been constructed for the following six positions:

(a) The bull's eye position - If the patient is suffering from osteoporosis, immobilisation of the fracture is impossible even if walking is prohibited. If the bone is of normal consistency early ambulation is permissible only if the fracture line is horizontal, and this applies as well if four Austin-Moore wires are used.

(b) Pin parallel to cervical axis resting on inferior cervical cortex - This method has little to recommend it providing about the same degree of internal fixation as in method (a).

(c) The near vertical position - Early ambulation is permissible for all degrees of obliquity of the fracture line if the nail is correctly placed.

(d) Nail in bull's eye position attached to a plate - Irrespective of whether there is osteoporosis and little frictional resistance at the site of the fracture or the consistency of the bone is normal and substantial resistance to movement is offered at the site of the fracture, early ambulation is permissible only if the fracture line is horizontally disposed.

(e) Nail inserted parallel to cervical axis resting on inferior cervical cortex and attached to a plate - In vertically disposed fractures early weightbearing will cause bending of the pin. Only if the fracture line is mainly horizontal is early ambulation permissible.

(f) Near vertical nail attached to a plate - Early ambulation is permissible for all degrees of obliquity of the fracture line if the nail is correctly placed. It has been stressed that in all cases early weightbearing may crush the capital cancellous bone between pin and acetabulum.

Trochanteric fractures - Nail plates are essential for the internal
fixation of these fractures. It is customary to insert these in the bull's eye position to avoid excessive surgical trauma to the vastus lateralis. Early ambulation results in a large bending moment on the nail-plate junction and can only be permitted if the implant used is exceptionally strong, the fragments are firmly impacted, or the patient merely sustained an undisplaced hairline fracture.
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CHAPTER III
A NEW SLIDING PIN

In 1931 Smith-Petersen, Cave and Vangorder reported a series of femoral neck fractures treated by internal fixation. They exposed the hip and under direct vision, reduced the fracture and fixed it by means of a three flanged nail. Since then the technique has been improved to such an extent that with the aid of a mobile image intensifier one of the writer's colleagues can insert a trifin nail through a 1" incision in seven minutes. But the failure rate of this method is 50% (Eyre-Brook and Pridy, 1941; Charnley, Blockey and Purser, 1957; Harrold, 1960).

It was only natural that alternative techniques should have been developed. The catalogues of Surgical Instrument manufacturers are full of implants which can be used for treating fractured hips. Yet not a single one of these gives a uniformly high rate of good results.

3.1 DEVICES USED FOR THE INTERNAL FIXATION OF FEMORAL NECK FRACTURES

These may be classified as follows:

(a) Simple nails, screws with or without compression springs, and multiple small pins. It has already been demonstrated in Chapter II that none of these implants can provide firm fixation of vertically disposed fractures.

(b) Nail plates. These firmly secure these fractures. However, the tips of the nails are apt to enter the acetabulum as a portion of the femoral neck becomes absorbed whilst the fracture is healing. Alternatively the nail tends to keep the fragments apart because it cannot back out laterally. These two drawbacks are overcome by sliding nails. Of these the only one with a compression spring is the one designed by Charnley et al. (1957). None of these implants has been outstandingly successful. Moreover, all the sliding pins available at present are somewhat weak and tend to break or
to bend when a heavy patient walks on his ununited vertically disposed fracture.

(c) Two crossed screws. Fixation by means of two lag screws, one making an angle of $30^\circ$ with the vertical and resting on the inferior cervical cortex and the other near horizontal was advocated by Garden (1964). Smyth et al (1964) added a bracket to which the screws were bolted. In the writer's experience, these brackets always back away from the femoral shaft causing pain on the outer side of the hip.

The undesirable features of the devices used for the treatment of fractured femoral necks fall into five groups.

(a) Damage to the femoral head by nailing. It has already been shown in Chapter I that pile driving a blunt object, such as a trifin nail, into the head of the femur can be damaging.

(b) Inadequate immobilization. Haboush (1954) showed convincingly that a vertical femoral hip fracture could only be adequately immobilized by means of a nail plate with the nail traversing the fracture and the plate being screwed to the femoral shaft. He called this method shaft fixation. A simple pin, even if placed as vertically as possible, does not secure fractures of the femoral neck rigidly.

(c) Inadequate strength of the implant. Many of the patients with fractured hips are elderly and confused. Directly they find that their injured hip has been rendered comparatively painless by internal fixation they start to walk even if firmly instructed not to put any weight on their injured limb. Since only nail-plates provide adequate fixation the nail-plate junction must be able to withstand a bending moment of the order of 800 - 1 000 lb ins as described in Chapter II.

(d) Separation of the fragments. Any implant that is hammered across a femoral neck fracture tends to separate the fragments and the gap created thereby cannot always be abolished by applying a series of hammer blows to the lateral aspect of the femoral shaft by means of a so-called impactor.
Seldom is the displacement as gross as shown in Fig. 54, but minor degrees are quite common.

(e) Projecting pieces of metal from the outer aspect of the femur.

Having seen the sliding pin described by Charnley, Blockey and Purser, (1957) cause ulceration of the skin just distal to the great trochanter, the writer felt that no implant that backed out laterally from the shaft of the femur was suitable for the treatment of femoral neck fractures. This view rules out the so-called Charnley pin, the sliding pins described by Schumpelick and Jantzen (1955) as well as Pugh (1955). Similar objections apply to the triangle pinning developed by Smyth et al (1964).

In view of the above considerations and the analysis of the internal fixation of femoral neck fractures presented in Chapter II the writer felt that there was room for a new sliding pin and he was fortunate to obtain the necessary help.

3.2 NEW SLIDING PIN

In order to avoid the faults described in the preceding section a new sliding pin was developed. It consists of:

(1) a pin,

(2) a tube-plate, and

(3) a locking device. (Fig. 55)

The proximal portion of the pin was given a screw thread in order to screw the pin into the femoral head thereby preventing any damage which hammering might cause. A triangular thread with a wide base and a comparatively narrow (\(\frac{1}{4}\)")) root diameter was chosen, so that a substantial female thread in the cancellous bone of the femoral head is formed and firmly grips the tip of the implant as it is screwed home. The pin itself can slide in the hollow portion of the tube-plate thereby giving the muscles round the hip joint the opportunity to keep the fragments in firm apposition. The tube-plate provides the shaft fixation and rigid immobilization of
the femoral neck fracture already discussed. The pin itself and the
junction between the plate and the tube are made strong enough to withstand
the bending moment which walking produces. The dimensions of the implant
were carefully worked out so that the lateral end of the pin does not form
a metallic spur on the outer side of the femur even if a substantial
portion of the femoral neck disappears during the healing process. The
purpose of the locking device is to keep the pin in the femoral head.
A detailed description of the three components all manufactured from
EN 58J steel now follows:

(1) The pin. This is machined from a \( \frac{3}{8} \)" diameter stainless steel
rod. The proximal 1" has a triangular screw thread. The root diameter
is \( \frac{3}{8} \)" and the pitch 1/6". The distal 1" of the pin is square. The pin
is supplied in eleven sizes going up by \( \frac{1}{4} \)" steps. It is important to
realise that the length stamped on the pin corresponds to the distance
from the pin-plate junction to the tip of the pin, when the pin is fully
screwed into the head of the femur. The actual length of the pin is \( \frac{1}{2} \)" less.

(2) The tube-plate. The external diameter of the tube is \( \frac{1}{2} \)". It is
attached to a plate. The angle between the tube and the plate equals 135°.
Although the neck-shaft angle of the femur is about 10° less, a greater
angle was deliberately chosen to give the pin a more vertical position and
thereby to lessen the bending moment on the implant as explained in the
previous chapter. An even greater angle, although desirable, would have
made it impossible to treat patients with a coxa vara deformity unless,
of course, a number of implants were provided which we wanted to avoid.
Initially only three hole plates were made, but later on when it was
decided to treat trochanteric fractures as well, the plate was lengthened
to receive five screws. The length of the tubular portion is 2" and the
lengths of the plates are \( 2\frac{3}{4} \)" and \( 4\frac{1}{2} \)" respectively.

(3) The locking device. This miniature tube-plate prevents rotation
and extrusion of the pin. Its tubular portion contains a square keyway
which engages the distal square end of the pin when inserted into the large tube. The miniature plate has a hole exactly opposite the first hole in the large plate so that the two plates can be screwed together with one screw. (Fig. 55, central and right illustrations.)

Testing of the new implant revealed that it was innocuous and of adequate mechanical strength. Even if the point of the pin was screwed right up to the articular cartilage of cadaveric specimens, the femoral head was not damaged, as reference to Figs. 56 - 58 shows. No metallic spurs project from the lateral aspect of the femur, yet provision is made for disappearance of the whole of the superior cortex of the femoral neck because fully 1" of telescoping is possible, as demonstrated in Fig. 55. The implant is strong enough for immediate weightbearing. Several tube-plates were tested to destruction by screwing the plates to a metal block and then applying a gradually increasing load to the top of the tube. It was found that the tube-plate junction of the earlier models could withstand a bending moment of 507 lb ins. Subsequently the tube-plate junction was thickened and the models currently in use can withstand a bending moment of 700 - 800 lb ins. At first sight this value appears low, but the axial component of the joint force created by walking firmly impacts the fragments, so that the tube-plate junction has to withstand a much smaller bending moment. If, on the other hand, no provision for sliding is made, a much stronger implant must be used, e.g. the one described by Holt (1963).

Before the implant was used on patients an experimentally produced femoral neck fracture was pinned and an increasing vertical load was applied to the femoral head. (Fig. 59). At first the capital fragment was firmly driven into the femoral neck. When the dial on the testing machine registered 629 lbs the femoral head split in two and dropped to the floor, but the implant itself was neither bent nor damaged. Since weightbearing even in heavy patients hardly ever produces a force in excess of 600 lbs
this experiment demonstrates that weightbearing is unlikely to bend such an implant, but that the femoral head may yield first.

3.2.1 Special Tools

A guide wire technique is used to insert the pin into the femoral head. Three introducers are available. Of these the one most frequently used is shown in Fig. 60. It is a parallelepiped with three parallel channels \(\frac{3}{8}\)" apart making an angle of 45° with the long axis. The medial side of this block is hollowed for the shaft of the femur. The lateral side is straight. The proximal edge of the block is meant to abut against the vastus lateralis ridge on the great trochanter. Two additional introducers and the remaining tools are shown in Figs. 61, a - g.

(a) is an alternative guide wire introducer which is useful if the shaft of the femur is curved. It consists of a tube for the guide wire fixed to a plate at an angle of 135°. The lower portion of this plate can be clamped to the femoral shaft leaving a small space superiorly so that the distal portion of the plate can be firmly fixed to the femoral shaft with two or more screws depending on the length of plate used and only the cephalad screw traverses an empty space. If the distal portion of the plate is allowed to diverge from the shaft of the femur the screws would have to traverse a much larger gap distally and screws longer than 2", the maximum length usually supplied, would have to be used. Neither situation is desirable, but experience has shown that distal divergence of a plate from the femur causes more pain than a proximal space between metal and cortex.

(b) a caliper with two guide wire channels which is used if one guide wire is correct in the antero-posterior view and it is necessary to correct an angular displacement in the lateral view. This caliper is a must if the glutaeus maximum insertion encroaches unduly on the lateral aspect of the femoral shaft rendering the application of the guide wire block difficult.
(c) a counter bore tool, the same diameter as the tube to be inserted. It is passed over the finally selected guide wire and is turned by an electric or pneumatic drill. This instrument cuts a circular hole through the femoral cortex without causing any splintering. A collar is provided to arrest its progress directly the desired penetration, \( \frac{4}{12} \)" in excess of the length of the tubular portion of the implant, has been reached.

(d) a notched cannulated cylinder chamfered at is proximal end. The notches are \( \frac{1}{4} " \) apart. This device is passed up one of the guide wires inserted until its apical portion is in contact with bone. X-Rays are now taken. If the films show that the guide wire is, say, three notches shorter than it should be, the surgeon knows that he has to add \( \frac{3}{4} " \) to the length of the guide wire inside the bone to obtain the correct length of the pin to be inserted. (Fig. 62) In the lateral radiograph the chamfered end of the cylinder indicates where the guide wire enters the bone making it possible to estimate, or to measure with a protractor, the angular displacement of the guide wire. (Fig. 63)

(e) a 7" direct reading rule to measure the length of a 7" guide wire inside the femur. This rule is calibrated in inches from right to left. Attached to the last inch on the left is a cannula for the guide wire projecting from the femur. When the tip of the cannula touches the bone a reading taken where the guide wire ends gives the length of the guide wire inside the upper end of the femur.

(f) a calibrated flat drill with an adjustable collar with marks ranging from \( 3\frac{1}{2} " \) to 5". Its width is half-way between the root and the outside diameters of the threaded portion of the pin.

(g) a box spanner to screw the pin into the femoral head through the tube.

The guide wire introducers, especially the parallelepiped, the counter bore tool, the notched cannulated cylinder and the direct reading rule can, of course, be used for the insertion of other nail plates. The counter bore tool is especially valuable to perforate the lateral cortex prior to
insertion of a nail. If a gouge is used to make a small hole in the cortex or worse still the nail is hammered into the femoral head without any precautions, complete and partial fractures of the lateral cortex are frequently produced.

3.3 SUMMARY

A sliding pin made of EN 58J steel has been described. It consists of a pin which is screwed into the head of the femur, a tube-plate and a locking device. This implant does not damage the femoral head. It is so designed that muscular action keeps the fragments in compression. Fixation of femoral and trochanteric fractures is rigid. The tube-plate junction is strong enough for early weightbearing. The patient can lie on the operated side because there are no pain-producing pieces of metal projecting from the lateral aspect of the femur. When a femoral neck fracture was tested to destruction the femoral head of the specimen fractured, but the implant itself was not damaged. For the insertion of this sliding pin special tools had to be designed.
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Triangle Pinning for Fracture of the Femoral Neck.
Both cervical and trochanteric fractures were treated by this method. The results will be presented in this chapter.

4.1 CERVICAL FRACTURES

4.1.1 Technique of Operation

Only a few points need special emphasis. The patient is placed on an orthopaedic table and the fracture is reduced. The injured limb should be fixed to the foot portion of the table with the thigh horizontal and the leg in internal rotation. In this position the central axis of the femoral neck is horizontal because internal rotation cancels out anteversion. The foot is fixed to the footplate of the table with a complete roll of adhesive elastic plaster. The back of the heel is left completely unsupported to prevent any subsequent sloughing. (Fig. 64) With the aid of one of the special introducers two guide wires, one high and the other low, are driven into the head of the femur with a power tool. They should pierce the centre of the lateral cortex and be horizontal. It is essential to place one guide wire correctly, so that it passes through the intersection of the two trabecular systems in the antero-posterior and lateral radiographs. The counterbore tool is then passed over the selected guide wire and advanced until its collar makes contact with the cortex. The cannulated cylinder is next pushed up the guide wire as high as it will go. A three-hole tube-plate is now inserted over the cylinder, gently tapped into position until the plate lies snugly against the femoral shaft to which it is secured by a screw through the distal hole. After the femoral head has been steadied with two extra guide wires (Fig. 66) the cannulated cylinder plus its guide wire is withdrawn. The flat drill, whose collar has been pre-set to the right
<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age</th>
<th>Survival in Days</th>
<th>Cause of Death</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>88</td>
<td>21</td>
<td>Broncho-pneumonia</td>
</tr>
<tr>
<td>15</td>
<td>83</td>
<td>30</td>
<td>Pyelitis</td>
</tr>
<tr>
<td>19</td>
<td>86</td>
<td>30</td>
<td>Uraemia</td>
</tr>
<tr>
<td>24</td>
<td>78</td>
<td>11</td>
<td>Broncho-pneumonia</td>
</tr>
<tr>
<td>40</td>
<td>85</td>
<td>4</td>
<td>Cerebral thrombosis</td>
</tr>
<tr>
<td>41</td>
<td>81</td>
<td>5</td>
<td>Influenza</td>
</tr>
<tr>
<td>43</td>
<td>80</td>
<td>3</td>
<td>Perforated duodenal ulcer</td>
</tr>
<tr>
<td>56</td>
<td>85</td>
<td>31</td>
<td>Coronary thrombosis</td>
</tr>
<tr>
<td>64</td>
<td>92</td>
<td>5</td>
<td>Lobar pneumonia</td>
</tr>
<tr>
<td>69</td>
<td>88</td>
<td>10</td>
<td>Broncho-pneumonia, pyelonephritis</td>
</tr>
<tr>
<td>80</td>
<td>94</td>
<td>14</td>
<td>Coronary thrombosis</td>
</tr>
<tr>
<td>82</td>
<td>78</td>
<td>30</td>
<td>Pulmonary embolus</td>
</tr>
<tr>
<td>91</td>
<td>81</td>
<td>9</td>
<td>Congestive cardiac failure</td>
</tr>
<tr>
<td>98</td>
<td>82</td>
<td>21</td>
<td>Unknown</td>
</tr>
</tbody>
</table>
depth is then used to ream out a hole for the pin. A pin of measured length is now screwed into the femoral head. X-Rays are taken. If necessary the pin can be screwed out again and replaced by one of the correct length. Finally the locking device and the last two screws are inserted and the two guide wires are withdrawn. Provided that the operator is reasonably skilled and there are no mishaps, the operation can easily be completed in 45 minutes to one hour. With an image intensifier it should be possible to reduce the operating time to 30 minutes.

4.1.2 Clinical Results

In 1965 all the patients with femoral neck fractures operated on between May 1958 and February 1963 were reviewed. They numbered 103. Of these only 55 patients, 14 men and 41 women, are available for study of the late results. The remaining 48 patients are accounted for as follows:

(a) 24 operative failures, including two attempted salvage operations after failed trifin nailings, four poorly reduced fractures and eighteen grossly off-centre pinnings.

(b) 20 deaths before the outcome of the treatment could be assessed. The hips of these patients had been adequately pinned. Table V shows the causes of death of 14 patients who died in hospital during the first post-operative month.

(c) A female patient aged 80 who fell on her hip again 18 months after pinning. Her fracture was united at that time. She sustained an undisplaced second fracture of the femoral neck, not a re-fracture. Her femoral head subsequently collapsed and it was impossible to state whether the first or the second fracture was responsible for this complication.

(d) Two cases of infection of the hip.

(e) One patient lost to follow-up a few weeks after operation.
TABLE VI

CERVICAL FRACTURES

LATE RESULTS OF TREATMENT IN 55 CASES

<table>
<thead>
<tr>
<th>Age Group in Decades</th>
<th>Number</th>
<th>Unions</th>
<th>Non-Unions</th>
<th>Avascular necrosis (collapse after union)</th>
<th>Osteo-Arthritis</th>
<th>Failures</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 - 49</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>50 - 59</td>
<td>8</td>
<td>8</td>
<td>-</td>
<td>3</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>60 - 69</td>
<td>6</td>
<td>6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>70 - 79</td>
<td>21</td>
<td>19</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>80 - 89</td>
<td>16</td>
<td>14</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>4</td>
</tr>
<tr>
<td>90 - 99</td>
<td>2</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>TOTAL</td>
<td>55</td>
<td>51</td>
<td>4</td>
<td>8</td>
<td>1</td>
<td>12</td>
</tr>
</tbody>
</table>
The series was now reduced to 55 survivors, 14 men and 41 women. Of these 49 had vertical fractures and 4 had horizontal fractures using the simple classification in Chapter I. One patient had an impacted vertical fracture which subsequently became disimpacted. There was only one horizontal fracture with minimal displacement. The remaining 53 cases demonstrated a varus deformity of the hip with the leg in external rotation.

The results arranged according to age groups are shown in Table VI. The fractures of the 14 men all united, but two femoral heads collapsed after union and one hip developed osteoarthritic changes. Concerning the 41 female survivors the pin cut out of the femoral head in four instances, but two of these patients were suffering from rheumatoid arthritis. Thirty-seven fractures united, but six femoral heads subsequently collapsed. These six patients did not have disabling pain when reviewed. Nevertheless they are presented as failures because they are suffering from a progressive condition which makes further operative interference necessary, provided the patient lives long enough and remains fit for further surgery. Strangely enough there were no collapsed ununited femoral heads in this series. The healing time of the individual cases arranged according to age groups is shown in Table VII.

4.1.3 Discussion
4.1.3.1 The Quality of the Operation

Twenty four hips were poorly pinned. This was unavoidable in two cases (failed trifin nailings) where after extraction of the previous implants the writer's pin was screwed into an intact portion of the femoral head and had to be marginally inserted. In the remaining twenty two cases reduction of the fracture was poor in four instances and in eighteen cases the insertion of the pin was grossly off-centre. For maximum holding power the implant must be inserted into the toughest portion of the femoral head, the intersection of the lateral and medial trabecular systems.
<table>
<thead>
<tr>
<th>Age Group</th>
<th>Number of Patients</th>
<th>Healing time (months) of individual cases</th>
</tr>
</thead>
<tbody>
<tr>
<td>90 - 99</td>
<td>2</td>
<td>6, 6</td>
</tr>
<tr>
<td>80 - 89</td>
<td>14</td>
<td>4, 5, 2.5, 2, 12, 2, 3, 3, 4, 4, 3, n.a., 8, n.a.</td>
</tr>
<tr>
<td>70 - 79</td>
<td>19</td>
<td>6, 4, 7, 3, 2.5, 13, 2, 5, 5, 1, 5, 5, n.a., 2, 5, 3, 3, 12, 6.</td>
</tr>
<tr>
<td>60 - 69</td>
<td>6</td>
<td>11, 3, 4.5, 3, 5, 2.</td>
</tr>
<tr>
<td>50 - 59</td>
<td>8</td>
<td>4, 5, 5, 3, 6, 5, 3, 4.</td>
</tr>
<tr>
<td>40 - 49</td>
<td>2</td>
<td>8, 5</td>
</tr>
</tbody>
</table>

n.a. = not ascertained

Arithmetical mean = 4.8 months
However, it is permissible to place the pin just behind the centre of the femoral head. The reason is that the composite implant used is fixed to the shaft of the femur, which in all these cases tends to roll outwards thereby pushing the pin forwards through the femoral head. The above-mentioned placement resists this movement as suggested by Strange (1965).

There were two reasons for twenty two poorly performed operations:

4.1.3.2 The Operators

The patients reviewed here were operated on by the writer and his registrars. No junior colleague was allowed to operate on these hips until and unless he had assisted the writer once and had in turn been assisted twice. All the patients reviewed here were treated at so-called peripheral hospitals. Hargadon and Pearson (1963) working at a teaching hospital reported two poorly inserted pins in their series of 75 cases. They used, of course, Charnley's pin which requires more technical skill for its insertion than the writer's implant. The greater incidence of operative failures in this series highlights the difficulty peripheral hospitals have in recruiting top-flight junior surgeons. Strangely enough they are all keenly interested in being taught how to insert a Thompson or Moore prosthesis and the majority of them become reasonably proficient in this operation, which is more complicated than the accurate insertion of a pin into the centre of the femoral head.

This somewhat dismal picture is the outcome of Government policy and inadequate representation of peripheral hospitals at policy-framing committees.

4.1.3.3 Radiography

The majority of radiographers succeed in providing reasonable antero-posterior radiographs of patients' hips in the operating theatre. Unfortunately quite frequently the joint space of the hip and the head and neck of the femur are poorly visualized in the lateral view. If there is
under-penetration or under-exposure, the target area is shrouded in a grey fog, but if there is over-exposure the fog is black.

It is desirable that the surgeon performing the operation should know the exposure factors so that, if necessary, he can come to the radiographer's aid.

The average factors are:

**A - P radiographs:**
- **Film focus distance**: 36"
- **kV**: 80
- **mA**: 15 \( \rightarrow \) 7.5 - 12
- **Exposure time**: 0.5 - 0.8 sec. \( \rightarrow \) MAS

**Lateral radiographs:**
- **Film focus distance**: 36"
- **kV**: 80
- **mA**: 15 - 20 \( \rightarrow \) 15 - 20
- **Exposure time**: 1 sec. \( \rightarrow \) MAS

The above factors apply to fast film used in conjunction with a fast intensifying screen. Scatter is reduced by using a long cone. If a grid cassette is used as well, the exposure times given above are increased by a factor of \( 2\frac{1}{2} - 3 \). Further, if the patient has massive thighs, the exposure time must also be increased. It must be decreased if his limbs are lean or if the film focus distance is less than 36".

A rapid developer and a rapid fixer should always be used so that fully processed negatives can be examined within forty to sixty seconds.

4.1.3.4 **Analysis of Results**

Three comparable series together with the writer's own are presented in Table VIII.
**TABLE VIII**

<table>
<thead>
<tr>
<th>Authors</th>
<th>Number of cases</th>
<th>Union</th>
<th>Non-union</th>
<th>Late collapse</th>
<th>Total failure rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hargadon and Pearson (1963)</td>
<td>58</td>
<td>38</td>
<td>20</td>
<td>9</td>
<td>50%</td>
</tr>
<tr>
<td>Brown and Adami (1964)</td>
<td>146</td>
<td>100</td>
<td>46*</td>
<td>28</td>
<td>51%</td>
</tr>
<tr>
<td>Smyth et al (1964)</td>
<td>45</td>
<td>38</td>
<td>7</td>
<td>15</td>
<td>49%</td>
</tr>
<tr>
<td>Present series</td>
<td>82</td>
<td>51</td>
<td>31</td>
<td>8</td>
<td>48%</td>
</tr>
</tbody>
</table>

* Their doubtful cases are included in this square
Examination of the last column of this table reveals the sombre fact that a patient with a fracture of the neck of the femur only stands a fifty-fifty chance of walking normally again after his hip has been pinned. The methods analysed in this table are rather sophisticated ones, yet the results are no better than those achieved by the use of a trifin nail.

However, there is an alternative method of analysis. In reviewing Charnley's pin, Hargadon and Pearson (1963) excluded eight cases of operative failure, namely, breaking of the screw in four cases, poor surgery in two cases, inability of the femoral head to withstand compression in one case and sepsis in another. While in the series here presented not a single implant fractured, the results were chiefly marred by poor surgery. Since the efficacy of the new implant rather than the skill of a number of operators is on trial, the writer considers it reasonable to follow the example of the above two authors and to analyse separately the survivors whose hips had been pinned accurately. The picture that now emerges is totally different.

Fifty-five femoral neck fractures were pinned. Of these one was an undisplaced horizontal fracture which would have united by any method of adequate internal fixation. This leaves fifty-four cases, all displaced fractures. Fifty (92.5%) united, eight (14.8%) femoral heads collapsed after union, so that the total number of unsatisfactory results was twelve, corresponding to a failure rate of 22.2%. The chi square test reveals that the probability of such a result occurring due to chance alone is well below the 1.0% level.

4.1.3.5 Classification of cervical fractures

After the writer had studied the paper by Hargadon and Pearson (1963) he made no attempt to determine the angle of the fracture adequately. Moreover, extensive experience with immediate prosthetic replacement of the
capital fragment has shown that these injuries are quite frequently ball
and cup fractures, that they are often comminuted, and that in many
instances periosteum is interposed between the fragments inferiorly. The
two last-mentioned factors are probably of considerable importance, but
unfortunately they cannot be determined radiologically.

Further, it is quite unnecessary to distinguish between subcapital
and transcervical fractures. Klenerman and Marcuson (1970) have suggested
that this distinction is the result of radiological interpretation without
consideration of the effects of varying degrees of rotation.

In this thesis cervical fractures have been divided into vertical and
horizontal fractures as explained in Chapter I. Either type may be impacted,
undisplaced or displaced, so that there are altogether six groups.
Impacted fractures are usually treated conservatively. However, included
in this series is one impacted vertical fracture which subsequently became
disimpacted and displaced. Horizontal fractures with minimal displacement
do not usually give rise to difficulty in treatment, and for this reason
the one example belonging to this group has been excluded from the analysis
dealing with the efficacy of the method under discussion. There were four
horizontal fractures. They all united, but their number was too small for
statistical analysis. The question of the classification of these fractures
will be further considered in the final chapter of this thesis.

4.1.3.6 Timing of the Operation

Very few of these hips were pinned as emergencies. The majority were
operated upon during the next operating session so that in most cases the
delay amounted to three or four days. Several patients were suffering from
gross cardiac failure and had to have medical treatment before the
anaesthetist was prepared to accept them as reasonable risks. It is
obviously desirable to perform internal fixation as soon as possible, but
our facilities are limited, and for this reason some delay is inevitable.
Early Walking

Weightbearing before union was discouraged at first because it was felt that placing a load on the femoral head might cause the pin to cut out or the femoral head itself to collapse. However, it was soon realised (as will be explained in Chapter X) that deferring walking might merely put off the evil day. Therefore, in the long run nothing is gained by keeping the patient off his feet. For this reason the writer now encourages his patients to resume weightbearing early. They are sat out of bed the day after the operation. Their active rehabilitation starts a few days later directly the cut muscles on the outer aspect of their thighs cease to be painful. Full weightbearing is permitted directly the patient feels fit enough to do so and the hip is sufficiently painless, usually three weeks after operation.

Strength of Implant

Not a single implant fractured. By comparison Hargadon and Pearson (1963) reported breaking of Charnley's pin in four cases in their review of 100 patients. To avoid mechanical failure of the writer's screw any requests to provide a central cannula, which would undoubtedly facilitate insertion, have been firmly resisted.

Age of Patients

There are two cases in this series, a man and a woman, both well over 90 who, two years after operation, have normal hips. Age alone is, therefore, no contr-indication to internal fixation. Nor does age affect the rate of healing as reference to Table VII clearly shows. In the 80 - 89 year group there are two patients whose fractures healed in two months, whereas the fractures of the two patients in the 40 - 49 year old group took eight months and five months respectively to unite.
4.1.3.10 Follow-up

The importance of a long follow-up cannot be over-stressed. One patient in this series had a radiologically normal femoral head in two years, yet at forty months it was completely collapsed. Ideally all these cases should be followed up five years, but in practice this would present insuperable difficulties. The expectation of life of many of these patients is well below five years. They frequently leave the catchment areas of the Hospitals where they are operated on and are then difficult to trace.

4.1.3.11 Re-pinning

Five failed trifin nailings were re-pinned with the writer's implant. One patient was lost to follow-up. Two fractures united and two did not. An illustrative case is shown in Figs. 65 - 67.

Case report 8 - The patient was a woman aged 64 years. Her vertical fracture was originally treated with a trifin nail. When this cut out in two weeks, the writer's pin was inserted twenty-three days after the first nailing. Bony union occurred. The telescoping amounted to almost 1". Thirteen months after operation the hip was painless.

In spite of the experimental findings presented in Chapter I a good case can be made for re-pinning these trifin nailings. Judging from this limited experience the patient can be offered a fifty-fifty chance of a normal hip. If the second operation fails a prosthesis can be inserted.

4.1.3.12 Osteoporosis

Fifty-four displaced fractures were treated. The fractures of the fourteen men all united and only two femoral heads collapsed after union. On the other hand in forty-one female patients reviewed the pin cut out of the femoral head in four instances, but two of the patients were suffering from rheumatoid arthritis. Thirty-seven fractures united but six femoral heads collapsed after union. It is a well-known fact that osteoporosis
is commoner in women than in men. Rheumatoid arthritis unquestionably causes bony softening. The above findings, therefore, strongly suggest that the outcome of a hip pinning may depend upon the degree of osteoporosis of the patient's femoral head. This point will be further examined in Chapter X and XI.

4.2 TROCHANTERIC FRACTURES

4.2.1 Technique

A four or usually five-hole plate is used depending on the length of the patient's femur. The fractured limb should be fixed on the orthopaedic table either in neutral or preferably external rotation. The reason for this position is based on the anatomy of the upper end of the femur. The fracture line passes through the inter-trochanteric line in front and the inter-trochanteric crest behind. Usually there is posterior comminution. The proximal fragment cannot be manipulated, but the distal fragment can be externally rotated to close the fracture gap.

4.2.2 Clinical Results

As far as the writer is aware there has been only one previous paper on trochanteric fractures treated by a sliding pin, namely, one by Schumpelick and Jantzen (1955) who reported 28 cases. In this section a much larger series will be presented.

Only basal, inter- and peri-trochanteric and comminuted trochanteric fractures were pinned. (Fig. 68) Subtrochanteric fractures with reversed obliquity (Evans, 1951) and fractures involving the upper third of the femur were not treated by this method. The operators were the writer and his registrars.

Between May 1958 and December 1963, 100 of these fractures were dealt with. One patient fractured both her hips so that only 99 patients were reviewed. Of these 28 were men and 71 women. Their average age was
77.5 years. The age distribution is shown in Fig. 69 and the follow-up in Fig. 70.

At the time of the review in February/March 1965, 41 patients were dead. Fifteen died within a month of their operation and the causes of death and survival periods are shown in Table IX.

There were no known non-unions. Amongst the 41 fatalities, 21 died with their fractures united, but in twelve cases union had not yet occurred and our records of 8 dead patients were incomplete. The time to early union was ascertained in 74 cases. It averaged 1.6 months or 48 days. The criteria for early union were painless hip movements, absence of tenderness and disappearance of the fracture line across the neck-shaft junction. Nevertheless, when there was union at the neck-shaft junction, the patient was usually able to walk without pain. Firm radiological consolidation usually took four to six months.

The telescoping was assessed in 78 cases. The range was from $\frac{1}{8}$" to 1". The average was about 0.4". Fortunately not a single case of sepsis occurred.

The following complications were observed: Bending of the plate at the first screw-hole - 2 cases; overdrive due to faulty technique - 1 case; mild coxa vara due to inadequate mechanical strength of the proximal fragment causing upward movement of the pin - in 30% of the cases.

The fracture of the two patients whose plate bent were reported on by our Radiologists as having united in 62 days and 23 days respectively. As a result of this experience the plate was strengthened and no further cases of bending occurred. There were no fractures of the plate in this series.

A case with fairly rapid bony union is herewith reported:

Case Report 9 - Mrs. A. H., aged 81 years, had her trochanteric fracture (Fig. 71) pinned a few hours after injury (4th October, 1958) (Fig. 72). Thirty nine days after injury (12th November, 1958) there was early bony
# TABLE IX

## TROCHANTERIC FRACTURES

### DEATH WITHIN ONE MONTH OF OPERATION

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age</th>
<th>Survival after operation (days)</th>
<th>Cause of Death</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>88</td>
<td>21</td>
<td>Broncho-pneumonia</td>
</tr>
<tr>
<td>15</td>
<td>83</td>
<td>30</td>
<td>Pyelitis</td>
</tr>
<tr>
<td>16</td>
<td>75</td>
<td>23</td>
<td>Carcinoma of tongue</td>
</tr>
<tr>
<td>19</td>
<td>86</td>
<td>30</td>
<td>Uraemia</td>
</tr>
<tr>
<td>24</td>
<td>78</td>
<td>11</td>
<td>Broncho-pneumonia</td>
</tr>
<tr>
<td>40</td>
<td>85</td>
<td>4</td>
<td>Cerebral thrombosis</td>
</tr>
<tr>
<td>41</td>
<td>81</td>
<td>5</td>
<td>Influenza</td>
</tr>
<tr>
<td>43</td>
<td>80</td>
<td>3</td>
<td>Perforated duodenal ulcer</td>
</tr>
<tr>
<td>56</td>
<td>85</td>
<td>31</td>
<td>Coronary thrombosis</td>
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<tr>
<td>64</td>
<td>92</td>
<td>5</td>
<td>Lobar pneumonia</td>
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<tr>
<td>69</td>
<td>88</td>
<td>10</td>
<td>Broncho-pneumonia</td>
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<tr>
<td>80</td>
<td>94</td>
<td>14</td>
<td>Coronary thrombosis</td>
</tr>
<tr>
<td>82</td>
<td>78</td>
<td>30</td>
<td>Pulmonary embolus</td>
</tr>
<tr>
<td>91</td>
<td>81</td>
<td>9</td>
<td>Left ventricular failure</td>
</tr>
<tr>
<td>98</td>
<td>82</td>
<td>21</td>
<td>Broncho-pneumonia</td>
</tr>
</tbody>
</table>
union. (Fig. 73) Two months later (14th January, 1959) her fracture was consolidated. (Fig. 74) The telescoping amounted to 1/6th of an inch.

More rapid union was achieved in the following two cases:

Case Report 10 - Mrs. G. T., aged 85 years, sustained a comminuted per-trochanteric fracture on 22nd March, 1960. Internal fixation was performed on 26th March, 1960. Thirty one days after operation she died from coronary thrombosis. The main portion of the fracture was in compression and was firmly healed, but the fractured great trochanter, which was healing in tension, was not yet united. (Figs. 75, 76 and 77). Two separate slabs of cortical bone, including the line of the fracture across the shaft, were removed, one medially, the other laterally. They were both treated with trypsin to dissolve any residual collagen which might keep the fragments together, as suggested in Charnley's book (1953), but they did not fall apart. After decalcification the fragments could be hinged quite easily about the fracture line showing that such bony union as had occurred was not yet firm. Histological examination showed that there was no primary union of cortical bone as described by Perren et al (1969), because cartilage cells and osteoid tissue could be demonstrated. (Figs. 78 and 79).

Case Report 11 - Mr. E. D., aged 82 years, sustained a per-trochanteric fracture on the 24th March, 1963. Internal fixation was carried out on 26th March, 1963. He died from lobar pneumonia on the 17th April, 1963, 22 days after internal fixation. His fracture was uniting. (Figs. 80, 81 and 82). The post-mortem specimen was completely solid in one piece and it was impossible to obtain any movement at the site of the fracture by applying pressure to the femoral head or trying to pull the fragments apart. Because the detailed examination of the specimen described in the previous case history had resulted in its complete and utter destruction it was decided to forego the histology and to be satisfied with the gross appearance.
100 fractures were treated by this method. There were no mishaps of any kind and not a single hip became infected. Exact placement of the pin in the femoral head and accurate reduction of the fracture are less important than in femoral neck fractures. Not a single operator succeeded in transgressing the wide margin of error. All the fractures united uneventfully.

Two features call for special comment: (1) Penetration of the hip joint, quite frequently observed with Capener-Neufeld, Jewett and McLaughlin nail plates; occurs only if the technique is faulty. This so-called overdrive was seen only once in the present series. (2) The time to early union is short, only 48 days in this series, which compares very favourably with other series in which sliding pins were not used. For instance, Cleveland, Bosworth and Associates (1959) reported that their trochanteric fractures treated with Jewett nails united on an average in 4.5 months. In this series comminuted trochanteric, inter-trochanteric and per-trochanteric fractures all healed equally quickly. Although two specimens are presented in which the physiological compression produced by the sliding pin resulted in complete stability of the fracture in 22 and 31 days respectively, no claim is made that a sliding pin endows the osteoblasts near the fracture with magical qualities. The most that can be claimed is that this type of internal fixation rigidly holds the fragments together in close apposition allowing healing to occur under optimum conditions. Detailed examination of one specimen showed that primary bony union as described by Perren et al (1969) does not occur. Of course rapid union of bone under compression is no new discovery. Charnley (1953) showed convincingly that bony bridging across two compressed fragments of cancellous bone can occur in four weeks.
4.3.1 Mortality

At first sight the mortality appears rather high. In the first series 8 patients died within a month of their operation and another 12 in under one year. Of these 12, only one had a pulmonary embolus. The others died from natural causes. However, the average age of those who died was 80.75 years. In the second series fifteen patients died within a month and out of 99 patients operated on between May 1958 and December 1963, reviewed in February/March 1965, 41 patients were dead.

The mortality will always be high with this type of surgery because the patients are elderly and often decrepit. By refusing to operate on unfit patients with active bronchitis and advanced cardiac disease, the mortality could be appreciably lowered. But the risk of withholding operation is generally agreed to be greater than operating. Scuderi in discussing the paper by Cleveland, Bosworth and Associates (1959) stated: "If the patient survives the first three to five days after operation and then dies of something else, you shouldn't blame the surgeon." By this criterion the mortality for the two series would be only 2%.

4.3.2 Appraisal

The sliding pin here described offers secure, atraumatic fixation of cervical and trochanteric fractures alike. Early weightbearing is possible. If the radiographs taken in the theatre show that the pin is either too long or too short, it is very easy to screw it out and replace it by one of the correct length, whereas the extraction of a trifin nail can be very difficult. The provision of a sliding mechanism allows healing to occur in physiological compression by muscular action, rendering a bulky device with a compression spring completely unnecessary. There are no projecting metallic lumps on the outer side of the hip. The patient can lie on the operated side in comfort.
The chief disadvantages of this method are that with cervical fractures special care is needed and that the operation undoubtedly takes longer than the insertion of a trifin nail. Nevertheless, if the surgery is meticulous the success rate can approach 80%. It will never be 100% because in any series there will always be a number of elderly patients whose femoral heads will be so soft and spongy that the proximal end of any implant will work loose preventing adequate fixation of their fractures.

Fortunately the disappointing experience with cervical fractures was mellowed by the results obtained with trochanteric fractures. The two above-mentioned objections do not apply. The pin need not be placed accurately inserted into the centre of the femoral head. Provided that its tip firmly engages a portion of the capital cancellous bone, union will occur. Moreover, it is easier to insert the writer's implant than a McLaughlin nail plate. Because the fragments are not kept apart as they are if a conventional device is used, bony union occurs rapidly on an average in seven weeks.

4.4 SUMMARY

The experience gained from the use of a new sliding pin providing secure atraumatic fixation of femoral neck and trochanteric fractures is described. The implant in its final form is strong enough for early weightbearing.

103 cervical and 100 trochanteric fractures are reported. 44% of the cervical fractures failed to unite. The reasons for these comparatively poor results have been stated. Analysis of a subset comprising 55 adequately treated fractures showed a success rate of nearly 80%.

All the trochanteric fractures united. The average time to union was seven weeks, but two specimens are demonstrated in which there was complete mechanical stability 22 and 31 days respectively after internal fixation.
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CHAPTER V
THE ARTICULAR CARTILAGE AND THE SPONGY BONE OF THE UPPER END OF THE FEMUR

Reference to Table VI shows that avascular necrosis or collapse of the femoral head is the main cause of disappointment after a technically successful pinning of a femoral neck fracture. Before this phenomenon can be explained, it is necessary to carry out further studies including an examination of the minute anatomy of the upper end of the femur. The cortex of the femoral neck has to absorb tensile stresses superiorly and compressive stresses inferiorly. These stresses are lessened by the action of the articular cartilage on the head of the femur and the spongy bone inside the head and neck. The mechanical properties of these two structures will be analysed in this chapter.

5.1 THE ARTICULAR CARTILAGE

The upper end of the femur is covered by a layer of articular cartilage 3 - 4 mm thick. Like articular cartilage elsewhere it consists of cells, collagen fibres and ground substance.

The cartilage cells are flat and parallel to each other near the surface, but near the sub-chondral bone, from which they are separated by a thin layer of calcified cartilage, they are larger, oval and arranged in vertical rows forming definite clusters or chondrons. The function of the cartilage cells is to secrete ground substance and collagen fibres.

The ground substance consists of a mixture of hyaluronic acid, a jelly-like acidic polyacharid and chondroitin sulphate. This mixture is visco-elastic, a term applied to materials which, when stressed, do not deform in a linear manner and when the stress is removed do not regain their original shape in a short period of time. In the fifth decade these features become less marked owing to the gradual disappearance of chondroitin
The collagen fibres are doubly refractile. Their course was studied by Benninghoff (1925 a and b). They are normal to the subchondral plate but they intersect each other at angles of $70^\circ - 90^\circ$ in the middle-third of the articular cartilage and finally run parallel to the surface which normally is smooth or gently undulating and lined with a membrane-like structure (Meachin and Roy, 1969). Collagen contains glycine, proline hydroxy proline as well as a little sulphur. Proline is a five ring hetero-cyclic organic compound, related to pyrrole. The molecules of collagen consist of three coiled chains forming a helix which cannot be stretched (Datta and Ottoway, 1969).

The collagen fibres plus the ground substance are often referred to as the matrix. The fibres form a three dimensional network. Its interstices and pores are filled with a mixture of hyaluronic acid and chondroitin sulphate. Zarek and Edwards (1966) studied the behaviour of the matrix when loaded. When a load is applied statically the full weight of the load is taken by the matrix and transmitted to the subchondral bone. When the load is applied dynamically the external force acting on the articular cartilage equals the weight of the load plus the inertia force (mass by retardation). This greater force is partially absorbed by the cartilage so that the subchondral bone is protected to some extent. In either situation pore fluid is forced to the surface which is sometimes referred to as weeping lubrication. (McCutchen, 1959). This mechanism may well be responsible for the amazingly low co-efficient of friction of 0.013 which articular cartilage possesses. (Charnley, 1959.)

5.2 THE SPONGY BONE

The elements of bone are called osteons or Haversian systems. Such a unit consists of a central canal containing fluid round which spiral interlacing fibrils of collagen laden with calcium hydroxy apatite known
as lamellae. An individual osteon may have from three to eight lamellae and accordingly its diameter may range from 70 to 400μ. The length of an osteon is difficult to define because it anastomoses with nearby osteons, gives off branches and becomes continuous with interstitial lamellae running in various directions. Some lamellar systems encircle the bone completely and are known as circumferential lamellae. Where the lamellae are tightly packed they form cortical bone, but in the trabeculae of spongy bone they are more loosely arranged.

The minute anatomy of bone generally was studied by Knese (1958). He considers that the collagen fibres are pre-stressed because they lack the wavy appearance which they normally demonstrate. As a result they can to some extent absorb compressive stresses. Moreover, when the fluid in the Haversian canal is compressed they can resist the membrane stress produced thereby. He further suggests that bone resembles re-inforced concrete. In this compound material the compressive stresses are borne by the concrete and the tensile stresses are dealt with by pre-stressed steel. In bone the compressive stresses are borne by crystals and the tensile stresses are dealt with by collagen fibres which as previously stated are well designed for this function.

The dynamic force transmitting properties of subchondral cancellous bone and articular cartilage were compared by Radin, Paul and Lowy (1970). They found that cancellous bone was ten times stiffer than articular cartilage per unit of thickness and would, therefore, be well capable of acting as an energy absorber. They concluded that alteration in the quality of subchondral bone could have a profound effect on its ability to withstand compressive dynamic force. Both cartilage and cancellous bone can dissipate energy, but bone is more important because there is more of it. These three writers also mentioned that cartilage and bone demonstrated visco-elastic behaviour which could be represented by a so-called Voigt model, a single spring A in series with another spring B and a dashpot in parallel.
When a load is applied to this system spring A is responsible for some instant displacement, but owing to combined action of spring B and the dashpot in parallel the displacement increases exponentially after an interval.

5.2.1 Trabecular Arrangement

Near joints the subchondral bone is usually arranged in palisades normal to the subchondral bone. (Fig. 83) This orientation of the spongiosa is noted at the elbow, the distal radius, the metacarpals and phalanges of the hand, in the spinal column, at the knee, the ankle and the bones of the foot. Inside the head of the humerus there is no definite pattern. The trabecular arrangement inside the head and neck of the femur is different and has given rise to a great deal of speculation.

A system of trabeculae arches from the lateral femoral cortex at the base of the great trochanter to the inferior portion of the femoral head reaching its summit at the junction of the superior cervical cortex with the femoral head. In the centre of the femoral head these trabeculae are crossed at right angles by another trabecular system which extends from the end of the medial cervical cortex to the so-called weightbearing area at the top of the femoral head. (Fig. 84) Inside the femoral neck, bounded by the two trabecular systems and the neck-shaft junction laterally, there is a space normally occupied by bone marrow and devoid of spongy bone. In radiographs this area looks triangular and is often referred to as Ward's triangle. The right angled intersection of the two trabecular systems and their termination normal to the articular cartilage has given rise to the so-called trajectorial theory which tries to show that the trabecular pattern of the spongiosa coincides with the maximum principal stresses inside the bone end.

To understand this problem the stresses inside a cantilever loaded at its free end must be examined. (Fig. 85) The load $F$ produces
flexural and shear stresses. In the example shown the flexural stresses increase in the manner shown with the distance from the point of application of the load, but the shear stress remains constant. In an analysis of plane stress a given point inside the beam is regarded as a tiny square the sides of which are subjected to flexural and shear stresses. The original position of the square is such that two of its sides are parallel and the other two normal to the surfaces of the beam. It is always possible so to twist the square that the shear stress vanishes and the opposing sides are subjected to normal stresses only. (Fig. 85) These two stresses, which are maximum and minimum direct stresses at that point, are known as principal stresses. Two families of curves, one for principal tensile, the other for principal compressive stresses, can be constructed. These curves give the directions of the principal stresses at a number of points in a cantilever or any other loaded beam. Some distance away from the point of application of the load these curves are asymptotic or parallel to the beam surfaces where they start. They are normal to the surfaces where they end and they cross each other at a right angle in the so-called neutral axis, the line of zero flexural stress. An alternative name for these curves is principal stress trajectories and their course in a cantilever with a load at its free end is demonstrated in Fig. 86.

Text books of Mechanics merely indicate the general principles governing the construction of these curves. For this reason it is considered worthwhile to develop the differential equation from which the series of curves shown in Fig. 86 can be constructed.

Let \( I \) be the length of the cantilever, \( x \) the distance of a point from the wall, \( y \) its distance from the neutral axis and \( h \) the height of the cantilever. If \( F \) is the force acting on its free end we have:

\[
\sigma_x = \frac{M_x y}{I} \quad \text{(flexure formula)} \quad \ldots \ldots \ldots (26)
\]

\[
\tau_{xy} = \frac{F_x}{2I} \left( \frac{h^2}{4} - y^2 \right) \quad \text{(shear stress distribution)} \quad \ldots \ldots (27)
\]
In the calculations which follow \( F \) will be taken as positive, but \( F_x \), the bending moment, will be considered negative. In Fig. 85 a Mohr circle construction has been used to determine the direction of the principal stress at a given point. Its direction can also be calculated from the formula:

\[
\tan 2\varphi = -\frac{2F_{xy}}{F_x} \tag{28}
\]

devolving for \( \tan \varphi \), we get:

\[
\frac{-2F_{xy}}{F_x} = \frac{2\tan\varphi}{1 - \tan^2\varphi} \tag{29}
\]

or bearing in mind that \( F_x \) is negative:

\[
\left(\frac{h^2}{4} - y^2\right) \tan^2\varphi + 2xy \tan\varphi - \left(\frac{h^2}{4} - y^2\right) = 0 \tag{30}
\]

which may be written as:

\[
\left(\frac{h^2}{4} - y^2\right) \left(\frac{dy}{dx}\right)^2 + 2xy \frac{dy}{dx} - \left(\frac{h^2}{4} - y^2\right) = 0 \tag{31}
\]

or:

\[
\frac{dy}{dx} = -\frac{\sqrt{xy(xy)^2 + \left(\frac{h^2}{4} - y^2\right)^2}}{\frac{h^2}{4} - y^2} \tag{32}
\]

It is now possible to construct the curves in question by graphical or numerical methods by letting \( l \) range from 1, 2 ... to \( h \), \( y \) from 0 to \( h/2 \) and \( \frac{dy}{dx} \) from 0 to \( \pi/2 \). For instance for \( y = 0 \) \( \tan y = 1 \), which means that the trajectories make an angle of \( 45^o \) with the neutral axis and intersect each other at \( 90^o \).

Further for \( y = h/2 \) one of the solutions is \( \frac{dy}{dx} = \pi/2 \) showing that the curves end normal to the upper and lower surfaces of the beam.

The complete solution of this equation is beyond the scope of this thesis.

The lines curving downwards in Fig. 86 represent principal tensile stresses whereas those curving upwards represent principal compressive
stresses. According to the trajectorial theory the lateral trabecular system absorbs tensile stresses and the medial compressive stresses. This theory was first put forward by Culmann, a Swiss engineer, in 1866 and supported by von Meyer in 1867 and taken up by Wolff who, between 1869 and 1901, published numerous papers on the trajectorial orientation of trabeculae in the spongiosa of bone. Wolff's law of transformation of bone (1892) merely states that the architecture of the spongiosa changes if the shape of the bone is altered.

A further expansion of the trajectorial theory is the maximum-minimum law by Roux (1912) according to which a maximum of mechanical strength of bone is achieved by a minimum of structural material.

A full account of these theories is given by Kummer (1959) who states that one of the early opponents was Otto Christian Mohr, the father of Mohr's circle, who from 1873 to 1900 held the chair of Engineering Sciences at Dresden. Nevertheless, another engineer, Koch in 1917 tried to place the trajectorial theory "upon a sound foundation". Knowledge of his paper has assumed the importance of a status symbol with orthopaedic surgeons, e.g. Chalmers (1970) and Singh et al (1970). Fig. 19a in Koch's monograph is usually regarded as absolute proof of the trajectorial theory. Yet Zarek (1959) showed that there are several fundamental errors in this Fig. 19a. For instance, Koch was wrong in taking a line linking the centroids of serial cross sections of the femoral head and neck as the neutral axis. Koch ignored the simple fact that super-imposition of the compressive axial stress in the femoral neck upon the flexural stress therein must shift the neutral axis laterally. Further Zarek pointed out that Koch had assigned two different tensile stresses, one 13 lbs/In² and tensile, the other 145 lbs/in² and compressive to a point on the neutral axis. Since Koch's Fig. 19a resembles a cantilever with a transverse load, a point on the neutral axis cannot possibly have two different values. As Fig. 85 clearly demonstrates, the flexural stress on the neutral axis
is zero and only the maximum shear stress is operative at this level. A Mohr circle for this situation has its centre coinciding with the origin of the co-ordinate system. The circle, therefore, cuts the x-axis at two points equidistant from the origin which means that the above maximum shear stress is equivalent to a compressive and tensile direct stress each of the same magnitude as the shear stress and each making an angle of 45° with the neutral axis.

Careful examination of Koch's monograph by this writer did not reveal the methods which were used to compute the stresses in Fig. 19a. Moreover, the values shown in this figure are not in agreement with those given in Table 6: from which they are said to have been derived. For instance, the tensile stress at the upper end of section 8 in Fig. 19a has been given a value of 711 lbs/in², and must obviously be the maximum value of the tensile stress at this particular level. Yet according to table 6 this stress has a value of 974 lbs/in². Koch assumed that the flexural stress at this point was 1132 lb/in² and deducted an axial stress of 168 lb/in² to arrive at the figure of 974 lbs/in². This value for the axial stress acting on section 8 is of the wrong order. Koch's Fig. 15 demonstrates this section 8. It is a roughly elliptical area with axes of 1.5" and 1.15". Strangely enough he does not give the area of this section in any of his tables. Multiplying 1.5 by 1.15 by π/4 gives the approximate area of this ellipse as 1.355 in². According to Koch's Fig. 16 the axial load on section 8 is 80 lbs which means the axial stress on this section equals 59 lbs/in² just under a third of Koch's value.

The only possible conclusion which can be drawn from the data here presented is that Koch's explanation of the trabecular arrangement in the upper end of the femur is wrong. He disregards the action of muscles and obvious mistakes can be found in his presentation.

The problem which Koch tackled is complex and can only be solved in general terms. The joint force acting on the upper end of the femur makes
a median angle of $10^\circ$ to $15^\circ$ with the sagittal plane. During the weight bearing phase of the walking cycle, it reaches two peaks and oscillates backwards forwards and sideways round the median value. However, the above vector will always have an axial component and another normal to the axis of the femoral neck. In addition the joint force produces contact stresses over the so-called weightbearing portion of the upper end of the femur. Further the horizontal component of the force generated by the abductors of the hip probably causes contact stresses acting on the medial portion of the femoral head as well. It will be shown in Chapter IX dealing with avascular necrosis that deep to the circle of contact all the stresses acting on a small solid cube are compressive (or negative by a sign convention) within a small solid of revolution. A Mohr circle depicting this situation in an analysis of plane stress would be wholly to the left of the Y-axis. On the other hand some distance away from the contact area all the stresses are tensile (positive) in a certain region and Mohr's circle would lie completely to the right of the Y-axis.

Flexural stresses develop distal to the centre $C$ of the femoral head. At first there is no neutral axis because the direct compressive axial stress due to the axial component of the joint force is greater than the tensile flexural stress created by the transverse component of this force.

As with increasing distance from $C$ the stresses due to bending become greater there will be a point where the tensile flexural stress exactly equals the axial compressive stress so that at this point there is no direct stress at all. If this principle of superposition of the two stresses is carried out for a number of cross sections and the points of zero direct stress are linked, the resultant line is the neutral axis. According to Zarek (1959) this axis appears at the superior cervico-capital junction, travels distally close to the superior cervical cortex, traverses the trochanteric region and ends laterally at the base of the great trochanter.
Unfortunately the joint force is not constant during the walking cycle. Moreover, in a mathematical analysis of the neck of the femur flexural and axial stresses as well as shear and torsional stresses would have to be considered. The first two can be added by superposition and the other two vectorially by a parallelogram construction. Naturally a number of phases of the walking cycle would have to be analysed. The result would be different from Köch's solution, but as yet the problem is unsolved.

Attempts have been made by Fessler (1957), Pauwels (1965) and Kummer (1959) to explain the trabecular arrangement in the upper end of the femur in terms of the trajectorial theory by subjecting a model of the femur from a plate of plastic material to photo-elastic studies. Objections can be raised to all these experiments. Spongy bone is anisotropic. For instance Knese (1958) mentioned that bone has three different axes of elasticity and that bone can withstand tensile stresses twice as well as compressive ones. In view of these statements it is obviously pointless to apply the flexure formula to any analysis of plane stress of a model of the femur. One further objection is that the so-called tensile system arching from the lateral cortex into the inferior portion of the head of the femur deals really with compressive stresses because the force generated by the hip abductors in locomotion has a transverse component pushing the femoral head firmly into the acetabulum. The trajectorial theory applied to the head of the femur has been rejected by Strange (1965) and by Trueta (1968) and is doubted in the best known textbook of osteology in the English language, namely Frazer's Anatomy of the Human Skeleton (1965).

An alternative theory was put forward by Garden (1961) who held that the proximal end of the femur represented an upward continuation of the shaft which has undergone rotational expansion.
Probably the best theory is the one put forward by Trueta (1968). He believes that compression alters the enzyme production by the osteoblast-osteocyte units, and that under the stimulus of these enzymes osteogenetic cells become active and trabeculae in the line of maximum pressure become thickened. The writer feels that this theory can be simplified. It is known that active osteoblasts are responsible for the manufacture of bone. Why not assume then that when mechanical forces, either tensile or compressive, act on osteoblasts a number of substances are squeezed out of them and form bone outside their parent cells?

Such a theory would explain the tremendous hypertrophy of the fibula in Figs. 87 and 88, but like any of the theories examined it would not explain, for instance, the regular trabecular arrangement inside the head and neck of the radius. (Fig. 83) The same objection applies to the suggestion that either piezo-electric potentials or potential changes in the p-n junction formed by collagen and hydroxy apatite are responsible for the minute anatomy of spongy bone. These theories are based on the discovery by Fukada and Yasuda (1957) and Bassett and Becker (1962) who showed that an electric potential is generated by bone in response to mechanical stress. Their findings were further elaborated by Jahn (1968).

A chance observation based on a case of Perthes' disease of the hip treated by varus osteotomy as described by Axer (1965), probably explains the trabecular arrangement better than any of the theories mentioned so far.

The patient whose hip is shown in Fig. 89 was seven years old when he was operated upon. Eighteen months later his fragmented articular cartilage had healed (Fig. 90) and a new trabecular system is visible extending from the lesser trochanter to the weightbearing area in the rotated femoral head. Wolff's law is confirmed. The newly formed trabecular system is in line with the course of the ilio-psoas. Re-examination of Fig. 84 shows that the outer fibres of the lateral trabecular system follow the course of the abductors. It is, therefore, justifiable to put
forward the suggestion that the two main trabecular systems in the upper end of the femur owe their existence to the action on bone of the hip abductors and the ilio-psoas respectively. Genetic influences play their part as well. The shape of the human femur itself is without question genetically determined. No other explanation can be offered for the trabecular arrangement inside the neck of the radius. It may well be that the internal architecture of the upper end of the femur represents a mixture of mechanical response to muscular action and inherited factors.

By now it has become clear that the intersection of the two trabecular systems inside the head of the femur cannot readily be explained in terms of mechanics. Such a stress analysis would be tremendously complicated because compressive, tensile and shear stresses would have to be dealt with in a three dimensional model. Moreover, the action of all the muscles acting on the upper end of the femur must be taken into account. It is not sufficient to analyse only the action of the abductor muscles attached to the great trochanter. The powerful ilio-psoas, which on its own can almost stabilize the hip completely, as well as the rectus femoris must be dealt with. To the best of this writer's knowledge nobody has ever constructed such a complicated model, nor attempted to analyse it mathematically.

Nevertheless the intersection of the two trabecular systems provides mechanical strength. Hardinge (1949) found it to be the part of the femur best able to deal with compressive stresses. Pauwels (1965) put forward the theory that this particular arrangement prevented bending of the trabeculae inside the head of the femur.

5.3 SUMMARY

(a) The upper end of the femur is well adapted to absorb energy. This capacity is shared by the ground substance of the cartilage with its collagen fibres, the osteons themselves and the subchondral spongy bone.
(b) No wholly satisfactory explanation seems to exist for the decussating trabeculae inside the femoral head. Nevertheless the theory is put forward that their orientation is related to the action of the ilio-psoas and the hip abductors, but genetic factors cannot be excluded. The two trabecular systems inside the femoral head absorb compressive stresses and impart mechanical strength to the bone end, especially its central portion.
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In Chapters I and II it was stressed that a pin inserted into an osteoporotic femoral head could be loosened by forces which were minor compared with those produced by weightbearing and than osteoporotic distal fragment could not support a trifin nail. Further, analysis of the results of pinned cervical fractures in Chapter IV suggested that the outcome of internal fixation might well depend on the degree of osteoporosis present.

For a full understanding of the difficulties experienced in the treatment of fractures of the neck of the femur, it is essential to have a sound working knowledge of osteoporosis and its effects on the upper end of the femur.

Bone may be weakened by hyperparathyroidism, osteomalacia, malignant disease and a number of rare disorders. As far as traumatic fractures of the upper end of the femur are concerned, the chief condition of practical importance is senile osteoporosis because the majority of the patients are elderly.

6.1 REVIEW OF SENILE OSTEOPOROSIS

In this disorder the trabeculae and the cortical bone become thinned. Both calcium and collagen are lost. A normal subject usually excretes up to 200 mg of calcium in a 24-hour specimen of urine. In osteoporotic subjects the writer has found a daily loss of calcium of up to 400 mg of calcium in the urine. Collagen is broken down into hydroxyproline which is also excreted in the urine. Smith and Nordin (1964) examined forty-two osteoporotic subjects. The mean hydroxyproline output in the osteoporotic patient was 0.53 mg/kg/day reducing to 0.38 on calcium supplements. The normal range according to these two investigators is from 0.2 to 0.5 mg/kg/day.
The cause of osteoporosis is still unknown. However, Nordin (1971) stresses the fact that osteoporosis is commoner in women and mentions that the X-Ray density at the wrist may fall up to 15% in the fifteen years after the menopause. He also produces evidence that some degree of negative calcium balance probably occurs in everyone. This is due to the action of the parathyroids. To some extent the action of parathyroid hormone produced is counteracted by oestrogens. He mentions that it is impossible to produce osteoporosis in parathyroidectomized animals. After the menopause the amount of oestrogens circulating in the body is reduced and for this simple reason osteoporosis develops in women after they have passed this milestone. Men have to wait until they are approximately seventy years old before they develop osteoporosis as a result of inadequate production of sex hormones. It is, therefore, reasonable to conclude that osteoporosis is due to loss of the protective action of the gonadal hormones allowing the parathyroids to attack bone without opposition. The investigations by Dymling (1964) suggest that the fundamental metabolic error is an inability of bone to take up calcium. He gave intravenous injections of Ca$^{45}$ and Sr$^{85}$ to osteoporotic subjects and found that the accretion rate (litres of plasma cleared per day) was less than normal. There is no effective treatment for osteoporosis, but there is evidence that muscle weight is an important determinant of bone mass (Doyle, Brown and Lachance, 1970). This observation suggests that osteoporosis can to some extent be minimized by leading a physically active life. The beneficial effects of androgens are probably due to giving the patient a sense of well being and increasing his muscle bulk to some extent. The writer considers that redeveloping the patients muscles as far as possible and prescribing androgens periodically is the only worthwhile treatment. The administration of extra Vitamin D, calcium or phosphorous supplements, including diphosphonates and sodium fluoride or calcitonin are of unproven value. None of these measures helps a patient who is actually suffering from a fracture of the neck of the femur.
6.2 THE UPPER END OF THE FEMUR IN OSTEOPOROSIS

The loss of calcium from the upper end of the femur of osteoporotic patients is discernible in high quality radiographs. Singh, Nagrath and Maini (1970) recognize five groups of trabeculae in the upper end of the femur (see Chapter IX) and show that as osteoporosis becomes more marked these trabecular systems gradually disappear. The last one to go is their principal compressive group extending from the proximal end of the inferior cervical cortex to the weightbearing area of the femoral head. In the writer's opinion these three authors have not gone far enough. They have failed to realize that in the young, the upper end of the femur is almost completely occupied by cancellous bone showing no particular arrangement. The appearance of trabecular systems is already evidence of osteoporosis. Fig. 91 is a radiograph of the right and left femoral heads of a young man aged nineteen years who died in a road traffic accident. The right femur was bisected in the coronal plane and the anterior portion was removed. The left femur was divided at the level of the great trochanter and a 1 cm wide axial slab normal to the coronal plane was cut. An excellent view in two planes is provided. The only definitely recognizable trabecular pattern is the one connecting the inferior cervical cortex with the upper portion of the femoral head. The trabeculae resemble in their pattern a honeycomb structure used extensively in industry and particularly in aircraft construction (Vicars 1965, and Coussell 1966). In osteoporosis the trabeculae gradually disappear, but they do so in a definite manner giving rise to a number of stages as described by the above authors.

One well-known phenomenon was omitted by these three writers, namely, the expansion of the upper end of the femur associated with reduction of the width of the cervical cortex. According to Frost (1966) the cross-section area of ribs increases with age, but after the age of twenty-five
the endosteal envelope enlarges faster than the periosteal envelope, Frost's method of describing expansion of the cross-section accompanied by cortical thinning. This may be nature's way of compensating for loss of mechanical strength of a bone consequent upon the drain of calcium and collagen already described. A simple worked example will make this statement clear. The cross-section of the femoral neck at the head-neck junction is almost circular. One specimen measured by the writer has a radius of 0.6" at this level. If it is assumed that this radius gradually increases to 0.7" with age and that the section is roughly isotropic, then it can be shown by using the formula, stress = \( \frac{M \times y}{I} \), \( \ldots \) (33) that the same bending moment produces a 60% smaller surface stress on the wider section. This expansion of bone may well be responsible for the loosening of prostheses secured with acrylic cement after they have been in situ for many years. The writer has seen such specimens, but he has not carried out any histological investigations. Such studies were, however, performed by Charnley (1970). He noted that the load of body weight was transferred from cement to bone via points of fibrocartilage. In These were ample/specimens examined up to five years post-operatively, but they were relatively sparse in two specimens examined seven years after insertion of cement. Although these two specimens were clinical successes, the observations by Frost (1966) and by Charnley (1970) must cast some doubt on the ability of cement to hold a prosthesis securely in position inside the medullary cavity of the upper end of the femur for periods of up to fifteen years, the estimated life of a total replacement of the hip joint.

Quite naturally the drain of calcium and collagen weakens bone and predisposes it to fractures. Mather (1968) subjected 145 femora,

\* M = bending moment, y = distance from neutral axis, I = moment of inertia.
91 female and 54 male specimens to bending tests to destruction. The femoral ends were embedded in hemi-cylindrical end pieces and rested on the bed of a testing machine which moved upwards against a pusher acting on the summit of the forward curve of the femur. He found that the breaking load decreased with age. Lower loads were necessary to break female bones which he attributed to the fact that they were generally smaller. He concluded that the decrease in strength with age was caused by a deterioration in the mechanical properties of bone. He did not explain the nature of this process although he suspected reduction in the specific gravity and porosity of bone. Although it would have been better to use two pushers instead of one, thereby subjecting the tested segment of bone to a constant bending moment and no shear, this paper nevertheless shows that the strength of bone tends to decrease with advancing age. Vose and Lockwood (1965) examined the normal hips of patients with one femoral neck fracture by a sophisticated densitometry method. They evaluated the aluminium bone equivalencies in centimetres of aluminium per centimetre of bone thickness as determined from comparative photometric scans across the radiographic image and a calibration wedge. The incidence of hip fractures among 104 patients referred for X-Ray diagnosis was found to increase quite gradually with age, but increased sharply when the femoral neck density of the opposite uninvolved limb was below 0.20 cm/cm equivalency as determined by radiographic densitometry. One of their conclusions was that bone density was a better predictor of hip fracturing than the subjects age alone. Spontaneous fractures were observed in females only and occurred when the femoral neck aluminium equivalency was below 0.10 cm/cm. They were unable to explain why men were less susceptible to hip fractures regardless of comparative bone densities.

SUMMARY

(a) In osteoporosis both calcium and collagen drain away from the
skeleton. This disorder starts in women after the menopause and in men at approximately seventy years of age. The chief aetiological factor seems to be loss of the protective action of gonadal hormones which normally inhibit the hormone of the parathyroids which can then remove bone without opposition. There is no effective treatment.

(b) The gradual disappearance of calcium and collagen from the upper end of the femur leads to the emergence and eventual disappearance of the usual trabecular pattern in the upper end of the femur. Osteoporosis predisposes its victims to fractures of the neck of the femur.
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Chapter VI dealt with the effects of osteoporosis on the upper end of the femur. It is, however, difficult to tell from X-Rays alone whether a given femur is osteoporotic or normally mineralized. This chapter is concerned with the diagnosis of generalized senile osteoporosis enabling the clinician to draw conclusions regarding his patients' hips. Amongst the disorders leading to poor mineralisation of bone we find overactivity of the hypophysis, the thyroid and hyperparathyroid glands, neoplasia, osteomalacia, rheumatoid arthritis and a number of rare conditions, but the commonest cause is ageing. As will be explained in the final chapter the presence or absence of osteoporosis has an important bearing on the treatment of femoral neck fractures. The purpose of this section is to present the clinical aspects of senile osteoporosis and its radiological diagnosis. Further the feasibility of using X-Ray generators as provided in general hospitals to measure the calcium concentration of bone is investigated.

7.1 CLINICAL ASPECTS

The patient is usually a woman past the menopause in her fifties and sixties. Some of these women have had bilateral oophorectomies but in the majority of cases the previous history is non-contributory. Men are less frequently affected. Those who develop the disorder do so in their seventies.

A typical sufferer complains either of pain between the shoulder blades girdling round the chest or low back pain travelling down a leg. Neck pain radiating down an arm also occurs quite frequently. In advanced cases, the patient stands with a marked dorsal kyphosis. The painful segment of the spine is tender and its movements are restricted. There
is some loss of height, sometimes amounting to 2" or 5 cm and the ratio:
\[
\frac{\text{Crown to pubic symphysis}}{\text{Pubic symphysis to ground}}
\]
normally equal to 1 drops below unity, because the spine shrinks and the legs do not. The ribs may sink into the iliac fossae. The writer has examined one patient whose ribs clicked painfully over her iliac crests every time she rotated her trunk.

The appendicular skeleton is also involved predisposing the patient to bony injury affecting especially the distal end of the radius and the upper end of the femur as mentioned in the previous chapter.

Biochemical investigations reveal normal or slightly lowered values for the serum calcium and phosphorus. The serum alkaline phosphatase is usually within normal limits, but may be slightly raised in the presence of pathological fractures.

Examples of gross osteoporosis are easily diagnosed in radiographs. The dorsal spine is unduly curved (Fig. 92), pathological fractures may be present (Fig. 93) and often the discs swell and indent the vertebrae. (Fig. 94). The femoral cortex is frequently thinned and eroded (Fig. 95). However, lesser degrees of osteoporosis are more difficult to diagnose.

The following sub-section of this chapter deals with this particular problem.

7.2 RADIOLOGICAL DIAGNOSIS OF CALCIPENIA

It is generally agreed that a given bone must lose approximately 30% - 50% of its calcium content before a diagnosis of calcium deprivation or calcipenia can be entertained from a study of radiographs. Exton-Smith and Millard (1969) state that there are two main methods of measuring the amount of bony tissue in the skeleton:

7.2.1 Densitometry

An accurate technique of measuring the density of bones in radiographs
was first described by Mack et al in 1949. Vogt (1967) reports that the astronauts on project Gemini were investigated by a similar method. Radiographs of the hands and calcaneum were taken before and after spaceflights and compared with an aluminium step wedge. Losses ranging from 2.8 to 23.2 per cent of bone mass were recorded on a fourteen day space flight. This painstaking investigation included collecting samples of the sweat, the faeces and the urine of the astronauts. The radiographs were evaluated by a complicated technique in the laboratories of the Texas Woman's University Research Institute. Obviously this method is not practicable in a general hospital.

7.2.2 Measurements of the Dimensions of Bones

Barnett and Nordin (1959) examined (a) the femoral, (b) the metacarpal and (c) the spinal scores of 150 patients suspected of osteoporosis and compared them with 125 controls. These terms denote the following fractions multiplied by 100.

(a) Sum of the cortices at the narrowest portion of the femoral shaft divided by the outside diameter at the same level.

(b) The same procedure applied to the midpoint of a metacarpal.

(c) The vertical height of the middle of a lumbar vertebra divided by the vertical height of the anterior border.

A femoral score below 46, a metacarpal score below 48 and a spinal score below 81 are suggestive of osteoporosis.

Exton-Smith et al (1969) applied a somewhat more elaborate technique to the density mensuration of hand X-Rays. They found a good correlation \( r \approx 0.85 \) between the cortical area of the third proximal finger phalanx in radiographs and the ash content of the bone.

These methods are somewhat time consuming and probably too elaborate for a general hospital, but they are of considerable value if special facilities are available.
There are, of course, a number of additional methods. Of these two deserve special mention.

7.3 USE OF I - 125

Sorenson and Cameron (1967) used an I - 125 tightly collimated photon source to measure the density of the forearm and hand bones and of the calcaneum. The attenuated radiation passes into a detector and is analysed by a computer which provides a write-out. Radiographs are not necessary with this method. For their calculations they relied on the assumption that the above-mentioned radiation is absorbed in a perfectly exponential manner which simply cannot be correct because bone is anisotropic. Nevertheless their results are reproducible.

7.4 COLOUR CODED RADIOGRAPHS

Quite recently coloured radiographs were published in World Medicine (1971) and it was mentioned that this method could also be used to measure bone density. Writing to Agfa-Gevaert quickly established that the method was based on the use of Agfacontour Professional, a film which only records areas or lines of equal density or equidensities. The film becomes transparent only at a given exposure. Lengthening or shortening this exposure results in blackening of the film. Therefore, all transparent areas in a film correspond to a given density in the original X-Ray film. A single exposure gives only the equidensity of a single density value of the X-Ray film. The association between the density (D) of an original at which the equidensity appears and the corresponding exposure (t) is governed by:

\[ t_2 = t_1 \times 10^{D_2 - D_1} \]  

where \( t_1 \) is the exposure at density \( D_1 \) and \( t_2 \) the exposure at density \( D_2 \). To obtain a coloured radiograph it is, therefore, necessary to copy the original X-Ray film on to Agfacontour film five or seven times with a
different exposure on each occasion. The five or seven Agfacontour films are then recopied on black and white films each of which can then be given colour development. When the five or seven coloured films, each of which has been coloured differently, are now arranged in register a coloured radiograph results.

This is an ingenious method of colour-coding different shades of grey in radiographs which the human eye cannot perform accurately. Unfortunately the remarks made under the heading of densitometry all apply. There is one further adverse point. Investigation of the beam of one X-Ray generator with an oscilloscope revealed that there was a 75% fall-off in the intensity of the radiation from the centre to the periphery. As a result of this finding it is clear that only the central area of a radiograph can be analysed by this method which appears to be promising, but has not yet been sufficiently developed for use in a general hospital.

7.5 FEASIBILITY STUDIES

The last two methods require resources which will forever be beyond the reach of general hospitals. In an attempt to find a simple solution to the problem of bone density mensuration the writer has carried out two feasibility studies. Nothing more elaborate than an X-Ray generator with an image intensifier is required. Two possibilities were investigated.

7.5.1 Use of Image Intensifier to Measure Absorbed Radiation

The intensity of the light leaving the image intensifier proper is proportional to the intensity of the radiation striking its photocathode. The intensity of the light reaching the television camera can be measured. On its way there in a Philips image intensifier this light is reflected off a mirror. 1/100th of the light can be filtered off by a small second mirror to strike the photosensitive surface of a photomultiplier. The current leaving the photomultiplier is meant to control the diaphragm of a
Bolex 16 mm cine camera so that a cine record of the images on the television monitor can be obtained. If the current is fed into a micro-ammeter instead, the amount of radiation absorbed by a bone, or any radio-opaque material, can be measured. A study of Fig. 96 makes this clear. The X-Rays on the left are a poly-energetic photon source. They pass through an absorber: bone, soft tissues or both. The attenuated radiation is converted into light in the image intensifier. The intensity of this light is proportional to the radiation striking the photocathode of the image intensifier. The emergent light is focused by the lens of the television camera on to another photocathode and then converted by the scanning beam of an electrode gun into the video signal which gives rise to an image on the screen of the monitor.

By measuring the intensity of the radiation without an absorber and then with an absorber interposed two values for the intensity of the radiation are obtained. Assuming that the fact that bone is anisotropic does not make a great deal of difference the above situation is governed by the equation:

$$I_t = I_o e^{-\mu t}$$

$I_t$ = intensity of radiation leaving the absorber in arbitrary units
$I_o$ = intensity of radiation striking the absorber
$\mu$ = coefficient of linear absorption in cm$^2$/gm
$t$ = thickness of absorber

$\mu$ is determined experimentally. The quotient $\frac{I_t}{I_o}$ is highly informative indicating the amount of radiation absorbed.

Experiments with blocks of perspex and squares of aluminium 0.3 mm thick showed that the method has possibilities. Although a polyenergetic photon source was used true exponential absorption was demonstrated. A typical experiment is recorded in Table X and Fig. 97.

However, there were great difficulties. For instance, it was quickly found that $\mu$ was not constant and tended to vary with the mA and kV
**TABLE X**

EXPERIMENT III - 14th February, 1967

<table>
<thead>
<tr>
<th>2.5 cm Units of Perspex</th>
<th>Lightmeter reading I</th>
<th>$\log_e I$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>4.09</td>
</tr>
<tr>
<td>2</td>
<td>36.5</td>
<td>3.60</td>
</tr>
<tr>
<td>3</td>
<td>21</td>
<td>3.04</td>
</tr>
<tr>
<td>4</td>
<td>12</td>
<td>2.48</td>
</tr>
<tr>
<td>5</td>
<td>6.8</td>
<td>1.92</td>
</tr>
</tbody>
</table>
values used. In addition the mA readings on the control panel had to be adjusted constantly by a technician owing to quite unpredictable variations in the mains current. Moreover, for an absorber consisting of two materials, e.g. soft tissues and bone, the previously mentioned simple equation will have to be expanded. For all these reasons this method was not persevered with. Nevertheless, it could be used if a computer and skilled staff were made available.

7.5.2 Analysis of the Video Signal with an Oscilloscope

Four blocks of Perspex were drilled into four times for 8 cm from one edge. The diameters of the four holes were the same in each block, but varied from block to block. They were 20 mm in the first, 14.5 mm in the second, 11.0 mm in the third and 7.5 mm in the fourth. Bone marrow was simulated by a concentrically inserted rod varying in diameter from 3 mm for the smallest holes to 8 mm for the largest holes. Each hole was then filled with a mixture of calcium phosphate B.P.C., starch, gelatin and water. Four mixes, each with a different calcium concentration were prepared. The four holes of each Perspex block were then filled with a mix of known concentration. The mix with the lowest concentration was poured into the left hand hole of each block. The second and third holes were filled with mixes of greater concentration and the mix with the highest calcium content went into the right hand holes. Sixteen dummy bones were thus available for analysis. They were X-Rayed through small apertures and the wave form was displayed on an oscilloscope. As expected the wave form on the oscilloscope screen corresponded closely to the geometrical pattern of the cross section of the dummy bones. (Fig. 98)

The writer is indebted to Mr. D. G. Haley (1968) of Marconi Instruments Limited for carrying out these experiments. The results were repeatable to an accuracy of 10%. Calculations carried out by the writer revealed that the maximum and minimum amplitudes of the oscilloscope display were
directly proportional to:

(a) the thickness of the dummy cortices, and

(b) to the calcium concentration of the individual mixes.

For lack of finance and time it has not been possible to follow up this very simple method of bone density mensuration. It will be necessary to calibrate the oscilloscope so that each millimetre on the Polaroid picture of the oscillogram corresponds to a known calcium density of bone. By coning down the X-Ray beam on vertebrae and the femoral head it should be possible to measure the density of these bones.

It would, of course, be necessary to have a standard. This could either be a bone of known calcium density or an aluminium stepwedge. Caldwell and Collins (1961) determined the radiographic density of post-mortem vertebral bodies in stepwedge units and measured their calcium concentration. Their work could be used as a basis for radiographic mensuration of the degree of calcification of lumbar vertebral bodies in the living. Only lumbar vertebral bodies are suitable. One such vertebra not obscured by intestinal gas can always be found. It would be quite simple to allow for soft tissue absorption by shifting the base line of the oscilloscope display a calculated amount. If the studies carried out on vertebrae are repeated with femoral heads their calcium concentration could also be measured. The writer is looking forward to the day when a patient with a femoral neck fracture has such an examination and his treatment is then planned according to the degree of calcipenia present.

Since nothing more elaborate than an oscilloscope with a Polaroid camera is required it should be possible to do this work at a general hospital.

7.6 SUMMARY

(a) The clinical aspects of senile osteoporosis are presented together with radiographs showing gross degrees of this disorder.
(b) A number of methods of bone density mensuration have been examined. The feasibility of carrying out these measurements at a general hospital was investigated. It would appear that analysis of the video signal of an image intensifier by an oscilloscope might provide a simple solution if further work is carried out.
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CHAPTER VIII
THE BLOOD SUPPLY OF THE UPPER END OF THE FEMUR
IN NORMAL HEALTH AND AFTER CERVICAL FRACTURES

It was shown in Chapter IV that the results of femoral neck pinning are frequently marred by collapse of the head of the femur, which is usually referred to as avascular necrosis. Before this condition can be investigated fully it is necessary to study the normal blood supply of the upper end of the femur and the effect which cervical fractures can have upon it. Cases personally treated by the writer will be used to illustrate all salient points.

8.1 NORMAL BLOOD SUPPLY OF THE UPPER END OF THE FEMUR

Fig. 99 demonstrates the main arteries of the proximal end of the femur in schematic form. The veins accompanying these arteries are not shown. This simple diagram is based on the painstaking studies of a number of workers. Trueta and Harrison (1953) followed by Judet et al (1955) injected the proximal ends of cadaveric femora with suspension of barium sulphate (Micropaque) and then X-Rayed the treated specimens. From their studies the following picture emerges. The medial femoral circumflex artery, usually a branch of the profunda femoris gives off two ascending vessels. One of these makes for the posterior aspect of the femoral neck to end in (1) the superior metaphysial artery which supplies the superior portion of the metaphysis and (2) the lateral epiphyseal branches which supply most of the femoral head including its weight-bearing portion. The other vessel springing from the medial femoral circumflex artery is the inferior metaphysial vessel which runs a short course to the inferior and medial portion of the femoral head and the medial portion of the femoral neck.

These vessels once they have reached the femoral neck remain closely
applied to it. They are covered by capsular reflexions or retinacula and for this reason they are also known as retinacular vessels. Occasionally an anterior retinacular artery, a small vessel, supplying the front of the femoral neck, but not the head, is present. Like most of the unnamed vessels carrying blood to and from the distal half of the femoral neck, the anterior retinacular artery comes off the so-called digital anastomosis at the lateral extreme of the superior cervical cortex. The nutrient artery of the femur itself also reaches the cervical region of the femur. Finally, there is the artery of the ligamentum teres, the medial epiphysial artery of Trueta and Harrison (1953), which is usually a branch of the obturator artery, but occasionally it stems from the medial femoral circumflex artery. This vessel anastomoses with the lateral femoral epiphysial vessels and Trueta and Harrison (1953) have published an illustration showing these two vessels in continuity. In children of white, but not of negro, parents, this anastomosis is usually absent until they are six years old. (Trueta, 1937). During the growth period there is, of course, no blood flow across the epiphysial line. These features are thought to be important in the aetiology of Perthes' disease of the hip.

All the arteries mentioned in this account are accompanied by veins. Additional venous drainage is provided by the intramedullary vessels in the femoral neck.

8.2 BLOOD SUPPLY OF THE COXAL END OF THE FEMUR AFTER INJURY

An inevitable complication of a displaced femoral neck fracture is disruption of the blood supply of the femoral head. Of the many contributions to this topic the writer has selected three which he regards as the most informative.

Sevitt (1964) examined 25 cadaveric femoral heads after cervical fractures. Nineteen had been nailed or nail plated. Four heads were histologically viable, four showed partial avascular necrosis with little
or no revascularization. (The term avascular necrosis denotes disappearance of osteocytes and the presence of dead cells in the spaces between the trabeculae.) In seven femoral heads there was extensive revascularization of grossly necrotic heads. The chief cause of gross necrosis was interruption of the retinacular vessels. He found that a nail could sever the artery of the ligamentum teres, the main source of revascularization of necrotic heads after displaced fractures. Other less important sources were vessels growing from the engorged femoral neck across the fracture line and small vessels growing from newly formed soft tissue below the head-neck junction. Only 50% of the specimens he examined were united or uniting. Necrosis of the neck side of the fracture was not responsible for non-union, because there was rapid revascularization of this zone in some of his specimens.

Rosingh et al (1969) studied the consequences of avascular necrosis in 63 rabbits. In 42 animals the artery of the femoral ligament was cut and the blood supply to the head of the femur was interrupted by tying a nylon ligature round the femoral neck. Simple transection of the artery of the femoral ligament in 21 animals did not lead to any histological changes. However, the above extensive interference caused avascular necrosis of the femoral head followed by an ingrowth of granulation tissue. After three weeks large quantities of new bone were deposited on the dead trabeculae leading to an increase in bone volume at the expense of the marrow. There was also increased radiographic density of the femoral head. At six weeks these changes started to retrogress, but the duration of their experiments did not exceed 21 weeks. It is not stated in their paper when the density of the femoral head returned to normal.

A different kind of density of the femoral head after fracture is described by Watson-Jones (1952). He considers that if a fracture disrupts the blood supply of the femoral head, this structure retains its original
density, whereas the distal fragment loses some of its calcium as a result of reactive hyperaemia. This increased density is only relative. It is best seen two to four months after injury and then slowly disappears.

8.3 ILLUSTRATIVE CASES

The studies by Trueta and Harrison (1953) and Judet et al (1955) make it clear that fractures with marked displacement can deprive the femoral head of most of its blood supply. However, it is not necessary to use their sophisticated methods to demonstrate femoral head ischaemia, because gross examination of a given specimen usually gives all the required information. A normal femoral head with its blood supply intact is maroon or pink in colour. A totally ischaemic femoral head has a faint yellow colour. If there is partial ischaemia, a mottled maroon and yellow appearance is found.

8.3.1 Completely Avascular Femoral Head

The specimen depicted in Fig. 100 has lost its entire blood supply. The artery of the ligamentum teres was probably destroyed by the nail as described by Sevitt (1964) and below the inferior portion of the ischaemic head there is the newly formed connective tissue mentioned by him. Revascularization of the femoral head from the maroon femoral neck and the newly formed granulation tissue is possible, but has not yet occurred. There was no bony union of the removed anterior half of the specimen. The radiograph shows a band of diminished radiolucency at the site of the fracture.

8.3.2 Revascularization

Revascularization via the ligamentum teres similar to the specimens reported by Sevitt (1964) is seen in the following case.
Case Report 12 - A woman aged 74 years sustained a vertical fracture of the right femoral neck. Because of her poor general condition, internal fixation was deferred one month. A biopsy specimen from the centre of the femoral head taken at the time of operation showed dead bone. Three and a half months after injury she died. The specimen exhibited a red zone of revascularization near the fovea, (Black in Fig. 101). On microscopic examination there was creeping substitution of dead bone by living osteoid. (Fig. 102) The rest of the bone was necrotic although the cells of the articular cartilage were alive. This specimen demonstrates the usual method of revascularization of femoral heads as well as the importance of not damaging the foveolar artery with implants. To the best of the writer's knowledge, no case of complete revascularization of the femoral head by the intact vessels of the cervical fragment has ever been reported.

8.3.3 Absolute Increase in Density of Femoral Head

If, instead of creeping substitution, there is deposition of new bone on dead trabeculae, the femoral head will finish up with more bone per unit volume than it had before injury, i.e. with an absolute increase in bone density. Such a case is reported herewith.

Case Report 13 - A woman aged 82 years sustained a displaced vertical fracture of the femoral neck which was pinned within 24 hours. A biopsy taken at that time showed that most of the bone examined was alive. It will be shown in Chapter X that such a report does not mean a great deal. She started to walk a few months after operation. Two years after internal fixation increased density of the femoral head was noted. Twenty-nine months later her hip was painless and a radiograph (Fig. 103) showed that the head of the femur was still unduly dense. The virtual disappearance of the femoral neck can be regarded as evidence of loss of the blood supply of the femoral head. (Charnley et al, 1957) The reason is that the
femoral neck slides up the implant and more and more of its proximal portion is driven into the defenceless femoral head and disappears. Yet this patient had no disability. Soon after her last examination, she was lost to follow-up. The writer believes that this case resembles the increased density Rosingh et al (1969) found in the femoral heads of rabbits totally deprived of their blood supply. The most likely explanation of the radiographic appearance is that this patient's femoral head had somehow become revascularized and was occupied by abnormally stout trabeculae consisting of old and new bone.

8.3.4 **Apparent increase in density of Femoral Head**

In the last-mentioned case the increased density of the femoral head appeared late, approximately two years after injury. The cases illustrated by Sir Reginald Watson-Jones in 1952 are different. They demonstrate transient increased radiolucency of the femoral neck after internal fixation, causing apparent increased density of the femoral head. A case which fits this description is reported herewith.

Case Report 14 - The femoral neck fracture of a woman aged 78 years was nailed one month after injury. The pin cut out of her femoral head in a few days. A replacement arthroplasty was performed. There were no abnormal operative findings. The histology of the removed femur head was that of dead bone. Fig. 104 should be compared with Fig. 100 in which the head is known to be avascular. In this last-mentioned case the time interval between internal fixation and death was 5 months, yet in the radiograph the coxal fragment has the same density as the peripheral.

Charnley et al (1953) described a similar case. Their patient died 4½ months after operation. Although most of the head appeared dead in the published colour photograph, the radiograph of the specimen showed normal density of the femoral head, but increased density at the site of the
fracture, probably due to compaction of the cancellous bone by the implant used. It is, therefore, clear that a completely ischaemic femoral head does not always appear unduly dense in the radiographs. In the writer's opinion, the transient osteoporosis of the femoral neck described by Sir Reginald Watson-Jones (1952) represents no more than the effects of post-traumatic hyperaemia as described by Sevitt (1964) acting on the femoral neck, possibly augmented by surgical trauma and the reaction of bone to metal and perhaps even mild subclinical infection.

8.4 SUMMARY

(a) The literature dealing with the blood supply of the upper end of the femur is reviewed. The single most important vessel is the lateral epiphysial artery which supplies most of the femoral head with blood and anastomoses with the artery of the ligamentum teres.

(b) Revascularization of an ischaemic femoral head is possible after disruption of all the retinacular and cervical vessels provided the artery of the ligamentum teres remains intact. This vessel must not be destroyed by a nail when a femoral neck fracture is internally fixed.

(c) After a fracture of the neck of the femur, increased density of the femoral head may appear late, i.e. two years after internal fixation, denoting an absolute increase in bone density; or within a month indicating transient osteoporosis of the femoral neck.
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CHAPTER IX
AN ANALYSIS OF THE DISORDERS REFERRED TO AS AVASCULAR NECROSIS OF THE HEAD OF THE FEMUR

To the writer the term avascular necrosis of the head of the femur denotes a white or yellow femoral neck with complete loss of blood supply and on microscopic examination death of osteocytes and marrow cells precisely as demonstrated in Fig. 100 in Chapter VIII. A cervical fracture with an avascular head can unite, though most of the femoral neck disappears. The significance of the radiologically dense femoral heads after cervical fracture was discussed in the previous chapter. Nowadays there is a tendency to regard avascular necrosis as synonymous with collapse of the weight-bearing area of the head of the femur, or separation of a solid segment. An attempt will be made to explain these disorders in terms of physical forces acting on structurally weak bone. It was for this reason that the structure of the head and neck of the femur in normal health and the effects of osteoporosis on this bone end were studied in detail in Chapters V and VI respectively. A number of case histories will be presented showing collapse of the femoral head and every example attributable to so-called natural causes will be matched by one following a fracture.

9.1 CONTACT STRESSES IN THE FEMORAL HEAD

To an engineer the hip joint is essentially a ball in a spherical seat. During locomotion this system becomes stressed and as a result of local deformation a small circle of contact forms. The stresses acting on this are called contact stresses and it can be shown that the maximum pressure at the centre equals one and a half times the average pressure calculated for the whole area. The distribution of these stresses over the contact area is given in Fig. 105. Of special interest are the stresses inside the ball. (Fig. 106) The areas designated A, B and C must be imagined as solids of revolution. In zone A the pressures on the
six surfaces of a small cube are all compressive. In the interrupted zone B they are compressive on four surfaces and tensile on two. In zone C they are compressive on two surfaces only and tensile on four. (Fig. 107) Zone A is surrounded by shearing stresses. Along the boundary there is pure shear of magnitude 0.133 \( q' \) where \( q' \) is the maximum pressure at the centre of the contact circle. (Fig. 108) Timoshenko and Goodier (1951) state that the maximum shearing stress is on the \( z \)-axis (see Fig. 105) at a depth equal to about a half of the radius of the surface of contact, but they do not give the orientation of this stress whose magnitude is about 0.31 \( q' \).

Evidence that contact stresses can produce considerable deformations is provided by Figs. 109 and 110. These two high speed photographs also demonstrate that if two bodies of differing hardness make violent contact with each other the soft body becomes markedly deformed, whereas any change in the shape of the hard body is so small that it does not show in the photographs.

The size of the circle of contact depends on the force applied and the elastic properties of articular cartilage and subarticular bone. These two materials are anisotropic and demonstrate visco-elastic behaviour. Any attempt at an exact mathematical analysis is therefore impossible. Nevertheless there is a resemblance between (a) the flattened golf ball and football and crush fractures of the femoral head and (b) the effects of contact stresses as shown in Figs. 105 and 106 and idiopathic necrosis or segmental collapse of the head of the femur.

9.2 CRUSH FRACTURES OF THE FEMORAL HEAD

The weightbearing portion of the acetabulum consists of tough bone heavily reinforced by the coxo-sacral strut. In disorders weakening bone generally the femoral head usually becomes deformed more readily
than the acetabulum. Occasionally conditions are the other way round. The femoral head is then driven into the pelvis which gives rise to protrusio acetabuli, a well known complication of prosthetic replacement of solely the femoral head with a metal prosthesis. In this section only crush fractures of the femoral head will be considered.

Case histories will now be presented which demonstrate that the femoral head can become crushed as a result of natural causes and after trauma.

9.2.1 **Idiopathic Crush Fracture of Femoral Head**

**compared with Ununited Tibial Fracture**

Case Report 15 - A man aged 72 years developed slight pain in the right hip. The X-Ray appearances were thought to be normal. (Fig. 111) The presence of a Judet's prosthesis in the left hip was noted. This implant had been inserted 13 years before for osteoarthritis. His left hip was painless and had a full range of movement. A coned view of the right hip showed minor flattening. (Fig. 112) One month later the head of the femur appeared crushed. (Fig. 113) The head and neck of the femur were excised. The histological preparation of the whole femoral head demonstrated that the cartilage was intact, but to one side of the fovea there was a gap between articular cartilage and subchondral bone. (Fig. 114) Microscopic examination revealed dead bone (Fig. 115), zones of active repair (Fig. 116) and metaplastic cartilage. (Fig. 117)

Case Report 16 - A man aged 32 sustained simple closed fractures of the right tibia and fibula. When after three months of plaster immobilisation there was no evidence whatever of incipient union (Fig. 118) the tibial fracture was nailed and a biopsy was taken. As in the above specimen there was dead bone (Fig. 119), regenerating bone (Fig. 120) and metaplastic cartilage. (Fig. 121)
9.2.2 Collapse of Femoral Heads after Trauma

Case Report 17 - A woman aged 81 years sustained an impacted cervical fracture. Partial weightbearing was allowed four weeks after injury and full weightbearing three weeks later. (Fig. 122) She was followed up for 16 months. Her hip returned to normal.

Case Report 18 - A woman aged 79 years sustained a fracture identical with the one described in case (17). Immediate weightbearing was allowed. The top of Fig. 123 shows the radiograph on the day of the accident and the bottom picture the same hip three weeks later. Some flattening of the femoral head is already present. Eventually her femoral head collapsed completely.

Case Report 19 - A woman aged 88 years sustained a subcapital fracture of the neck of the femur. Two years after fixation with the writer's pin, the femoral head was collapsed, but the fracture was united. (Fig. 124) This case will again be referred to in the chapter dealing with femoral head biopsy.

Case Report 20 - A woman aged 44, an innocent victim of a road traffic accident, sustained an anterior dislocation of the right hip. She was treated conservatively. Her progress was entirely satisfactory. When examined for a medico-legal report in connection with her claim for compensation by two surgeons, she had no disability and a good prognosis was given. However, seven years later her hip became painful. Her symptoms got slowly worse. A radiograph taken nine years after injury, when she was 53 years old, showed complete collapse of the femoral head. (Fig. 125) The writer's colleague, Mr. W. G. France, F.R.C.S., performed a McKee arthroplasty with an excellent short term result. (Fig. 126)

9.2.3 Discussion

All these cases with the exception of (16) and (17) have one feature in common, namely, collapse of the whole of the weightbearing area of the...
head of the femur. In case (15) there was no history of trauma, yet the histology is that of a fracture, as comparison with case (16) clearly demonstrates. Case (15) is analogous to the so-called pathological fractures of vertebral bodies in senile osteoporosis which was illustrated in Chapter VII. The writer believes that in this disorder the spongy bone inside the femoral head and vertebral bodies loses some of its capacity to absorb energy. This point will be followed up in the next two chapters.

It was explained in Chapter I that the forces acting on the head of the femur in normal locomotion may easily reach values of four times the subject's body weight. Such a force is sometimes in excess of what osteoporotic spongy bone can deal with and as a result crush fractures occur in the spine and in the hip.

In favour of this theory is that the patients in case reports (15), (18) and (19) had reached an age when osteoporosis is usually present. Careful study of the radiographs of cases (15) and (18) shows evidence of this disorder. At this stage it is necessary to refer back to the paper of Singh, Nagrath and Maini (1970) mentioned in Chapter VI. They describe five trabecular systems in the head and neck of the femur. (Fig. 127) As the individual ages and his bones become porous, these systems become first attenuated and then disappear. The last one to become thus affected is the medial trabecular system, No: 1 in Fig. 127. They regard a break in the continuity of system (4) as definite evidence of osteoporosis. This discontinuity is present in the radiographs of case (15) (Fig. 113), and case (18) (Fig. 123) It is, therefore, logical to regard osteoporosis as the main aetiological factor causing collapse of these two femoral heads. Loss of blood supply can certainly not be blamed for the flattening of the femoral head in case (18) (Fig. 123) because the fracture described in case report (17) (Fig. 122) is identical with the one in case (18). The femoral head in case (17) did not collapse because it was not osteoporotic: all its trabecular systems are clearly identifiable in Fig. 122. The fact
that the patient whose femoral head collapsed was allowed to bear weight early is irrelevant, as will be explained in Chapter X.

From case (15) we have learnt that osteoporosis may be the only cause of collapse of the femoral head. Trauma can introduce three additional factors:

(a) The violence of the fracture damaging the spongy bone inside the femoral head.

(b) The insertion of a nail especially if preceded by the insertion of a large number of guide wires.

(c) Loss of blood supply of the femoral head including disruption of the foveolar artery by a nail.

The crushing of the femoral head in case (19) illustrated in Fig. 124 was due to senile osteoporosis (her age was 88 years) with factors (a), (b) and (c) contributing. She had sustained a displaced fracture, the operation was difficult and the nail had been inserted into the foveolar region.

The patient whose hip disintegrated nine years after a road traffic accident causing anterior dislocation of the hip, case (20), is of special interest. What happened is probably this. The dislocation of her hip deprived the femoral head of its entire blood supply and with it the ability to repair the minor trabecular infractions which occur after activity. According to Swanson and Freeman (1970) an adult walks about one to three million paces a year. With each step the hip is loaded and eventually in the absence of the normal processes of repair a compression fatigue fracture of the femoral head occurred in this case.

Once such a catastrophe has happened, the histological picture is difficult to interpret. Dead bone abounds as it does in every recent fracture, but in the cases studied by the writer some attempts at repair can always be found in the deeper layers, i.e. creeping substitution, intense cellular activity of islands of metaplastic cartilage, features similar to the ones
described in case report 15.

The deformations of the femoral heads are similar to the flattened golf ball and football shown in Figs. 109 and 110. However, they are not caused by a single violent impact, but by the repeated trauma of weightbearing. Nevertheless they represent crush fractures affecting living bone as well as bone deprived of its entire blood supply. In some cases the flattening is a complication of avascular necrosis, but this term should never be used as a primary diagnosis for these crush fractures.

9.3 SEGMENTAL COLLAPSE OF THE HEAD OF THE FEMUR

In 1965 Merle d'Aubigne et al described idiopathic necrosis of the head of the femur in adults. Brown and Adami (1964) described the same condition a year before using the term "superior segmental collapse". An alternative name is osteochondritis dessecans of the hip.

Four cases, two idiopathic and two post-traumatic, will be presented, and an attempt will be made to explain the aetiology of the condition in terms of contact stresses.

9.3.1 Two Idiopathic Cases

Case Report 21 - A 70 year old woman presented with pain in the left hip of a few months duration. The radiograph of her hip (Fig. 128) showed a somewhat displaced sequestrum.

Case Report 22 - A 31 year old negro suffering from S-C haemoglobinopathy had a painful left hip of several years duration. (Fig. 129) The radiograph showed a saucer-shaped depression with two well demarcated edges.

9.3.2 Two Cases Following Trauma

Case Report 23 - A woman aged 53 years sustained a subcapital fracture on 19th December, 1961. Two days later her hip was pinned. (Fig. 130)
Unfortunately the implant, although mechanically soundly placed, damaged the foveolar vessels. Two years and three months after pinning and six months after removal of the pin the femoral neck had almost completely disappeared, which must be regarded as unequivocal evidence of loss of the blood supply of the head of the femur. The weightbearing area of the femoral head demonstrated segmental collapse. (Fig. 131) Subsequently the patient's femoral head was replaced with a prosthesis, but unfortunately only the specific gravity of the specimen was determined.

Case Report 24 - A woman aged 77 years was admitted to hospital on account of low back pain. The films of her pelvis showed a metal implant in the left hip and superior segmental collapse of the head of the right femur as well as a well-healed displacement osteotomy. (Fig. 132) Clinically the result was good. In one of her lucid moments she told us that she had fractured her right hip when she was 73 years old. A nail was inserted. A few months later it was taken out and she then spent four months in a plaster spica.

9.3.3 Discussion

Zone A in Fig. 106 must be regarded as a solid of revolution. (From now on the symbol A will be used for this solid.) Inside A all the three principal stresses are compressive. Around A shear stresses are active and as a result trabeculae surrounding A are fractured. Eventually A may become completely isolated or sequestrated. Its entire blood supply is cut off and its cells die. The histological picture of the cut off portion is that of avascular necrosis. This hypothesis is based on the resemblance in shape between Zone A in Fig. 106 and the isolated portions of bone demonstrated in this section. Such a piece of bone may become displaced laterally as in Fig. 128, or driven into the femoral head forming a saucer-shaped depression as in Fig. 129. Both living bone as in cases 21 and 22, and dead bone as in case 23, may become affected. It would appear
that the stresses which locomotion generates inside the femoral head can
fracture both living and dead trabeculae.

Known predisposing factors of idiopathic necrosis of the femoral head
are:

(a) Prolonged steroid administration which causes generalised
osteoporosis.

(b) Haemoglobinopathies in which bone infarcts weaken the subchondral
bone of the femoral head.

(c) Chronic alcoholism and medication with anti-rheumatic drugs,
e.g. phenobutazol or indomethacin. It is reasonable to assume that patients
in this group have structurally weak subchondral bone which would normally
induce them to use their hips carefully. However, when under the influence
of the above-mentioned agents, patients feel little pain, they move about
vigorously and overload their hips. Force F in Fig. 106 therefore becomes
larger with a corresponding increase in the stresses round A which then
becomes cut off.

The views here presented are similar to those expressed by Catto (1965)
who wrote: "It is suggested that this fragmentation and separation is in
the nature of a stress fracture, the necrotic trabeculae having stood up
to the stress of weightbearing for some years before giving way." To bring
this suggestion into line with the views here presented, it is merely
necessary to state that living femoral heads may demonstrate the same disorder
and to change "stress fracture" to "circumferential stress fracture"
round A.

A different explanation is put forward by Garden (1971) who considers
that gross malreduction of cervical fractures inevitably leads to segmental
collapse of the head of the femur, but he does not suggest a possible
mechanism and he completely ignores the fact that this disorder also occurs
in patients who did not sustain fractures, e.g. cases 21 and 22.

The writer feels that it is possible to advance an explanation of the
phenomenon of superior segmental collapse if the following points are considered:

(a) Cases 21 and 24 in this chapter were elderly and suffering from senile osteoporosis.

(b) Case 22 was suffering from S-C haemoglobinopathy which is known to weaken the upper end of the femur.

(c) Cases 23 was only 53 years of age, but it will be shown in the next chapter that her femoral head was poorly mineralised.

(d) Cortisone medication causes generalised osteoporosis and is known to lead to superior segmental collapse of the femur in some cases.

Bearing all this in mind it is justifiable to conclude that superior segmental collapse is due to lack of mechanical strength of the upper end of the femur of which senile osteoporosis is the most important cause.

Why in some cases the whole of the weightbearing area of the femoral head should become crushed resembling a headed football or a golf ball struck by a club, both at the moment of impact, and in others a solid segment of bone should become isolated is by no means clear. But the explanation may be very simple. Femoral heads are not all alike. The majority are structurally sound. A small number have pliable subchondral bone which buckles and then fractures under the influence of contact stresses acting on the hip resulting in collapse of the weightbearing area. Another small group has trabeculae which are ductile and, therefore, vulnerable to shearing stresses which then cut off a solid segment of bone. After a fracture these changes are usually unilateral which suggests that trauma and the insertion of an implant are contributory factors.

9.4 SUMMARY

A femoral head completely deprived of its blood supply does not necessarily undergo changes in its shape. The conditions usually referred to as avascular necrosis of the head of the femur fall into two groups:
(a) Collapse of the weightbearing area.

(b) Isolation of a solid segment.

These two disorders can occur without any history of trauma but they are also seen after cervical fractures. The similarity between the two conditions and the effects of contact stresses acting on the femoral head has been analysed. It is possible that femoral heads do not all have identical properties and for this reason contact stresses may produce two different types of lesion.
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Avascular necrosis, so-called, was analysed in Chapter IX. In order to determine the likelihood of this condition occurring after femoral neck pinnings biopsies were examined. Taking these presented no problem.

In Chapter III it was stated that for the insertion of the writer's implant a channel in the femoral head and neck should be reamed out with a flat drill. If instead the trephine shown in Fig. 133 is used biopsies of the femoral head can be taken. A typical biopsy specimen is \( \frac{3}{4} ^{\text{th}} \) long and has a diameter of just over \( \frac{1}{6} ^{\text{th}} \) (Fig. 134) Femoral head biopsies were studied from 1962 to 1965, the first such investigation carried out. Its aim was to investigate (a) the histology, and (b) the specific gravity of the biopsy specimens and to relate the findings to the prognosis of pinned femoral neck fractures.

10.1 HISTOLOGY

83 femoral head biopsies obtained from 40 patients with cervical and from 43 patients with trochanteric fractures were studied. 80% of the cervical fractures and 50% of the trochanteric fractures demonstrated histological evidence of necrosis. Two interesting results are reported below.

Case Report 25 - A man aged 78 sustained a subcapital fracture of the neck of the right femur. He was not fit for operation on admission and internal fixation was deferred 12 days. The biopsy showed dead bone (Fig. 135) Three years after operation his right hip was clinically and radiologically normal (Fig. 136) although the fracture line was near vertical.

Case Report 26 - A woman aged 88, with a subcapital fracture of the right femur, was operated upon within 24 hours. The biopsy showed viable bone (Fig. 137) Twenty one months after biopsy her femoral head had collapsed. (Fig. 124) (This patient was reported as case 19 in Chapter IX.)
10.1.1 Discussion

In case 25 there was histological evidence of dead bone, yet the clinical result was excellent after three years. In case 26 the biopsy showed apparently viable bone, yet within twenty one months the femoral head collapsed. The explanation of these apparently contradictory findings is quite simple. Charnley (1970) wrote: "It is perhaps not yet widely known that quite often the femora of patients of 70 years of age contain tracts of dead bone as a normal occurrence." The dead bone of the biopsy in Case 25 and of the many biopsy specimens taken from trochanteric fractures which also contain dead bone merely confirms this statement.

Catto (1964) stated that the histological changes of bone ischaemia can only be recognised with certainty three weeks after fracture. Case 26 was biopsied within twenty four hours and if the above author's statement is correct then the presence of living bone cells is not surprising. They have not had sufficient time to disappear.

These two cases make it perfectly clear that the absence or presence of osteocytes in a biopsy specimen cannot be used as a guide to prognosis after internal fixation of femoral neck fractures.

10.2 SPECIFIC GRAVITY

15 specimens, all obtained from patients with femoral neck fractures were investigated.

10.2.1 Method of Study

Two methods were used:

(a) Dilution of Trilene. On completion of the operative procedure the bone biopsy was dropped into a glass cylinder containing Trilene, a fluid used by anaesthetists, which has a specific gravity of 1.6. The specimen remained lying on top of the fluid. When absolute alcohol was
added gradually and the contents of the cylinder were gently agitated a point was always reached at which the specimen floated anywhere in the fluid. The specific gravity of the fluid was now measured with a hydrometer of range from 1.1 to 1.6. This method was time-consuming and expensive. It had to be abandoned after five tests when a nurse broke the hydrometer and it proved quite impossible to obtain a replacement with the same range.

(b) Specific gravity bottle method. 10 specimens were placed in formol saline and were sent to our biochemical laboratory. There the specimens were dried in a desiccator and then weighed and then placed in a specific gravity bottle. The identity in Fig. 138 explains how this specific gravity of a given specimen is computed. From (weight of bottle filled to mark with water plus weight of dry specimen) the weight of the bottle with the specimen is deducted. The difference is the volume of the specimen. We now have the weight and the volume of the specimen and can easily determine the weight of its unit volume.

10.2.2 Results

After several discussions with biochemists it was decided that there was no essential difference between the results obtained by the two methods.

The specific gravity of the 15 specimens investigated ranged from 1.1 to 1.66. The biopsy with the lowest value was from the femoral head of a woman aged 53 (Case 28 below). The biopsy with the highest value was from the hip of a woman aged 82.

As the following two cases show, a low specific gravity spells disaster. Case Report 27 - A woman aged 53 years sustained a subcapital fracture of the neck of the femur. Twenty seven months after pinning her femoral head had collapsed (Fig. 139) and was replaced by a prosthesis. The specific gravity of a central portion of the femoral head taken after the last operation was 1.10. (This case was previously reported in Chapter IX.)
Case Report 28 - A woman aged 88 sustained a subcapital fracture of the neck of the femur. The specific gravity of her femoral head biopsy was 1.13. Within two months the pin cut out of her femoral head although it had been centrally inserted. (Figs. 140 and 141)

From this limited investigation it emerged that femoral neck fractures united and femoral heads did not collapse if the specific gravity of the relevant biopsies was above 1.35 to 1.4 always provided that the pin had been centrally inserted.

10.2.3 Discussion

The Trilene method is a variation of the practice of Collins (1959) who measured the specific gravity of small cubes of cancellous bone from vertebrae by dropping the specimens into copper sulphate solutions covering a range of specific gravities. His findings (relating to cancellous bone only) were: "Normal bone is heavier than specific gravity (SG) 1.075. The SG of some cubes of bone varied between 1.050 and 1.075, porotic bone had SG of less than 1.050 and a few specimens of various soft bone floated even at 1.025."

Both the Trilene and specific gravity bottle methods of determining the specific gravity of femoral head cancellous bone are obviously crude, because neither fat nor marrow are removed from the specimens. Nevertheless the results demonstrate that femoral heads vary widely in their degree of mineralization, because increased calcium content is the only plausible reason why some specimens are heavier than others. The validity of this conclusion is confirmed by Caldwell and Collins (1961) who investigated vertebral osteoporosis by examining 100 specimens. They found that the calcium content of vertebral cancellous bone ranged from 38 to 102 mg. per cubic cm. of bone, but that 75% of cases fell within the narrower range of 50 to 84 mg. per cubic cm. They regarded values of lower than 50 mg. per cubic cm. as demonstrating evidence of spinal osteoporosis.
In the present series the specific gravity of femoral head biopsies was much higher than the specific gravity of vertebral cubes described by Collins (1959). Although the calcium concentration was not determined, the low specific gravity of some of the specimens indicates that senile osteoporosis can also affect femoral heads in addition to vertebral bodies. This fact is not mentioned by Nordin (1971) in his comprehensive review of osteoporosis. The above finding is in the writer's view the most important result of the investigation of femoral head biopsies and explains why femoral heads after cervical fractures become crushed and pins work loose.

Cook (1955) tested vertebral bodies to destruction. He found that their cancellous bone could normally withstand a crushing force of 600 to 900 lbs per sq inch. He also tested osteoporotic vertebrae and found that they yielded under a pressure which was 300 lbs or less per sq inch.

If the pressures on the hip are calculated the following picture emerges. Let the circle of contact between the head of the femur and the acetabulum in weightbearing have a diameter of \( \frac{3}{4} \)" and the vertical component of the joint force on the hip be four times the patient's body weight of say 140 lbs. The average pressure on the circle of contact is then of the order of:

\[
\frac{560 \times 16 \times 4}{9 \times \pi} = 1270 \text{ lb/in}^2
\]

However, the maximum pressure at the centre of the circle is 1.5 times the average pressure or approximately 1900 lbs per sq inch. This stress is well in excess of the 300 lbs per sq in or less which according to Cook (1955) can crush osteoporotic vertebrae. In case 27 reported the contact stresses acting on the femoral head were obviously of sufficient magnitude to separate a solid segment and drive it slightly into the interior of the bone end.

Now take a trifin nail with one fin pointing downwards inside the head of a femur in the presence of a vertical neck fracture and assume that the
nail is firmly fixed to a plate screwed to the femoral shaft. Let the nail be inserted 1\frac{1}{4}'' into the femoral head in the bulls-eye position making an angle of 125° with the vertical and let the femoral shaft make an angle of 10° with the vertical. The distance between the two upper fins is \frac{3}{8}''.

The force acting on the nail is now 560 \times \cos 45° lbs or nearly 390 lbs. It is distributed over an area of 1\frac{1}{2}'' \times \frac{3}{8}'' or 0.47 square inches. The resulting compressive stress on the femoral head cancellous bone is now \frac{390}{0.47} or 830 lbs per sq in which osteoporotic bone cannot withstand either in vertebrae or in the femoral head.

If a nail is fixed to a plate and is inserted more steeply the joint force can act on it almost axially subjecting the bone round the tip of the nail to considerable pressure and forcing it into the acetabulum.

The above computations do not apply to normal femoral heads which as Hardinge (1949) found can withstand pressure varying from 2140 lbs per sq in to 7800 lbs per sq in depending on the portion examined. Moreover, normally mineralized femoral heads grip pins very firmly and prevent them from sliding and perforating the articular cartilage. As far as osteoporotic femoral heads are concerned, the writer feels that for any computations the values for compressive strength of vertebrae given by Cook (1955) rather than those by Hardinge (1949) for femoral heads should be used, because there is not a great deal of difference between the specific gravity of osteoporotic vertebrae (1.050 according to Collins (1959)) and the lowest value of 1.10 for femoral heads here presented.

Bearing in mind all the limitations of the methods used, it is reasonable to define an osteoporotic femoral head as one having a specific gravity of 1.35 - 1.4 or lower. This conclusion is based on the result of nailing cervical fractures with the writer's pin. Uneventful union occurs if the specific gravity of the biopsy specimens is above the value just stated, provided internal fixation is performed with reasonable skill.

The conclusions reached in this chapter reinforce those presented in
Chapters I and IX and show how important a factor osteoporosis is in the outcome of a femoral neck osteosynthesis. Further support for this finding will be provided in the next chapter.

10.3 SUMMARY

(a) Femoral head biopsies from patients with cervical and trochanteric fractures may contain either dead or living bone. The absence or presence of osteocytes in a given biopsy does not affect the result of internal fixation of a cervical fracture.

(b) The specific gravity of 15 femoral head biopsies taken after cervical fractures was found to range from 1.10 to 1.66. A specific gravity below 1.35 usually means that an osteosynthesis will fail or that the femoral head will collapse. It has been demonstrated that osteoporosis can also affect the femoral head. Computations have been presented showing that the stresses acting on the hip can damage osteoporotic femoral head cancellous bone and can loosen implants.
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CHAPTER XI

FIXING MOMENTS OF TRIFIN NAILS IN FEMORAL HEAD CANCELLOUS BONE

Probably the most important conclusion reached in Chapter X was that patients with fractured femoral necks fared badly after internal fixation if their femoral head biopsies had a low specific gravity. This chapter will provide further evidence in support of the above finding.

In Chapter I experiments were presented showing that whole femoral heads, unless rarefied by a disease process, could easily withstand bending moments of the order of 300-400 lb ins. The purpose of this Chapter is to present the moments which femoral head cancellous bone can withstand and to correlate the findings with its specific gravity and calcium concentration.

11.1 DETERMINATION OF FIXING MOMENTS, SPECIFIC GRAVITY AND CALCIUM CONCENTRATION OF FEMORAL HEAD CANCELLOUS BONE

All the specimens were stored in Formol saline until the writer had time to carry out his experiments. A 4½" trifin nail was driven into each femoral head tested over a centrally inserted guide wire. Each nail was hammered in 7/8" as near as possible normal to the head-neck junction. To cushion the blows each specimen was placed on a 1" thick sorbo rubber sheet which in turn was lying on two layers of corrugated cardboard. Using the fovea as a guide each nail was so inserted that one fin always pointed downwards or upwards.

The first specimen was transfixed by three guide wires which were then driven into a wooden board. Sand bags thought to weigh 5 lbs and 1 lb each respectively were next hung on the free end of the pin. (Fig. 142) A load of 10 lbs (9½" on weighing) loosened this pin so that it could be readily withdrawn.

When this experiment was repeated with the femoral head of a youth a load of 37 lbs bent the four transfixion pins used in this case. The pins
### Table XI

**Results of Experiments**

<table>
<thead>
<tr>
<th>No.</th>
<th>Sex</th>
<th>Age</th>
<th>S.G.</th>
<th>Ca %</th>
<th>M lb.ins.</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>M</td>
<td>19</td>
<td>1.70</td>
<td>294</td>
<td>250</td>
<td>Road traffic accident</td>
</tr>
<tr>
<td>2</td>
<td>M</td>
<td>29</td>
<td>1.30</td>
<td>170</td>
<td>152</td>
<td>C.O. Poisoning. Head cracked.</td>
</tr>
<tr>
<td>3</td>
<td>M</td>
<td>56</td>
<td>1.51</td>
<td>264</td>
<td>210</td>
<td>Carcinoma of caecum</td>
</tr>
<tr>
<td>4</td>
<td>F</td>
<td>69</td>
<td>1.22</td>
<td>201</td>
<td>72.5</td>
<td>Fracture</td>
</tr>
<tr>
<td>5</td>
<td>F</td>
<td>69</td>
<td>1.18</td>
<td>200.5</td>
<td>39</td>
<td>Fracture Hyperthyroidism</td>
</tr>
<tr>
<td>6</td>
<td>F</td>
<td>69</td>
<td>1.24</td>
<td>193</td>
<td>109</td>
<td>Acute lobar pneumonia</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Emphysema thoracis</td>
</tr>
<tr>
<td>7</td>
<td>F</td>
<td>87</td>
<td>1.12</td>
<td>157</td>
<td>35</td>
<td>Fracture</td>
</tr>
</tbody>
</table>

Serial numbers according to age

S.G. = specific gravity

Ca % in mg. per cc

M = fixing moment

Final column shows that four post mortem specimens and three fracture cases were examined. Case 5 was suffering from hyperthyroidism.

1 lb in = 0.113 Newton metres
also ploughed up the board. At the suggestion of Mr. John Charnley (1970) this femoral head and all subsequent ones were embedded in acrylic cement and fixed in a vice. It was now possible to attach much greater weights. (Fig. 143)

After the pins had been loosened, 1 - 2 cc of cancellous bone from the neighbourhood of the pin track were removed and sent to our Biochemical Laboratory for further investigation.

The specific gravity was determined with specific gravity bottles as described in Chapter X. A portion of the dried specimen was ashed in a platinum crucible after weighing. The ash was weighed again. The difference represented organic matter, but this particular aspect of the investigation was not followed up further. The weighed ash was dissolved in a known amount of $\frac{N}{10}$ hydrochloric acid and the calcium concentration of the solution was determined by an atomic absorptionometer. Following the example of Caldwell and Collins (1961) the calcium concentration was expressed in milligrams per cubic centimetres.

11.2 RESULTS

The relevant results are presented in Table XI. Only one specimen cracked as the nail was driven home and a photograph of the linear fracture produced by this type of piledriving will be shown in the final chapter.

From the data in Table XI three scattergraphs were constructed, and they are presented in Figs. 144, 145 and 146.

11.3 DISCUSSION

In the above experiments the pins were only driven in $\frac{3}{8}$" so that they could be easily loosened by bending moments not exceeding 300 lb ins. Higher moments would bend the pins as they did in Chapter I and it would not be possible to determine the "fixing moment".

Basically we are dealing with a cantilever fixed inside cancellous
bone. (Fig. 147) When the load \( L \) is applied to the end of the beam, reactive forces, \( R_1 \) and \( R_2 \), inside the femoral head are created which act at the point of entry and at the tip. If \( a \) is the length of the nail inside the femoral head and \( b \) its length outside we have:

\[
R_1 \times a = L \times b \\
R_2 = R_1 + L
\]

\( L \times b \) is known as the fixing moment, if \( L \) loosens a nail driven distance \( a \) into the femoral head. The distribution of the stresses inside the femoral head is most complicated because visco-elasticity and recovery are encountered. For instance, when it was attempted to re-insert a nail by hand into the femoral head from which it had been pulled out the day before by the method described, the hole had shrunk and no longer admitted the nail. For this simple reason no attempt whatsoever was made to evaluate \( R_1 \) and \( R_2 \). The above phenomenon was not observed when the cancellous bone inside the distal fragment of a femoral neck fracture was examined in Chapter I, and for this reason a triangular stress distribution was assumed.

Reference to Figs. 144, 145 and 146 shows that there is a 95% correlation between the specific gravity and the fixing moment, a 91.7% correlation between specific gravity and calcium concentration and an 81.4% correlation between calcium concentration and the fixing moment. Although only seven cases were examined the three graphs suggest that the case for a linear relationship between the properties investigated is very strong. Considering the fact that only neighbouring bone was examined, the correlation between the three parameters is surprisingly good.

In view of these findings, two methods of investigating the mechanical strength of a given fractured off femoral head suggest themselves.
(a) Determination of the specific gravity of its cancellous bone.
(b) Mensuration of its mineralization.

Determination of the specific gravity of a sample of a femoral head is not very useful in the management of a femoral neck fracture because it can only be measured after internal fixation. However, the alternative should prove exceedingly useful because it should be possible to measure the degree of mineralization of a femoral head radiologically as was outlined in Chapter VII before any operative treatment is undertaken. For instance the femoral head shown in Fig. 148 and investigated as Case 7 in Table X was mechanically too weak for successful internal fixation. Any nail would have cut through this particular femoral head. This patient was in fact treated by immediate prosthetic replacement.

From these experiments the interesting fact has emerged that the upper end of the femur is more heavily mineralized than vertebral bodies. Caldwell and Collins (1961) examined the cancellous bone of 100 fourth lumbar vertebral bodies. They found that the average specific gravity was 68 mgs. of calcium per cubic centimetre of bone with a range of 38 to 102. They considered that male specimens with a calcium concentration of 56 mgs. per cubic centimetre and below and female specimens with a calcium concentration of 50 mgs. per cubic centimetre and below were osteoporotic.

In the small series presented in this Chapter the average value of the calcium concentration of femoral head cancellous bone was 211 mgs. per cubic centimetre with a range of 157 to 294 mgs. per cubic centimetre. These figures mean that in 1 cc of femoral head spongiosa there is roughly three times the amount of calcium as in 1 cc of vertebral cancellum. The stresses on the hip are greater than those acting on vertebral bodies, but it would be rash to attempt to re-write Wolff's law in terms of calcium concentration.

The three male femoral heads examined were much stronger than the four female ones. By some strange coincidence three femoral heads from patients
aged 69 years were kindly provided by the writer's colleagues. The specific gravity of their femoral heads was of the order of 1.20. One of these patients (case 5) was suffering from hyperthyroidism, a disorder known to weaken bone by causing osteoporosis. This must be regarded as the main reason for the low fixing moment of 39 lb ins. in her case.

In general terms the seven specimens examined tend to show that using the fixing moment of trifin nails as a criterion, the mechanical strength of femoral heads decreases with age and the development of osteoporosis. In Chapter X it was stated that femoral heads with a specific gravity between 1.35 and 1.40 could be regarded as osteoporotic. This means that Cases 2, 4, 5, 6 and 7 in the small series investigated in this chapter were inadequately mineralized. Unfortunately no details of the post mortem are available of the 29 year old man, case 2 in Table X, whose femoral head had a specific gravity of 1.3. He might well have been suffering from a decalcifying disorder.

11.4 SUMMARY

(a) The fixing moments of trifin nails inside seven femoral heads was investigated. The specific gravity and calcium concentration of samples of cancellous bone from each femoral head were also determined.

(b) The specific gravity of male femoral heads whose erstwhile owners were respectively 19, 29 and 56 years old was greater than that of four elderly female specimens. The range was from 1.70 to 1.12. The specimen with the highest specific gravity belonged to a youth aged 19. The one with the lowest specific gravity to a woman aged 87.

(c) Graphs are presented strongly suggestive of a linear relationship between fixing moments and specific gravity, specific gravity and calcium concentration and calcium concentration and fixing moments of femoral head cancellous bone.

(d) It is suggested that the degree of mineralization of the hip of a patient suffering from a femoral neck fracture which needs internal
fixation should be investigated radiologically. In the presence of osteoporosis, prosthetic replacement is the method of choice.

(e) The calcium concentration of the samples of femoral head cancellous bone investigated had a mean value of 211 mgs. per cubic centimetre, three times the amount found in 1 cc of vertebral cancellous bone.

(f) Male femoral heads are mechanically stronger than female ones, and the femoral heads of both sexes can be weakened by osteoporosis.
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CHAPTER XII

ERRATA

Page
147 5th line from bottom - full weight should be full weight bearing.
150 10th line from bottom - these should read thesis.
153 12.2.3 After "Early ambulation" in second line of para. two, insert left out line - encouraged whenever possible. With comminuted trochanteric fractures ...
158 11th line from top should read: with bilateral oophorectomy can be performed in disseminated breast cancer.

Legend
152 should read - Radiograph of slightly displaced femoral neck fracture.
CHAPTER XII

AETIOLOGY AND TREATMENT OF FRACTURES OF THE UPPER END OF THE FEMUR

As the following 2 cases show the treatment of femoral neck fractures leaves much to be desired.

On Monday, 25th January 1971, the writer examined two patients, a man and a woman, who had sustained hip fractures.

Case Report 29 - The man was 35 years old when he fractured his femoral neck. It was pinned. Eighteen months later his fracture was barely united and the two implants used were protruding (Fig. 149). He was only able to walk short distances with pain.

Case Report 30 - The woman sustained her femoral neck fracture at 42 years of age. Her initial operative treatment consisted of the insertion of a trifin nail. Within a few months the femoral head disintegrated and the nail was removed. Her pain persisted. A high femoral osteotomy with internal fixation was next performed. This operation gave her no worthwhile relief. At this stage the surgeon responsible for her treatment called in help. A colleague inserted a so-called Minneapolis prosthesis and succeeded in lengthening the patient's leg by 1" without giving her a sciatic palsy. (Fig. 150). Seven months after insertion of this massive implant and two years after injury and four operations, she still had considerable pain and her name was on the waiting list of a hospital for total replacement of the hip.

Unsatisfactory results like these are by no means rare. The writer feels quite strongly that if fractures of the upper end of the femur are given competent treatment based on sound understanding of the pathological and mechanical principles explained in the previous chapters, the majority of patients with these fractures end up with reasonable hips.

Moreover, the methods advocated in the following pages should reduce the period of hospitalization to approximately four weeks. Some patients...
can, in fact, be discharged after only two weeks, but it must be borne in mind that many of these people are elderly, are suffering from other disabilities and have social problems. Owing to these extra factors many of them spend months in hospital after perfectly adequate treatment before they can be discharged. A sociological and demographic analysis of fractures of the upper end of the femur is, however, beyond the scope of this thesis. These special considerations do not apply to traumatic fractures of middle aged men and women who, in the majority of cases, should be able to resume a substantial amount of their former activities six weeks after injury and eventually they should progress to a full and normal life with only negligible permanent symptoms.

It is intended to classify these fractures according to their aetiology and then to consider their treatment, paying special attention to difficult, unusual and complicated cases.

12.1 AETIOLOGY

Like fractures generally bony injuries to the upper end of the femur fall into three groups:

(a) Traumatic fractures

(b) Fatigue or stress fractures

(c) Pathological fractures

Of these three groups (a) is by far the commonest affecting as was shown in Chapter IV more women than men. Fractures in the trochanteric region are slightly more frequent than those of the femoral neck. Children very occasionally sustain fractures of the upper end of the femur as well and their treatment poses a special problem. Groups (b) and (c) are of considerable academic and surgical interest.

12.1.1 Traumatic fractures

(a) Concerning traumatic fractures, it is generally accepted that
high speed road traffic accidents can cause any type of bony injury
including fractures of the neck of the femur. It is less well known that
a simple fall can also generate substantial forces which can easily
fracture a femoral neck as the computations presented below clearly show.

Worked example - Imagine a woman of average height and weight $W$ of
110 lbs falling to the floor. Let her centre of gravity be 32" above
ground level standing and 5" above ground level after her fall. The loss
of height $h$ due to the fall is, therefore, 27" or 2.25 feet. The kinetic
energy $KE$ produced by falling is:

$$KE = h \times W$$ ............ (37)

The mass $M$ of her body is $W/g$. From the equation

$$KE = \frac{1}{2}Mv^2$$ ............ (38)

we obtain

$$v^2 = 2hg$$ ............ (39)

If the soft tissues are compressed a distance $c = \frac{3}{4}$" or 1/24th foot
by her fall and the deceleration $d$ is uniform then we have from a well
known identity in dynamics:

$$v^2 = 2cd$$ ............ (40)

from which

$$d = \frac{h \times g}{c}$$ ............ (41)

Let $F$ be the total force unleashed by this fall then:

$$F = \frac{W \times h \times g}{g \times c}$$
$$= 110 \times 2.25 \times 24\text{lbs}$$
$$= 5940 \text{ lbs.}$$ ............ (42)
This force is suddenly applied which multiplies its destructive effect by a factor of nearly two. Some attenuation by soft tissues undoubtedly occurs, but it is quite clear that even a quarter of the above force is more than enough to fracture femoral necks (Bingold, 1959; Frankel, 1960).

Considering the magnitude of this force it is not surprising that these fractures are sometimes comminuted and that periosteum and even capsular folds should become interposed between the main fragments of a cervical fracture. Whether the patient sustains a cervical or trochanteric fracture probably depends upon the internal architecture of the femur and the position of his body when it makes contact with the ground, which, of course, determines the point of application of the force. If the patient suffers a cervical fracture the fragments can become firmly impacted into each other, but if he is unfortunate they can become widely separated and the proximal fragment can lose its entire blood supply.

12.1.2 Fatigue or Stress Fractures

(b) To understand fatigue or stress fractures affecting normal or apparently normal bone it is necessary to be familiar with certain terms used in engineering. The fatigue limit is the stress below which a material will withstand any number of stress cycles (usually a million in laboratory tests) of a designated type without breaking. If the stress is above the limit and applied repeatedly, a fatigue or stress fracture will occur. The fatigue limit is usually expressed as a percentage of the ultimate tensile strength. For instance, the ultimate tensile strength of cast cobalt chrome as used in the manufacture of surgical implants is 40 tons/in\(^2\). Its fatigue limit is only 17 to 18 tons/in\(^2\) or approximately 43% of the ultimate tensile strength. Bone possesses an ultimate tensile strength of 13,000 to 18,000 lbs/in\(^2\), but its fatigue
limit does not seem to have been determined. Nevertheless, if any bone is stressed the requisite number of times beyond its at present ill-defined fatigue limit, a stress or fatigue fracture will occur.

The best known example of this condition is the so-called march fracture, a stress fracture affecting either the second or third metatarsal or both bones, where two aetiological factors can frequently be recognised. (1) There is a history of prolonged walking or marching, providing the requisite number of stresses. (2) The patient has walked across hard surfaces thereby increasing the reactive forces on the foot beyond their normal values. (Cf equation 40 above.)

Griffiths, Swanson and Freeman (1971) subjected 37 specimens of the proximal third of the human femur to cyclically varying loads and ten specimens sustained subcapital fatigue fractures. They inferred that some femoral neck fractures in the elderly may be fatigue fractures caused by the cyclic loading of normal walking.

Devas (1963) reported 25 patients with stress fractures of the femoral neck. The aetiological factors in his series included rheumatoid arthritis treated with steroids, gastric ulcer osteomalacia and osteoporosis. A notable omission is Paget's disease of bone.

These fractures are comparatively rare. The writer has seen this type of injury in soldiers after route marches, in long-distance runners and rugby players whose healthy femora were unduly stressed. Until they were clearly recognized as an entity their occurrence gave rise to the belief that patients with femoral neck fractures sustained these injuries before they fell. This view is wrong because the majority of femoral neck fractures are due to trauma caused by falls. (Bingold, 1958)
12.1.3 Pathological Fractures

(c) In pathological fractures bone is eaten away by a disease process so that eventually a break occurs. These cases are not always clearly differentiated from stress fractures and there is a tendency to lump the two groups together. All spontaneous fractures occurring in disorders of bone characterized by thinning or weakening of the cortex should be designated stress fractures. The surgeon treating such an injury must be alive to the possibility of dealing with a complication of a congenital bone disease, a hormonal or metabolic disorder, renal disease, malnutrition, deprivation of or inability of the body to respond to Vitamin D and other types of rickets or osteomalacia, senile osteoporosis, rheumatoid arthritis, Paget's disease of bone, or examples of atrophy of bone in nerve lesions. A detailed consideration of these various diseases is outside the scope of this thesis. An excellent account may be found in Watson-Jones' book (1952). The term pathological fractures should be reserved for those cases where there is a definite destruction of bone by a cyst, by histicytosis X or such disorders as polyostotic or monostotic fibrous dysplasia, by a carcinoma of the thyroid, the breast, the lung, the kidney or the prostate, or other examples of secondary or occasionally primary malignancy.

12.2 Classification and Treatment

The classification and treatment of these three groups of fractures will now be presented.

12.2.1 Traumatic Fractures

There are only two groups: (a) Extracapsular or trochanteric fractures and (b) Intracapsular or cervical fractures.
12.2.1.1 Classification of Trochanteric Fractures

Usually the fracture line involves the intertrochanteric line in front and the intertrochanteric crest behind. The three main types have already been illustrated in Fig. 68. They are basal or intertrochanteric, pertrochanteric and comminuted trochanteric, collectively referred to as extracapsular fractures. In pertrochanteric fractures the lesser trochanter is avulsed, but it remains undamaged in basal fractures. Fractures in the subtrochanteric region are either transverse or oblique. Oblique subtrochanteric fractures are in most cases not parallel to the intertrochanteric line, but start two or three inches below the base of the greater trochanter to end in the region of the lesser trochanter, which is sometimes referred to as reversed obliquity.

12.2.1.2 Classification of Cervical Fractures

It has already been mentioned in Chapter I that there are two main types: vertical and horizontal. Each type may be impacted, in contact and only slightly displaced or markedly displaced so that there are six groups altogether. (Figs. 151, 152, 153, 154, 155, 156 and 157.) Approximately 90% of these fractures are vertically disposed and only 10% are transverse. Intermediate fractures are so similar to vertical fractures in appearance and treatment required that they will not be specially considered.

In complete vertical fractures the inferior spike shown in Figs. 151 and 152 is sometimes driven into the lower portion of the cervical fragment. However, radiographs taken after an interval frequently demonstrate complete separation of the fragments after their initial partial impaction. For this reason there is no need to recognise two groups of displaced
vertical cervical fractures as was done by Garden (1961).

It is clear that in all displaced fractures the retinacular vessels described in Chapter VIII can be damaged which jeopardizes the viability of the femoral head.

12.2.2 Treatment of Traumatic Group

Before the management of trochanteric and cervical fractures in adults as well as in children and adolescents is discussed, two points require special mention.

12.2.2.1 Potential Dangers of Nailing

A nail can only be hammered with impunity into an osteoporotic femoral head. If it is pile driven into a tough femoral head the cartilage may split as shown in Fig. 158. (This specimen was referred to in Chapter XI). It is reasonable to assume that such a lesion which cannot be detected radiologically, will, after a number of years, give rise to osteoarthrosis. (Fig. 159) If an innocuous implant like the writer's pin is not available and a nail with three or four fins has to be used, it is a wise precaution to ream out a channel for the nail with a \( \frac{3}{8} \)" cannulated drill inserted over a guid wire. The drilling must, however, stop \( \frac{1}{2} \)" short of the tip of the guide wire which will otherwise become loose.

12.2.2.2 Sepsis

Regardless of the care an individual surgeon may exercise, a certain number of his cases will always develop deep sepsis. In some hospitals the infection rate after hip surgery is as high as ten per cent. In the writer's experience, this risk is not abolished by pre- or post-operative antibiotics or by flushing the would repeatedly with antibiotics or
antiseptics during the operation. The risk can be reduced to under 2% by a scrupulous aseptic technique including operating in a clean air enclosure, Charnley's greenhouse, (Charnley, 1964), total enclosure of the faces of the operators and theatre staff by means of special helmets fitted with an exhaust system, wearing two pairs of gloves and impermeable gowns. Suction drainage should always be employed after extensive surgery.

In an established case the virulence of the infection can be lessened by antibiotics. A very small number of cases can even be cured thereby. Perfusion with antibiotics for several days is a most cumbersome method which neither the junior staff nor the nurses can manage at the writer's hospitals. If an implant is present it should, if at all possible, be kept in situ until the fracture is united. In some cases the infection subsides after simple removal of the implant. If it persists, or if the infection is ab initio severe and resistant to antibiotics Girdlestone's operation (excision of the head and neck of the femur) should be performed. A prosthesis surrounded by persistent infection should be removed completely which applies to cement in the acetabulum and the femoral shaft as well. Unless the cement inside the medullary cavity of the upper femor comes away completely with the prosthesis, it should be dug and chiselled out after guttering the lateral aspect of the bone. Removal of the implant leaves the patient with Girdlestone's operation, an acceptable salvage procedure.

12.2.2.3 Management of Trochanteric Fractures

Conservative treatment with skin or skeletal traction usually results in coxa vara and some rotary deformity after six to eight uncomfortable weeks in bed. Moreover, the sacral skin of elderly patients
tends to break down within a few days. For these two reasons these injuries are best treated by internal fixation.

Basal, pertrochanteric and intertrochanteric fractures are reduced on the orthopaedic table by applying traction to the somewhat externally rotated limb, as explained in Chapter IV. Owing to this position the anteversion of the femoral neck becomes more marked. The surgeon should, therefore, make his incision in line with the posterior border of the femur and so insert his guide wires so that they make an angle of approximately $30^\circ$ with the coronal plane.

A nail plate is then introduced. There is no need to transfix the great trochanter, if detached, with screws, because union invariably occurs.

Subtrochanteric fractures are sometimes treated with Kuntscher nails, but these do not adequately secure the proximal fragment. More secure fixation is provided by nail-plates. For fractures with reversed obliquity, nail plates with provision for up to seven screws are sometimes necessary, so that the upper two or three screws transfix the fracture. It is not always easy to reduce these fractures, but this difficulty may be overcome by driving a nail into the proximal fragment first, freeing the distal fragment, attaching the plate to the nail and then clamping the femoral shaft to the plate with a bone clamp. The fracture is now stable and can be secured with screws. The final screws are inserted after removal of the bone clamp.

Minor degrees of rotary mal-union and of coxa vara are common, but as a rule the disability caused thereby is negligible and can be accepted. Exceptionally an extreme deformity as described below calls for special measures.
12.2.2.3.1 Correction of Gross Coxa Vara

Case Report 31 - A woman, aged 35 years, was involved in a road traffic accident on the 4th April 1961. Her main injuries were closed fractures of the neck and shaft of the left femur. At first the limb was placed on a Thomas' splint. On the 20th April 1961 the shaft fracture was stabilised with an intramedullary nail. After this operation the splint was re-applied. On the 4th May 1961 her hip was protected with a single hip spica. On the 25th May 1961 an attempt was made to prevent mal-union of the basal cervical fracture by re-application of a Thomas' splint and skin traction. On the 19th July 1961 she was referred to the writer. Her two fractures were united. She had a marked coxa vara deformity with 1\(\frac{1}{2}\)" of shortening. (Fig. 160) It was decided to equalise her two limbs by performing a valgus osteotomy. On the 16th November 1961 the Kuntscher nail was extracted. This was rather difficult. The upper end of the femur was divided under radiological control at a calculated level. The proximal fragment was rotated until its cut surface faced medially. To the writer's complete surprise this was easy and there was no circulatory embarrassment or any undue stretching of the soft tissues. The two fragments were secured with a McLaughlin nail plate. (Fig. 161) Her progress was uneventful. By the 7th February 1962 her osteotomy was soundly united. On the 19th July 1962 the pin and plate were removed. Six months after this date she had no disability and was discharged. Her legs were the same length.

Rationale - This operation is similar to the one described by Scaglizetti (1962) but he did not investigate the geometry of the procedure which is explained in Figs. 162 and 163. The graph in Fig. 162 is a parabola. Such a curve is the locus of all points equidistant from a fixed line, the directrix, and a fixed point, the focus. If a line
parallel to the directrix is drawn through the focal point, the portion of this line inside the curve is called the latus rectum.

The problem in this particular case was to raise the centre of the femoral head, point C, to a point on line DD' which is 1\(\frac{3}{8}\)" above C (Fig. 152). The correct amount of lengthening was obtained by dividing the femur at point P along line PP' and then rotating the proximal fragment until the centre of the femoral head lay vertically above the medial cortex. (Fig. 153) The distance of point P from the centre of the femoral head, CP in Fig. 162 is identical with C'P in Fig. 163 and the ordinate y in Fig. 162. This point P is, therefore, equidistant from the centre of the femoral head and from line DD' and must lie on a parabola which has the centre of the femoral head and its focal point C and line DD' as its directrix.

Once this principle was understood, it was easy to find the line of osteotomy PP'. To obtain the correct dimensions a parallel beam radiographic projection of the affected hip with the two lower limbs touching was made and a two dimensional paper model was prepared from a tracing as shown in Fig. 162. It was not thought necessary to make any correction for the anteversion of the femoral neck. The Y-axis of the parabola to be constructed was drawn through point C in the sagittal plane. In the case under discussion, the shortening was 1\(\frac{3}{8}\)", corresponding to distance OC in Fig. 162. Line DD' drawn at right angles to line OC was the directrix of the curve and was also used as the X-axis of the reference system. The mid-point of line OC was obviously a point on the curve. Further points were found by describing a series of concentric circles about C and drawing a corresponding series of line parallel to KK. The distances of the parallel lines from DD' were always equal to the radii of the circles. Each straight cut its corresponding circle twice. Thus a number of points were found on each side of the axis OC. By connecting these points a
parabola was obtained which cut the femur at point P. Line PP', normal to
the Y-axis was the level of the osteotomy.

This level is critical and depends on the amount of shortening that
has to be corrected. Moreover, limitless correction is not possible.
Reference to Fig. 162 shows how the lengthening L can be expressed in
general terms. We have

\[ L = OT - CT \]  \[ (43) \]

If CT = 0 a theoretical maximum is reached. The osteotomy would then be
at the level of the latus rectum of the curve and would split the head
of the femur in two, but would not divide the shaft. The practical
maximum is, therefore, reached by an osteotomy at the highest point
of the medial femoral cortex along line AA'. The parabola for this situation
would be flatter than the one shown in Fig. 162. Its directrix would be
3" above point C, so that section along AA' followed by rotation of the
upper fragment would result in 3" of lengthening.

However, it is doubtful whether the main vessels and nerves of the
lower limb could withstand this considerable and rather sudden stretching.
This difficulty could probably be overcome by dividing the adductors and
the femur at the calculated level, distracting the fragments slowly and
then three or four weeks later rotating and securing the upper fragment
as shown.

By progressively shifting the line of section of the femur distally
less and less lengthening will be obtained and when point T reaches Q,
corresponding to an osteotomy along BB' so that

\[ CT = CQ = OC = 2a \]  \[ (44) \]

there will be no lengthening at all. The apex of this particular parabola
would touch the top of the femoral head and the directrix will be tangent to the parabola and the femoral head at their point of contact. The parabola itself will be slimmer than the one shown in Fig. 162.

The general equation of the parabola under discussion is

\[-y = -2a - \sqrt{y^2 - x^2} \]  \[\text{......... (45)}\]

which reduces to

\[-y = \frac{-x^2 - 4a^2}{4a} \]  \[\text{......... (46)}\]

The above consideration clearly shows that normal length can be restored to limbs shortened as a result of post-traumatic coxa vara by performing a valgus osteotomy of the upper end of the femur with rotation of the proximal fragment in the cervical plane at a calculated level.

12.2.2.4 Management of Cervical Fractures

It is hoped that the ideas here presented constitute an advance on the routine of many colleagues which can be summarized as follows: Nail in, nail out, prosthesis. The treatment of these injuries depends upon the type of fracture, the presence or absence of osteoporosis and the fitness of the patient. Each of the following situations demands a different line of approach.

(a) Impacted fractures should be treated conservatively. If the patient can actively raise his leg and thereby demonstrates that impaction is firm, he can be slowly mobilized with the aid of crutches. Full weight can be allowed at the end of a week or two depending on the amount of pain caused thereby. Some of these fractures become disimpacted on this regime. Others either have ab initio or develop fairly quickly a marked external rotation deformity. These two groups of cases and all those
patients who cannot raise their legs after about a week and, therefore, do not have firmly impacted fractures should be treated by internal fixation as described in the next two paragraphs.

(b) Undisplaced or slightly displaced transverse or vertical fractures including those special cases mentioned in (a) may be treated by low-angle pinning, first described by Kuntscher (1953). Either the nail developed by Kuntscher or a trifin nail may be used. An illustrative case is presented in Fig. 164. A Kuntscher hip nail has been correctly placed resting on the inferior cervical cortex, traversing the centre of the femoral head and avoiding the foveolar artery. This method is quick and provided that the periosteum is intact and the upper end of the femur is not too osteoporotic, reasonable results can be achieved in spite of somewhat imperfect immobilisation of the fragments. A mechanically still less sound method consists of the insertion of three or four 1 - 1.5 mm diameter wires.

(c) Displaced transverse and vertical fractures and originally impacted fractures which have become widely displaced should be treated with a sliding pin which rigidly secures the fragments by providing the shaft fixation demanded by Haboush (1953). Naturally the writer prefers the pin described in this thesis, but quite a number of similar models are now available. All sliding pins allow for disappearance of a portion of the femoral neck and keep the fracture in compression. For these two reasons they are superior to simple nail plates. As mentioned in (b) the tip of the implant should be directed away from the fovea for fear of damaging the artery emerging therefrom on which the survival of the femoral head may depend. Occasionally an open reduction is necessary if either periosteum or a capsular fold become interposed between the capital and cervical fragments. The hip can be very rapidly exposed by extending the usual lateral
incision upwards towards the anterior superior iliac spine and developing
the interval between tensor fasciae femoris and the hip abductors.
(d) All non-impacted fractures in osteoporotic subjects are best treated
by immediate prosthetic replacement provided the operator possesses the
necessary skill and the operating theatre is safe. The head and a portion
of the neck of the femur are removed and replaced either by a Thompson
or Austin Moore prosthesis. The first implant has a solid stem, the second
a fenestrated stem and an extraction ring. The purpose of the two
fenestrations was to give bone a chance to grow from the interior femoral
cortex to the posterior via the two windows, thereby firmly securing the
implant. This unfortunately does not happen in elderly patients. Unless
the implant is firmly cemented in with acrylic resin, the prosthesis
becomes mobile causing pain in the upper thigh and hip. (Fig. 165).
The writer prefers to use an Austin Moore prosthesis in conjunction with
acrylic cement. Should it become necessary to remove the implant at a
later stage, because it either causes pain or infection is present, most
of the cement, if not all, comes away with the prosthesis to which it has
become firmly attached by the two windows. (Fig. 166). Usually a few
taps with a Kuntscher nail extractor inserted into the hook at the top of
the implant suffice, but in some cases a portion of the lateral cortex
must be removed and the cement loosened with an osteotome. The patients
who require prosthetic replacement of a femoral head are usually elderly
and frail. Speed is essential. The surgeon should be able to complete
the whole operation in under one hour and it has been performed from
skin to skin in under 30 minutes.

Exceptionally in cases of rheumatoid arthritis or severe osteoarthritis
it is permissible to carry out immediate total hip replacement, but the
operation should not last more than one hour.
(e) In all cases where internal fixation is necessary and osteoporosis is merely a possibility, the hip should be pinned as described in (b) and (c). If the pinning fails, a prosthesis can always be inserted later.

(f) Cases on non-union are usually treated by removal of any implant present and insertion of either a Thompson or Austin Moore prosthesis. Patients who have had this operation have serviceable hips, but they have a locomotor handicap and frequently some pain. This is usually caused by medial migration of the head of the implant into the pelvis giving rise to a type of protrusio acetabuli, a process which may take two to five years before it can be detected radiologically. Nevertheless the results are acceptable for elderly patients. If, however, the patient has a reasonable expectation of life and is still in his sixties or early seventies, total replacement of the hip gives better results. The introduction of hip prostheses has rendered excision of the head and neck of the femur (Girdlestone's operation) somewhat obsolete. Patients who have had this operation usually have a marked limp, walk with their foot turned out and use a stick, but they can lead useful lives.

If the patient's hip is not osteoporotic, it is justifiable to remove the previous pin and try to obtain union by using the pin presented in this these, but it must be explained to the patient that at best the chances of success are only 50%. This operation has the advantage of simplicity and can result in a normal hip. It is only feasible if good quality X-Rays, including oblique projections, show that the central portion of the femoral head is undamaged and will firmly grip the pin.

Until hip prostheses were accepted by the profession in the late fifties and early sixties, the standard procedure for the situation described in the above paragraph was a so-called displacement osteotomy as shown in Fig. 167. The femoral shaft is displaced medially so that it supports and immobilizes the femoral head. The patient's hip is then
protected by a spica for three to four months. This treatment is not comfortable and is not well tolerated by elderly ladies, nevertheless it can be survived as case report 24 in Chapter IX demonstrates.

A similar method is to perform a high femoral osteotomy and to impact the divided femoral shaft into the trochanteric fragment by abducting the leg as shown in Fig. 168. As a result the fracture line is made a little more horizontal. At the same time the adductors are tightly stretched which in turn forces the two surfaces of the ununited fracture firmly together. The patient with his leg in abduction is then encased in a plaster spica.

To avoid plaster immobilization, a number of internal fixation devices were introduced to secure the great trochanter to the displaced femoral shaft. Although this method usually leads to union in cases of osteotomy performed for osteoarthritis of the hip and the failure rate is only of the order of 10%, the writer's experience suggests that this method does not work if used for non-union of the femoral neck after fracture. An alternative recommended by Pauwels (1965) is a cuneiform excisional osteotomy of the upper end of the femur. The purpose of this operation is to make the line of the fracture more horizontal. Pauwels (1965) does not mention the after-treatment of these cases in his book, but from the total absence of any reference to internal fixation it is reasonable to assume that his patients had to endure plaster spicas for several months. In the case reported below an osteotomy with internal fixation was performed.

12.2.2.4.1 Excisional Cuneiform Osteotomy for Non-union

Case Report 7 continued - The patient whose hip is shown in Fig. 169 and previously in Fig. 43 was a 16 year old girl whose osteosynthesis disintegrated. Because the wires had to be dug out of the centre of the femoral head, it was felt that the writer's pin would not help her. Instead a 45 wedge with its base laterally was excised to render the
fracture line more horizontal as explained in Figs. 170 and 171. Next a McKee pin was inserted into the inferior portion of the femoral head and fixed to the widely abducted shaft by means of its plate. Damage to the femoral head was avoided by reaming out a $\frac{3}{8}$" diameter channel before driving the nail home. For additional fixation two Austin Moore's pins were inserted. (Fig. 172). During the extraction of the proximal portion of the old pins, a piece of bone became detached and was secured with two small nails. It was noted that the bone of both fragments was exceptionally hard. Her fracture and the osteotomy united uneventfully in three months. No external splintage was applied. She was discharged from hospital three weeks after operation using crutches non-weightbearing on the operated limb until there was X-Ray evidence of union. The follow-up so far is fifteen months. She is at present awaiting re-admission for removal of the implants. Her hip is painless, but the movements of the joint are slightly restricted. There is no evidence whatsoever at this stage of collapse of the head of the femur, but this complication cannot be ruled out.

(g) The elderly, decrepit patient who is not moribund, but unfit for anaesthesia should not be confined to bed, because recumbency rapidly causes bed sores and broncho-pneumonia. He should be sat out of bed and with the aid of pain-relieving tablets he should be slowly mobilised. He does not tolerate calipers and it is far better to mobilise him with a walking frame and later tetrapod sticks. This regime leads to survival in many cases. Substantial portions of the head and neck fragments become rubbed away as the patient walks, leaving him with the equivalent of Girdlestone's operation (excision of the head and neck of the femur). A patient whose nailing has failed and who is unfit for a further lengthy operation should be treated identically after quick removal of his implant.
This line of treatment is expensive, because it may keep the patient in hospital for two or three months.

(h) Patients with collapsed or osteoarthritic femoral heads after internal fixation do not all require surgical treatment. Many of them need no more than a walking aid in addition to pain-relieving or anti-rheumatic tablets. However, if their sleep is disturbed and every single step causes severe pain, total hip replacement is clearly indicated. Similar remarks apply to osteochondritis dissecans of the hip, unless the patient is still in his forties or fifties, when a Varus osteotomy should be performed.

12.2.3 Rehabilitation

The regime recommended below applies to all cervical and trochanteric fractures and can be pursued with a little more vigour than the gentle methods advocated in (g).

Rehabilitation starts with breathing and generalised exercises. The patient should sit out of bed the day after operation. Early ambulation can only be permitted if an exceptionally strong implant, e.g. the one described in this thesis or the one by Holt (1963) has been inserted. Even so partial weightbearing with the aid of crutches or a Zimmer frame is not encouraged for the first few days for fear of starting up haemorrhage from the vessels cut during the operation. Rapid rehabilitation is the best method of preventing deep vein thrombosis, far better than anticoagulants which tend to cause troublesome bleeding either from the wound or into the thigh.

Patients with impacted fractures do not require operative treatment and can be progressed at a faster pace. They are allowed to start walking a day or two after their injury and within a few weeks should be able to discard successively two crutches or a Zimmer frame, two sticks and then
one. However, many elderly patients prefer to retain either a Zimmer walking frame or a stick.

12.2.4 Fractures of the Upper End of the Femur in Children

In 1966 Ratliff read a paper to the British Orthopaedic Association on this subject. He reviewed 82 cases of which 43% developed avascular necrosis of the head of the femur. The published account does not state how these cases were treated.

The paper by McDougall (1961) however, gives full details. He studied 24 patients under 17 years of age and emphasized that these injuries were frequently followed by a permanent disability owing to avascular necrosis, non-union, mal-union, including gross coxa vara and disturbances of growth. His cases were treated by a number of methods: skin and skeletal traction, Smith Petersen nails, nail plates, bone graft and nail multiple pins, plaster immobilisation, osteotomy and arthrodesis. Excellent results, i.e. normal hips, were recorded only eight times. Of special interest are two illustrations in this article. The first shows a standard size trifin nail driven into the femoral head of a ten year old girl. The second shows osteoarthritic changes nine years later.

Watson-Jones (1952) recommended that these injuries be treated by immobilisation in a plaster spica for six to eight weeks. The case described by him united with a coxa vara deformity, but the late result is not given.

The writer's personal experience of these injuries is limited, because they are rare. Nevertheless, he feels that if these fractures are treated by proper reduction and proper maintenance of reduction much better results can be achieved than those just reported.
These fractures should be treated by closed reduction on an orthopaedic table. Cervical fractures should be kept reduced by three or four pins and then protected with skin traction and a Thomas' splint or until there is X-Ray evidence of union, which usually occurs within six to eight weeks. In children shaft fixation of cervical fractures is not necessary because the cancellous bone in the distal fragment is tough and firmly grips and supports the pins allowing no movement at the site of the fracture. Trochanteric fractures should be secured with a Coventry nail-plate for children which is strong enough to support fractures in patients up to twelve years of age. (Fig. 173). No external splintage is required during the healing period of about four weeks, but weightbearing must be deferred until there is bony union.

On no account should a standard trifin nail ever be hammered into the femoral head of a child. The sudden increase in volume can split the articular cartilage of an adult femoral head (Fig. 158) and this is much more likely to happen to the smaller femoral head of a child because the nail will cause a greater rise in internal pressure.

12.2.5 Fatigue or Stress Fractures

These injuries are uncommon and for this reason a case report is presented. The patient sustained her femoral neck injury without ever falling.

12.2.5.1 Example

Case Report 32 - A woman aged 83 years was walking along the pavement doing her shopping. She was in good health and had no hip symptoms whatsoever. Suddenly she felt severe pain in her right hip, but she did not fall. She walked home, about half a mile, with assistance. Later on
she was admitted to hospital. Her X-Rays showed evidence of osteoporosis. The X-Ray film of her right hip demonstrated an impacted fracture of the femoral neck. (Fig. 174). Her other hip was not fractured. All biochemical investigations were negative. A diagnosis of fatigue fracture of the femoral neck due to senile osteoporosis was made. Her femoral head was replaced by a prosthesis. Its histology did not yield any features of interest.

12.2.5.2 Classification

Devas (1965) describes two main types:

(a) Transverse fractures. In these cases the fracture line starts at the superior cervical cortex, where tensile stresses are high, and travels transversely across the trabecular systems. These fractures are apt to become grossly displaced. They resemble either basal or vertical fractures. Fig. 2 in the paper by Devas (1965) is identical with Fig. 174 above. The writer would call this type of injury an impacted near vertical fracture.

(b) Compression fractures. These affect the inferior cervical cortex above the lesser trochanter and with one exception, Fig. 9 in his series, they are incomplete. They do not become displaced.

12.2.5.3 Treatment

Undisplaced transverse fractures should be stabilized by three or four Austin Moore wires inserted as vertically as possible. Displaced transverse fractures should be reduced and then internally fixed with an atraumatic sliding pin providing shaft fixation and continuous compression during the healing period. If the patient is elderly and suffering from osteoporosis, or the hip is affected by rheumatoid arthritis, prosthetic
replacement is the method of choice. Some of the patients are suffering from osteomalacia and require sodium phosphate in daily doses of 1.5 - 2 grammes. Some clinicians add Vitamin D in doses of 5,000 to 10,000 units daily. Both preparations are given for lengthy periods.

Compression fractures very often require no treatment other than avoidance of strenuous activities or perhaps even weightbearing for a few weeks. However, no objection can be raised to the insertion of a few Austin Moore guide wires if the patient has a fair amount of pain or the surgeon is anxious.

Fractures of the upper end of the femur in patients suffering from Paget's disease of bone usually require nail plates.  

12.2.6 Pathological Fractures

The various causes of these injuries have already been dealt with in an earlier section. In the writer's experience the commonest of these is a secondary mammary carcinoma, but any metastasizing carcinoma, e.g. carcinoma of the ovary or colon may produce such a fracture.

12.2.6.1 Classification

The lesions causing these fractures are either benign or malignant and the fractures themselves are either complete or incomplete. No further classification is possible.

12.2.6.2 Treatment

No hard and fast rules can be laid down. For benign lesions a variety of measures is available. (a) curettage of the lesion, packing the resultant cavity with iliac bone chips, followed by internal fixation or less effectively immobilisation in a plaster spica for several months.
(b) Excision of the head and neck of the femur. (c) Arthrodesis of the hip after curettage or excision of the lesion.

In many a patient a pathological fracture of the upper end of the femur due to primary malignant disease can only be treated by deep X-Ray therapy or a hind quarter amputation. Very often such a fracture is a terminal event in a patient suffering from generalised carcinomatosis and only palliative treatment is required. If the patient is reasonably fit, internal fixation with a nail plate should be carried out and followed up with deep X-Ray therapy, possibly augmented with hormone or chemotherapy, and as a last resort a hypophysectomy or bilateral adrenalectomy combined with bilateral oophorectomy can be performed.

Three patients who received somewhat unorthodox treatment are presented below.

12.2.6.2.1 Bone Graft for Polyostotic Fibrous Dysplasia

Case Report 33 - A 15 year old girl suffering from polyostotic fibrous dysplasia sustained a pathological fracture of the left hip. (Fig. 175). Immobilisation in a double hip spica for three months merely resulted in widening the fracture gap. It was, therefore, decided to drive a tibial bone graft across the fracture. This graft was 3\frac{1}{2}" long and had a roughly rectangular cross section with a width of \frac{1}{4}" and a depth of \frac{3}{8}". Its proximal end was pointed. To offer the maximum resistance to the flexural stresses acting on the upper end of the femur the graft was so inserted that its depth occupied a plane normal to the ground passing through the axis of the head and neck of the femur. For this difficult operation a guide wire technique and a cannulated osteotome was used. Post-operatively the patient's hip was again protected by a double hip spica. At the end of this period her fracture was united. She was followed up for two years after union of her fracture. At that time her hip was symptom
free. A radiograph of her hip is shown in Fig. 176. The writer reported this case many years ago. (Bingold, 1952).

12.2.6.2.2 Prosthesis for Cervical Bone Cyst
Case Report 34 - A 20 year old girl sustained a pathological fracture through a bone cyst, (Fig. 177), whilst walking. A prosthesis was inserted by a senior colleague after generous excision of the lesion, but worked loose within three months. (Fig. 178). A second attempt at prosthetic replacement was equally unsuccessful. She finished up with an unstable limb after removal of the second implant and had to wear a caliper.

This case demonstrates quite clearly that a short intramedullary stem is quite inadequate to secure an implant replacing the upper end of the femur. Either thorough curettage of the lesion and removal of the femoral head and neck or an arthrodesis bypassing the lesion with a bone graft fixing the femur to the pelvis, followed if necessary by curettage of the lesion would have given a better result.

12.2.6.2.3 Prosthesis for Seconday Mammary Carcinoma
Case Report 35 - Twenty years after a right radical mastectomy a 69 year old woman developed a secondary deposit with a fracture in her left hip. (Fig. 179). She was experiencing considerable pain. Her general health was good. A complete radiological survey of the skeleton and a chest film revealed no other secondaries. Her biochemistry was normal. After lengthy discussions with colleagues, it was decided to excise the upper portion of her femur and to replace it with a prosthesis. This consisted of a McKee cup and a Thompson head with a short stem, both manufactured from cobalt chrome. The stem was then shrink fitted into a hollowed titanium intramedullary rod with a cup to fit over the bony stump. The reasons for using a composite implant were that titanium can be easily machined, whereas cobalt chrome can only be shaped by casting and that there is not
interaction between cobalt chrome and titanium. The cup and the stem were secured with cement (Fig. 180). This implant gave her $3\frac{1}{2}$ years of comfort. At the end of this period she developed another painful secondary deposit below the prosthesis. Fortunately this lesion responded to deep X-Ray therapy and at the time of writing $4\frac{1}{2}$ years after insertion of the implant, she had hardly any pain in her left thigh.

Although her treatment had not been orthodox, the writer feels it has been worthwhile. If her hip had been irradiated she would have ended up with a misshapen femoral head and neck (Figs. 181 and 182) and the pain stemming from her cancer would have been quite successfully replaced by pain stemming from avascular necrosis of the femoral head.

12.3 SUMMARY

(a) The need for better understanding and treatment of fractured femoral necks is highlighted by presenting two unsatisfactory results after trifin nailing.

(b) Bony injuries to the upper end of the femur fall into three groups: Traumatic, stress or fatigue and pathological fractures. The factors leading to mechanical failure in each group are discussed.

(c) The dangers of damage to the hip by nailing and by sepsis are stressed.

(d) The various types of traumatic trochanteric fractures are considered. They are best treated with strong nail-plates allowing early ambulation. A case of gross coxa vara following a trochanteric fracture is described. $1\frac{3}{4}$" of shortening were corrected by a valgus osteotomy at a calculated level.

(e) A comprehensive classification of traumatic cervical fractures is presented. Impacted fractures should be treated conservatively. All displaced fractures should be treated with nail-plates, preferably sliding pins, atraumatically inserted. If the patient is suffering from osteoporosis,
rheumatoid arthritis, or severe osteoarthritis, prosthetic replacement usually femoral but occasionally total is indicated. If there is no overt osteoporosis the hip should be pinned. Failed cases can also be treated by osteotomies of the upper end of the femur. A successful cuneiform osteotomy of the upper end of the femur in a 16 year old girl is reported. The development of bed sores and bronchopneumonia in elderly patients unfit for anaesthesia can frequently be avoided by ignoring their fractures and mobilising them with the aid of pain-relieving tablets.

(f) The principles of rehabilitating patients with fractures of the upper end of the femur are presented.

(g) Fractures of the upper end of the femur in children should be secured with small implants, either multiple pins or a small screw plate.

(h) Fatigue or stress fractures are either transverse and liable to become displaced, or they are incomplete due to the medial cervical cortex failing in compression. Incomplete fractures require relief from weightbearing for a period. Undisplaced fractures may be stabilised with two or three pins. Displaced fractures should be treated by sliding pins or if there is evidence of osteoporosis by prosthetic replacement.

(i) Pathological fractures of the upper end of the femur are either caused by benign disorders, or more frequently by secondary malignancy. The treatment of these cases cannot be standardised, but the majority can be managed satisfactorily by routine measures. Benign lesions can be curetted, packed with iliac chips and then protected preferably with an internal splint or occasionally with a plaster spica. Alternatives are excision of the head and neck of the femur or arthrodesis of the hip. Pathological fractures due to malignant disease may be pinned and then irradiated. Three patients had unorthodox treatment. (a) A patient with polyostotic fibrous dysplasia whose hip fracture was secured with a bone graft
and united. (β) A patient with a bone cyst was treated unsuccessfully with a prosthesis. (γ) A patient with a secondary mammary carcinoma who 4½ years after insertion of a composite implant replacing the upper quarter of her femur had a serviceable limb with hardly any pain.
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5. Coexistence of Polyostotic Fibrous Dysplasia and Juvenile Tabes, March 1952 - by A.C. Bingold
6. Acrylic Replacement of Painful Osteomyelitic Femoral Amputation Stump, October 1953 - by A.C. Bingold
7. Congenital Kyphosis, November 1953 - by A.C. Bingold
8. Pseudarthrosis of Tibia treated with Four-Pin Compression Clamp, February 1954 - by A.C. Bingold
9. Paralytic Flat Foot treated by Triple Tendon Transplantation, October 1955 - by A.C. Bingold
10. Benign Fibrous Tumours of Single Bones, June 1955 - by A.C. Bingold (Hunterian Lecture)
11. Ankle and Subtalar Fusion by a Transarticular Graft, November 1965 - by A.C. Bingold
15. Experimental Work on Femoral Neck Fractures, November 1959 - by A.C. Bingold
16. Luetic Lumbar Spondylitis, May 1962 - by A.C. Bingold
17. Prosthetic Replacement of a Chondrosarcoma of the Upper End of the Femur, February 1972 - by A.C. Bingold
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