Many workers have over many years tried to find a reliable method of detecting damage to the blood supply of the femoral head soon after fracture of the neck of the femur. Up to now the most promising method has been that in which a radioactive isotope is given intravenously and the amount of it appearing in the femoral head and trochanter is measured.

In 1950 Tucker published a preliminary report on the use of radioactive phosphorus. The isotope was given intravenously one hour before operation at which small samples of bone were removed with a hollow drill from the femoral head and trochanter. The dried ash of these samples was measured for its $^{32}P$ content and the result was expressed as a ratio between the $^{32}P$ contents of the trochanter and head.

Before this, animal experiments had confirmed that the ratio was normally 1:0 but that if all vessels to the head of the femur were divided a ratio of up to 14 was obtained; evidently some absorption of $^{32}P$ into the head from the surrounding synovia and blood occurred.

Tucker applied this method to thirteen patients, carrying out the investigation at the time of nailing the fracture. With a one to two years’ follow-up there appeared to be a good correlation between a normal or near-normal ratio and bony union. He found that a ratio of up to 3:0 could be regarded as indicating a satisfactory blood supply in the head. He found no harmful effects from the use of $^{32}P$. Boyd in 1951 made a preliminary report on the use of this method in animals and in a few patients, taking direct measurements with a needle counter.

Arden and Veall in 1950 reported on the use of $^{32}P$ with bone sampling in twenty-two cases. They studied sixteen fractures of the femoral neck and six intertrochanteric fractures, following them up for six to twelve months. In all the five surviving patients with intertrochanteric fractures union occurred and the ratios were normal (0:4 to 2:0). In nine of the sixteen cases of fracture of the femoral neck the ratios were low (1 to 2:3) yet three of these failed to unite (possibly because of faults in the nailing technique).

In 1955 Boyd, Zilversmit and Calandruccio published a more extensive series of cases in which the method had been used first in dogs and then in patients.

They found that in dogs the $^{32}P$ level reached a plateau in about one and a half hours, in both the head and trochanter of the femur. Even if the blood supply to the head were damaged a plateau was still reached in the head in about the same time but the ratio was altered by the $^{32}P$ reading in the head being diminished. They found that in dogs the distribution of $^{32}P$ in the normal femoral head varied and that counts in the posterior inferior segment of the head were higher than in the posterior superior segment. The weight-bearing portion of the head had the lowest count. Autoradiographs of femoral heads removed from patients showed patchy areas of radioactivity, the unexposed areas corresponding to zones of avascularity. They used the method in thirty-two patients with fresh fractures of the neck of the femur and in ten with fresh intertrochanteric fractures (controls). As far as possible they took readings from the weight-bearing area of the head in each case. The ratios in the cases of fracture of the femoral neck varied from 1:3 to 16:7 and in the cases of trochanteric fracture from 0:7 to 1:9. The period of observation was not long enough to permit a comparison between the clinical results and the ratios of radioactivity.

The results of these studies are summarised in Table 1.

This paper records the results of an extended trial of the use of $^{32}P$ for the measurement of the vascularity of the head of the femur after fracture of the femoral neck.
METHOD OF INVESTIGATION

About one hour before nailing the fracture 200 microcuries of P³² were given intravenously in a sterile solution of sodium phosphate. The usual operative procedure was carried out until a guide wire was in the correct position. In the first twenty-two cases small samples of bone were removed at this stage by a Harris bone biopsy drill from the head of the femur and from the trochanter (Figs. 1 and 2). The nailing operation was completed in the usual way. Counts were taken from the bone samples over a period of one minute. The results were expressed as counts per minute per milligram of bone, the "ratio" being obtained by dividing the figure for the trochanteric by that for the capital sample.

![Radiographs showing needle in the counting positions in the trochanter and in the head.](image)

Since 1953 direct readings have been taken at the time of operation with a needle counter designed by Veall. This needle counter has a thin probe 15 centimetres long with a diameter of 3 millimetres. The sensitive eye is 12 millimetres long and is situated 6 millimetres from the tip. The wall of the probe is metal and only 0.005 inch thick. These needle counters are therefore fragile and only last about three to six months. A sterilisable lead connects the

### TABLE 1

<table>
<thead>
<tr>
<th>Year</th>
<th>Author</th>
<th>Number of fractures</th>
<th>Method</th>
<th>Normal ratio (2:1)</th>
<th>Doubtful ratio (3:1)</th>
<th>Abnormal ratio (4:1 or more)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1950</td>
<td>Tucker</td>
<td>12</td>
<td>Direct sampling</td>
<td>9</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>1953</td>
<td>Arden and Veall</td>
<td>16</td>
<td>Direct sampling</td>
<td>9</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>1955</td>
<td>Boyd, Zilversmit and Calandruccio</td>
<td>32</td>
<td>Direct reading</td>
<td>17</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>1958</td>
<td>Arden</td>
<td>18</td>
<td>Direct reading</td>
<td>15</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
enclosed base of the needle counter to a clinical monitor. This apparatus automatically counts the number of \( \beta \) rays picked up by the needle counter in thirty seconds. The needle counter and lead can be sterilised in hot formaldehyde vapour.

The needle counter was used as follows: the Harris drill was inserted along a suitable guide wire and both were then removed. The probe was then Passed into the head of the femur along this channel and its position was checked by radiographs. The site chosen was usually about the centre of the head. A reading was then taken. Immediately after this a further reading (Fig. 1) was taken from the trochanteric region of the drill hole. In each case the procedure was carried out three times so that an average of the readings could be taken. In twenty cases the drill hole was washed out with saline after each reading as it was suspected that the blood oozing into this canal might increase the subsequent reading. The irrigation was later found to make no difference and was therefore discontinued.

**TABLE II**

<table>
<thead>
<tr>
<th>Number of patients</th>
<th>61</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average age</td>
<td>74 years</td>
</tr>
<tr>
<td>Sex</td>
<td>50 F 11 M</td>
</tr>
<tr>
<td>Side</td>
<td>37 R 24 L</td>
</tr>
<tr>
<td>Average time</td>
<td>2.4 days</td>
</tr>
</tbody>
</table>

The nailing operation was then completed in the usual way. It was decided to nail the fracture whatever the results of the reading so that the results of the investigation could be compared with the clinical result two years after operation.

**MATERIAL**

One hundred patients were studied. In fifteen the investigation was abandoned because of technical faults—faults in the counter, false readings from the cable, faults in the clinical monitor and electrical disturbances from the mains supply. Seventeen more cases were discarded because, for reasons to be discussed later, the readings were considered to be
unreliable. In the sixty-eight remaining patients there were seven deaths, leaving sixty-one cases for analysis. Of these, forty patients had displaced (disimpacted) fractures of the neck of the femur and twenty-one had trochanteric fractures (Table II). The period of observation was not less than two years in any case.

RESULTS

No toxic effect from the P³² was found in any of the hundred patients. In the first twenty patients blood counts were done at weekly intervals after operation but no unusual changes were seen. Examination of the patients with a Geiger counter after operation showed that all had excreted nearly all the P³² in forty-eight hours.

In each of the seventeen cases omitted from the series there was a marked discrepancy between one reading and the other two, either in the head alone or both in the head and in the trochanter. These discrepancies were so large that it was considered that they must have been caused by some technical fault in the apparatus.

**TABLE III**

**ANALYSIS OF CLINICAL RESULT IN TWENTY-ONE TROCHANTERIC FRACTURES AND FORTY FRACTURES OF THE FEMORAL NECK**

<table>
<thead>
<tr>
<th>Type of fracture</th>
<th>Number of fractures</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>United</td>
<td>Avascular necrosis</td>
</tr>
<tr>
<td>Intertrochanteric</td>
<td>21</td>
<td>—</td>
</tr>
<tr>
<td>Fractured neck of femur</td>
<td>40</td>
<td>25</td>
</tr>
</tbody>
</table>

All the trochanteric fractures united. Twenty-five of the fractures of the femoral neck united; in seven there was evidence of avascular necrosis and eight went on to non-union (Table III).

**Comparison of clinical result with ratio of radioactivity** (Table IV)—In twenty patients with trochanteric fractures the ratio of radioactivity between the trochanter and head was below 2-5. In the remaining patient the ratio was 3-0. All these fractures united. The results in the forty patients with fractures of the femoral neck can be analysed as follows.
Of the twenty-eight patients with a normal $^{32}$P ratio two developed avascular necrosis and three went on to non-union. Details of these five cases are as follows:

1. \textit{Subcapital fracture}—$^{32}$P ratio 2.5. Good reduction and nailing—nail extruded—re-nailed with a plate. Non-union.
4. \textit{Subcapital fracture}—$^{32}$P ratio 2.1. Good reduction and nailing—good union—but after eighteen months segmental necrosis of weight-bearing portion of head occurred.
5. \textit{Transcervical fracture}—$^{32}$P ratio 1.3. Fair reduction and nailing—united—but at one year developed avascular necrosis.

The fractures in the remaining twenty-three patients in this group went on to bony union.

In the four patients with a borderline ratio one fracture united, two developed avascular necrosis and one failed to unite as follows:

2. \textit{Subcapital fracture}—$^{32}$P ratio 3.0. 80 per cent reduction—good nailing—developed avascular necrosis at two years.
3. \textit{Transcervical fracture}—$^{32}$P ratio 3.3. Good reduction and nailing—nail extruded—held but developed avascular necrosis at nine months.

In the eight patients with an abnormal ratio one fracture united, three developed avascular necrosis and four went on to non-union. Reduction and nailing were good in all these cases. The ratios obtained in them were as follows:

1. \textit{Union}—$^{32}$P ratios 4.1.
2. \textit{Avascular necrosis}—$^{32}$P ratios 6.7, 7.0, 10.0.
3. \textit{Non-union}—$^{32}$P ratios 11.0, 12.0, 20.0, 30.0.

The twenty-two cases examined by direct sampling compared fairly well with the forty-six cases in which direct measurements were taken except that sampling of a damaged head tended to give a much lower reading than examination with the needle counter. With sampling, ratios as high as 30.0 were recorded, whereas the highest recorded with the needle counter was 11.0. In two cases readings from the head and trochanter were taken at two-minute intervals from the moment of injection of $^{32}$P, as it was thought that the rate of climb on the resultant chart (Fig. 2) might give a better idea of the vascularity of the head. In both cases there was an almost equal rate of rise in the counts, yet union occurred in one case and failed in the other.

\textbf{DISCUSSION}

In 82 per cent of the cases in which a low $^{32}$P ratio seemed to indicate a favourable prognosis the clinical result was good. On the other hand union occurred in one patient with a borderline count (2.8) and in one with a definitely abnormal count (4.1). Further, five patients who should have done well, as judged by the $^{32}$P counts, developed non-union or avascular necrosis. The discrepancy between expected and actual results could be due to errors inherent in the method of investigation or to technical faults in the method of internal fixation.

\textbf{Sources of error in the method of investigation}—As Boyd and his colleagues (Boyd, Zilversmit and Calandruccio 1955) have pointed out, the amount of $^{32}$P in the bone depends on many factors apart from the circulation of blood through the bone. These factors however are common to all cases and cannot anyway be readily excluded. The efficiency of the probe in measuring the radioactivity and, by inference, the vascularity of the femoral head is clearly subject to many and serious limitations. Firstly, most of the β rays picked up by the probe
emanate from a relatively small area. If the distribution of P\textsuperscript{32} in the femoral head were patchy, misleading readings would assuredly be obtained. In fact, Boyd and his colleagues have shown that the distribution of P\textsuperscript{32} in the head after fracture of the neck is often patchy. In cases of non-union where removal of the head was necessary I gave P\textsuperscript{32} intravenously one hour before operation and took samples from various sites in the excised head. Readings were taken from the trochanter at the time of operation. The ratio was normal near the ligamentum teres and became abnormal near the fracture line (Fig. 3). It is clear that there may often be a difference in the radioactivity of different parts of the femoral head and that a misleading result can be given if the eye of the probe happens to lie in a patch of good vascularity.

The question is raised whether the position of the probe in the centre of the head as used in this study is the correct one. Trueta and Harrison (1953) showed that the superior weight-bearing part of the head, supplied by the superior epiphysial artery, is particularly liable to be deprived of its blood supply after a fracture of the neck. Boyd and his colleagues have suggested that, because of the liability of this part of the femoral head to avascular necrosis, counts should be taken from it rather than from the centre of the head.

**Technical faults in internal fixation**—Technical faults in operation may be imperfect reduction and inadequate internal fixation. These faults were in fact obvious in only one of the cases of subcapital fracture in which a poor result was associated with an apparently favourable P\textsuperscript{32} ratio. The solution to the problem of the apparently well-placed nail which slides out may lie in the use of nail plates and lag screws of the Charnley type (Charnley, Blockey and Purser 1957). Too little is known of the role of post-operative treatment in determining failure after operation on a fracture of the femoral neck to allow valid comment on this possible cause of failure. Lastly, it is possible that the damage caused by the introduction of a hollow drill may determine failure. Trueta and Claffey (1957) have produced evidence to show that the introduction of a nail is unlikely to cause damage to the blood supply of the head. It is therefore unlikely that the much smaller drill would inflict significant damage.

**SUMMARY**

1. A method is described for measuring blood flow to the head of the femur after fracture of the femoral neck, by estimation of the rate of uptake of radioactive phosphorus.
2. Of one hundred cases investigated the readings in fifteen were incomplete, and in seventeen were unreliable. Reasons are given for discarding the latter seventeen cases. After two years seven patients had died, leaving sixty-one available for analysis.
3. The results in sixty-one surviving patients with a follow-up of not less than two years are analysed. In twenty of these radioactivity was measured by bone sampling and in forty-one by direct readings with a needle counter.
4. The twenty-one intertrochanteric fractures studied were used as controls. In these the \( \text{P}^{32} \) ratio varied from 0-4 to 3-0. Union occurred in all patients and none developed avascular necrosis.
5. Of the forty patients with displaced fractures of the femoral neck twenty-eight showed a low \( \text{P}^{32} \) ratio. In twenty-three of these (82 per cent) the fracture united.
6. Twelve patients with fractures of the femoral neck showed a borderline or abnormal \( \text{P}^{32} \) ratio. In ten of these there was subsequent avascular necrosis or non-union.
7. The possible reasons for the discrepancy between expected and actual results are discussed.
8. Almost 40 per cent of the cases investigated had to be abandoned because of technical faults and in one-fifth of the remaining cases the expected results failed to agree with the clinical results. The method of investigation is therefore not of much practical value at the present time. Improvements in apparatus and technique might make the method more reliable and more useful.  

I am indebted to Mr N. Veall for his constant help and advice in this investigation. My thanks are also due to my colleagues, Mr W. Herschell and Mr R. H. Maudsley, for their cooperation. I am grateful to the Editor of the Postgraduate Medical Journal for permission to publish Figure 3.

REFERENCES