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VASCULARIZATION OF THE FEMORAL HEAD FOLLOWING FRACTURE OF THE NECK OF THE FEMUR

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In the course of time the common occurrence of necrosis of the femoral head after fracture of the femoral neck has been the subject of numerous publications, and it still remains a problem in the treatment of these fractures.

By now, it seems to be agreed that the incidence of necrosis is about 25–40 per cent, but opinions are divided as to what influence this should have on the primary treatment of femoral-neck fractures after the introduction of the various replacement arthroplasties, predominantly with Moore prostheses. In many hospitals, these operations have become standard procedures in dealing with old patients who have sustained sub-capital fractures. By this means it is believed that the patient may avoid a possible secondary operation and can relatively soon be mobilized. Thus, prosthetic arthroplasty is bound to be performed on many patients who do not need it.

It would be a great help in the primary treatment if it were possible to point out beforehand patients likely to develop necrosis and/or nonunion of the femoral head. Indeed, numerous attempts have been made. especially on the basis of studies on the vascularization of the capital fragment. Avascular necrosis is a common term, signifying that vascular injury is considered the essential pathogenetic factor in this necrosis. The blood supply to the head and neck of the femur and changes therein following fracture have been elucidated by numerous studies, *inter alios*, by Brodetti (1960), Claffey (1960), De Haas & McNab (1956), Judget et al. (1955), Sewitt (1964), Sewitt & Thompson (1965), and Trueta & Harrison (1953). The blood supply is effected partly by vessels passing up through the neck and partly, to a varying extent, by vessels in the ligamentum teres, but especially by vessels passing beneath the synovial membrane, along the femoral neck from the medial circumflex femoral artery in an inferior medial and a superior lateral

group. The lateral group supplies the greater part of the femoral head, including its upper, weight-bearing segment. In transcervical fractures the vessels within the neck are interrupted and, in the event of marked displacement, possibly also the vessels along the neck. After total interruption of these vessels, the head is only supplied by the vessels of the ligamentum teres which anastomose with the other groups, but which are as a rule unable to supply more than about one-quarter of the head. Major or minor parts of the head, depending upon the competence of the remaining blood supply, will then undergo necrosis. However, rapid invasion of vascular connective tissue occurs from the cervical fragment. A necrotic head may thereby become re-vascularized, and necrotic bony tissue will be replaced as in a free bone graft. This is the process known as "creeping substitution". It is a lengthy process, however, and is far from always complete. Therefore, parts of the head may remain necrotis. The re-vascularization must be assumed to have the best conditions after satisfactory reduction and fixation of the fracture (Phemister 1939). Indeed, this is an important pre-requisite for union. If left untreated, a fracture through the neck of the femur will usually end in pseudarthrosis. With the Whitmann method of conservative treatment, the frequency of pseudoarthrosis was considered to be around 40 per cent (Speed 1935). After the introduction of hip nailing, the frequency of non-union is around 15 per cent (Spotoft 1944). There is no doubt, however, that the blood supply of the capital fragment must also influence the union of the fracture, in this site as well as in others. Thus, when the blood supply to the capital fragment is reduced or abolished, the chances of union must be considered more unfavourable, although it certainly may occur despite necrosis of the head. Therefore, studies concerning the risk of capital necrosis must also be expected to afford some impression of the likelihood whether deficient union will occur.

Radiological signs of capital necrosis occur late. The first sign that has been described is increased density of the head as compared with the surrounding bones, due to decalcification of the latter. However, it has been pointed out by Hulth (1961) that presupposing early mobilization the decalcification is slight or absent and that the increased density is due to new formation of bone during the process of re-vascularization. Indeed, it has been demonstrated that in places bone trabeculae will undergo thickening because of bone formation on the surface of necrotic trabeculae (Bohr & Larsen 1965, Woodhouse 1962). Such thickening frequently occurs in patches in the femoral head

which thus acquires a heterogeneous radiological appearance. Owing to minor fractures in necrotic trabeculae, major or minor collapse may occur, especially in the upper capital segment, and this may be the first radiological sign of necrosis, often not visible until a year or two after the fracture.

Skeletal biopsies will show, but not until a week or two after the fracture, changes consisting in breakdown of cells, first in the bone marrow and later of osteocytes (Catto 1965). Barnes (1962) has emphasized that the only evidence of necrosis is collapse of the femoral head on the X-ray film or necrotic changes found in microscopic examination of the entire head.

Accordingly, it has been a matter of great interest for many years to arrive at tests which could determine, soon after the fracture, whether capital necrosis would occur in a given case. It applies to all such tests that at this early stage they can only indicate the likelihood that the clinical syndrome of capital necrosis is going to appear, as this does not happen until at a considerably later juncture. Any such method must be used on a sufficiently large material, and after a sufficiently long follow-up period – at least two and preferably three years – the course must be analysed before the value of the method can be assessed.

A number of different methods have been used for evaluating the extent of vascular injury in fractures of the femoral neck in order thereby to assess the risk of avascular necrosis.

Arteriography has been described by *inter alios* Brünner et al. (1967), McGinnis et al. (1958), Müssbichler (1956), and Rook (1953). This method appears to be rather uncertain, and visualization of the small vessels within and along the femoral neck cannot be expected.

More use has been made of venography, injecting the contrast medium into the femoral head (Dahlgren 1959), De Haas & McNab (1956), Eberle (1964), Hulth (1956, 1958, 1965), and Hulth & Johansson (1962). Under normal conditions the contrast medium is rapidly absorbed, and X-rays visualize the afferent veins which accompany the course of the arteries, as demonstrated by Trueta & Harrison (1953). If the veins are interrupted, this filling does not occur, and the contrast medium will stagnate in the femoral head. Hulth felt that this method was so dependable that in such cases replacement arthroplasty should be performed primarily on elderly patients (Hulth 1956, 1962).

A large number of methods are based upon the use of radioactive isotopes. Two different principles may be used. In part the uptake by the femoral head of intravenously injected isotope may be determined

and in part the rate of elimination of the isotope from the head after it has been injected may be determined, either by direct counting over the head or by determination of the activity in venous blood or over the heart. These methods possess the theoretical advantage that they afford a certain quantitative measure of circulation in the head, whereas a venography, for instance, can decide whether vessels have been preserved, but affords no information concerning the extent of the blood supply.

By various modifications of the former method, P^{32} has been used, first by Tucker (1950), later by Arden (1953, 1960), Bloch & Georg (1962), Boyd et al. (1955, 1963), Massie & Stevens (1964), and others. I^{131} has been used by Forgon (1966).

It is probably better, however, to determine the rate of elimination from the head of an isotope which is not taken up specifically by bony tissue. To this end Na^{24} (Laing & Ferguson (1958, 1959) and I^{131} have been used, *inter alios*, by Holmquist (1965), Johansson (1962, 1964), and Laing & Ferguson (1959).

Substances other than radioactive isotopes may also be used in the same way, e. g. dyes (Price 1962) and X-ray contrast medium (Matumoto 1966). Woodhouse (1962) has also advocated a method for direct measurement of the oxygen tension in the femoral head.

An entirely different method was described by Brücker et al. (1965). When the circulation in the head has been interrupted, changes in the enzyme systems of the cells occur within a few hours. This is demonstrable histochemically by staining a bone biopsy.

Simple determination of the course of the fracture line in relation to the head-neck junction after reduction of the fracture may, according to Piggott (1965), afford satisfactory guidance concerning the risk of necrosis.

Lastly, it may be mentioned that Soto-Hall (1964) has pointed out a little heeded factor, viz. the possibility of compression of otherwise intact vessels along the femoral neck due to intra-articular accumulation of fluid after the fracture. In his opinion, this may lead to anoxia of the head. He demonstrated that the intra-articular pressure in hip joints with accumulation of fluid could in certain positions exceed the expected pressure in small arteries. By means of animal experiments Woodhouse (1964) showed that an increase in intra-articular pressure in the hip joint up to 50 mm Hg for 13 hours would invariably lead to capital necrosis.

Summing up, it may be said that none of the named publications has

afforded the solution of the problem, viz. of predicting the occurrence of complications, especially capital necrosis, following fracture of the femoral neck by a method which is easy and devoid of risk. Many authors have studied only a few patients, and in a number of the investigations the follow-up has been short and has included only a few of the patients. As a rule, the accuracy is stated to be about 80 per cent. In addition, most of the methods give, as may be expected, an appreciable number of unassessable results.

PRESENT INVESTIGATION

During the period January 1963 to March 1966 a total of 104 patients with fracture of the femoral neck were studied with respect to the blood supply to the head of the femur – at the outset by injecting I^{131}-labelled albumin into the femoral head as described by O. M. Hansen in the Danish Surgical Society in 1963. Later, Xe^{133} was used in a major and I^{131}-labelled antipyrine in a minor series of investigations.

The test was performed on all patients having fracture of the femoral neck proper, except in cases of non-operated, wedged valgus fractures. In addition, the study included all patients with trochanteric fractures which cannot be expected to affect the vascularization of the femoral head. This latter group was meant to be a kind of control group, although it must be realized that of course it cannot pass for a normal group. Among other things, this group would be expected, a priori, to include a relatively large number of patients of advanced age and with osteoarthritis.

In two patients, one tested by I-labelled serum albumin and one by I-labelled antipyrine, the activity over the femoral head was so low that the result was not assessable. These patients were therefore excluded. Otherwise, the test could be carried through in all patients, and no complications could be ascribed to it.

Treatment was according to the current lines, reduction of the fracture, and traction immediately at admission, operation by the method of Smith Petersen or McLaughlyn being done a few days later.

Follow-up

As already mentioned, the follow-up period required for analysing the incidence of complications should not be shorter than 2 years. Therefore, patients who had not been treated in the meantime in the Department for complications of the fracure in the form of capital necro-

sis or non-union were followed, as far as at all possible, with a view to these complication for 2¼–4½ years. As a large number of these patients are of advanced age, many complicating diseases were present, in particular senile dementia and debility. Thus, 4 patients with trochanteric fractures and 7 with transcervical fractures died during the primary stay in hospital. Many died during the follow-up period, and several were too ill to be re-examined. For these reasons, the subsequent course is known for only 52 out of the 104 patients.

Apart from a general clinical examination, the follow-up study also included X-rays of both hip joints. A diagnosis of non-union was made when the study disclosed secondary displacement and a still visible fracture line. As a rule, there was also severe absorption of the femoral neck and slipping of the nail. A diagnosis of capital necrosis was made where collapse of the head was found apart from uneven structure or sclerosing. In addition, necrosis has been found in several cases histologically after removal of the head by secondary insertion of a Moore prosthesis.

1. *I^{131}-labelled Serum Albumin*

Sixteen patients were investigated by injection into the femoral head of a serum albumin solution labelled with radioactive I^{131} in a dosage of about 20 micro Curie, corresponding to a 0.3–0.8 ml solution. Thereafter, the rate of elimination from the head was determined by direct counting over the head. The half-life of the I^{131} isotope is 8.04 days. It emits beta and gamma rays. The gamma radiation, which has a great penetrating ability, was measured with a scintallation detector coupled to a counter. Prior to the test, potassium iodide was administered by mouth for 48 hours in order to block the iodine uptake by the thyroid gland, and this was continued during the test period. In the first 11 patients the injection was carried out during the operation for the fracture. The needle, 14 cm long and 1 mm wide, was introduced along a Kirschner wire inserted through the neck after X-ray checking of its position in 2 planes. In a few cases the needle was introduced through the nail canal after the osteosynthesis. Any fluid was carefully collected in a separate swab. Thereafter the activity over the femoral head was counted in the theatre, and the locally remaining activity was determined by daily counting through 7–10 days. The fall in the activity, apart from that conditioned by the physical half-life of I^{131}, must be due to absorption from the site of injection and thus dependent upon the vascularization of the femoral head. In calculating the

results a correction was made for the background radiation and physical breakdown of the isotope. Thereafter, the half-life of the injected activity was calculated. This quantity was called T/2 and was, as already mentioned, taken to be a relative measure of the circulation in the femoral head.

Of course, this procedure necessitated a moderate prolongation of the operation, and it was a disadvantage to have to set up apparatus in addition to that needed for the operation. Furthermore, the actual object was to study the possibility of assessing the blood supply to the femoral head before the operation. The last 5 patients of this series, and all of the subsequent ones, therefore, had the injection percutaneously into the femoral head. The injection was given through the needle described by Hulth (1958) which is introduced under local anaesthesia from the anterior aspect through a skin incision, a few mm long, just laterally to the femoral artery. Its position was checked by fluoroscopy with TV apparatus in the antero-posterior view. It is easy to feel when the needle enters the femoral head, and thereafter it is pushed 1 cm farther in. After removal of the obturator, a thin needle was inserted yet 1 cm deeper, and through this needle the isotope was injected.

RESULTS

A. 8 patients with trochanteric fractures showed a T/2 of 2.9–11.3 days, average 5.6. Age does not appear to have influenced the result. Two of the patients had osteoarthritis. In these cases T/2 was 3.1 and 3.3 indicating a relatively ample vascularization.

Three of these patients were followed. The fractures had united, and there was no osteoarthritis or other complaints from the hip.

B. 8 patients had a fracture through the femoral neck. The T/2 ranged from 2.2 to 12.1 days, average 5.5, with the same distribution as in the trochanteric fractures.

Four patients developed complications, capital necrosis in two – T/2: 6.5 and 6.9. Another two showed non-union and were treated with a Moore prosthesis. In both, microscopic examination showed a partially necrotic head, although there had been no radiographic signs thereof. In these cases the T/2 was 12.1 and 2.2.

Three showed at follow-up a united fracture without necrosis; in these cases the T/2 was 2.6, 3.3, and 6.0. One had died at the time of the follow-up study, T/2: 6.3.

It will be seen then that complications occurred in those patients in

whom the T/2 was highest and thus the circulation least satisfactory, except for pseudarthrosis in one patient with a T/2 of 2.2. She was suffering from severe rheumatoid arthritis. It was observed in several cases that patients with rheumatoid arthritis are particularly apt to develop complications after fracturing the femoral neck.

2. *Xenon* ^{133}

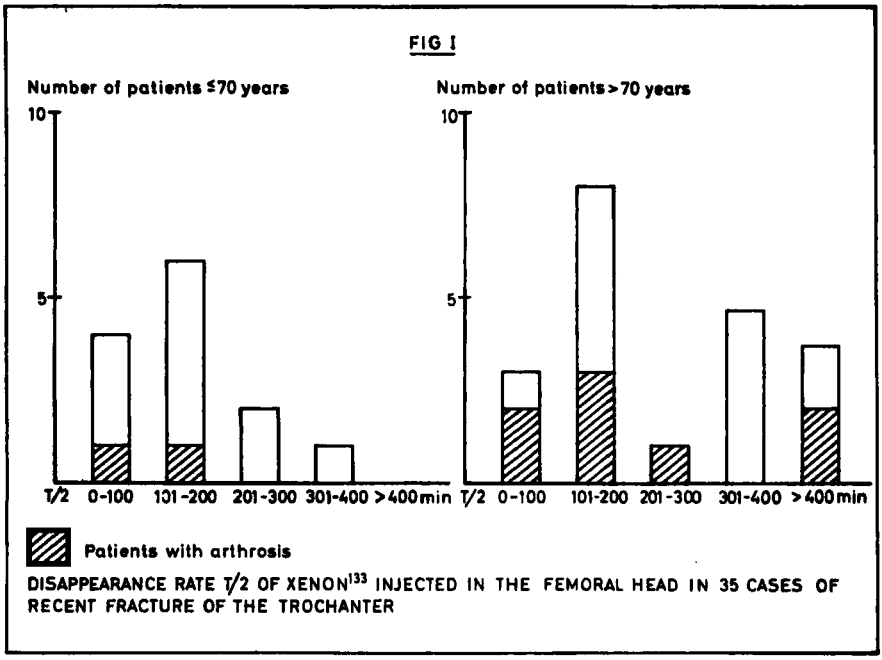
The tests using I-labelled albumin were extended over several days, as this isotope is bound to a high-molecular substance and is therefore slowly absorbed. It was great simplification, therefore, when after the establishment of our clinical-physiological laboratory, where the tests were now performed, we started using instead Xenon^{133} at the advice of Dr. O. Munck.

Xenon^{133} is an indifferent gas. It is rapidly eliminated from the organism with the expired air, more than 90 per cent of the amount dissolved in the blood being excreted in a single passage through the pulmonary circulation. Xenon^{133} has a half-life of 5.3 days and emits beta as well as gamma rays. It was used in a solution of physiological saline, injecting the femoral head with about 200 micro Curie, corresponding to 0.2–0.4 ml of the solution. The injection was in all cases percutaneous, using Hulth's needle as described above. Thereafter, the gamma radiation was determined by a scintillation detector placed over the femoral head, coupled to a counter and writer which recorded the counts per minute. Plotting of time as the abscissa and activity corrected for the background radiation logarithmically as the ordinate gives an elimination curve which is – apart from the first 5 to 10 minutes – almost rectilinear. The slope of this curve is considered a relative measure of the vascularization of the femoral head. The half-life T/2 gives a numerical expression thereof. In these tests the counting could be restricted to about 50 minutes, so that no regard had to be paid to the physical breakdown of the isotope.

RESULTS

The Xenon^{133} tests included 35 patients with trochanteric fractures and 45 hips with recent fracture through the femoral neck in 44 patients, a 46-year-old woman having a bilateral fracture sustained in an epileptic fit.

A. *Trochanteric fractures.* 35 patients from 31–91 years of age, average 69.2 years.



DISAPPEARANCE RATE T/2 OF XENON^{133} INJECTED IN THE FEMORAL HEAD IN 35 CASES OF RECENT FRACTURE OF THE TROCHANTER

The T/2 was highly varying from 39 minutes to ∞, i. e. during the test period of 50–60 minutes there was no decrease in the activity over the femoral head. T/2 was an average of 156 minutes, T/2 values exceeding 400 minutes being classified as ∞ and not included in the calculation of the listed means.

The numerical distribution may be seen from Figure 1 where the patients are divided into two groups, $\leqq 70$ years and > 70 years of age. In addition, patients with radiographic signs of osteoarthritis in the homolateral hip joint are indicated, as according to the studies of Harrison et al. (1953) on the development of osteoarthritis in hip joints, the femoral head in such cases must be expected to have a more ample circulation than in patients without osteoarthritis.

It is apparent that among the patients over 70 years of age there is a larger number with long half-lives, i. e. presumed to have poor vascularization. Indeed, the calculation shows that the group $\leqq 70$ years shows a T/2 averaging 131 minutes, whereas the over-70 group averaged 175 minutes. Ten patients, mainly elderly ones, had moderate to severe osteoarthritis in the homolateral hip joint. Despite a more advanced age, the group with osteoarthritis showed lower T/2 values, an average of 119 minutes, indicating a more ample vascularization of

the femoral head in these patients. This tendency corresponds to what was found in a study of osteoarthritic patients by I-labelled albumin. In both methods there was also a group among the patients with trochanteric fractures who had very little vascularization judging by the methods used in spite of the fact that these fractures could not be expected to affect the vessels supplying the femoral head.

Follow-up

The subsequent course is known for only 13 out of the 35 patients. In all, the fractures had united, and none had developed necrosis of the femoral head. Only one had developed osteoarthritis which had not been present primarily, and in another case osteoarthritis had become aggravated. Strangely enough, one patient with severe osteoarthritis, involving severe symptoms, had been almost relieved of complaints after the fracture with subsequent osteosynthesis.

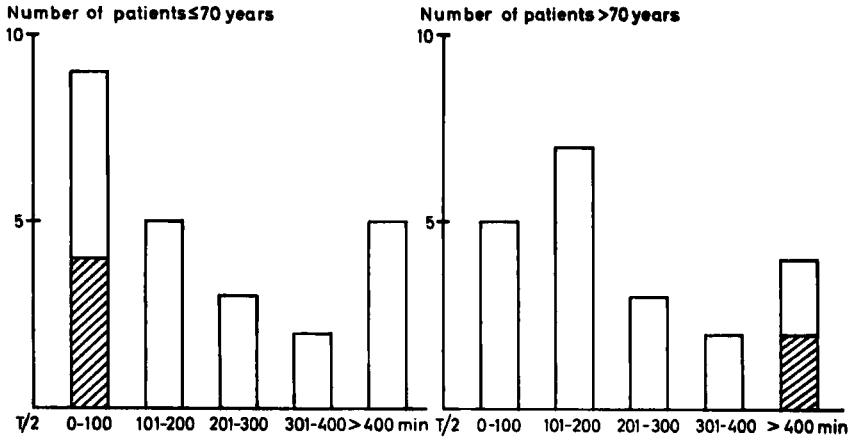
B. *Transcervical fractures.* 44 patients ranging in age from 44 to 89 years, average 70.1 years, i. e. the same average age as among the patients with trochaneric fractures. Generally, trochanteric fractures are reported to be most common among the oldest patients.

The T/2 was from 30 minutes to ∞, average 150.9 minutes. Figure 2 shows the distribution of the values plotted in the same way as in Figure 1.

The mean T/2 in patients $\leqq 70$ years was 138.6 and in those over 70 years 164.6 minutes. In other words, this group too evidently showed a somewhat inferior vascularization of the femoral head in the oldest patients.

Comparison with the values in the patients with trochanteric fractures shows very little difference. This, again, agrees with the findings in the tests using I-labelled albumin, but is at variance with all previous studies and with what would have been expected *a priori.* It would be expected that the group with fractures through the femoral neck were characterized by reduced vascularization, that it would in other words show higher T/2 values than the group with trochanteric fractures in which the circulation in the femoral head would not be expected to be impaired. *A priori,* one would also expect a difference in the T/2 values according to the degree of displacement in fractures of the femoral neck. However, no such difference was demonstrable in the present material. In greatly displaced fractures the T/2 averaged 149.7 and in two cases more than 400 minutes. In moderately displaced

FIG II



DISAPPEARANCERATE T/2 OF XENON^{133} INJECTED IN THE FEMORAL HEAD IN 45 CASES OF RECENT FRACTURE OF THE FEMORAL NECK.

and non-displaced fractures the T/2 averaged 152.0, and in two cases it exceeded 400 minutes.

Follow-up

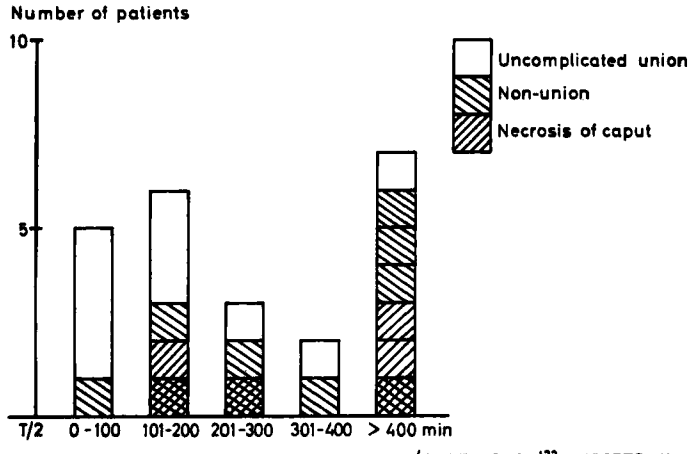
The course is known for 24 of the 45 fractures. A patient in a poor general condition, in whom the course had been stormy with severe pneumonias and cardiac arrest, developed severe wound infection, with osteitis and arthritis, after the osteosynthesis. In this case, therefore, the course cannot be assessed with a view to vascular complications of the fracture.

Figure 3 shows the course after the remaining 23 fractures plotted against the T/2 values.

From this figure it is apparent that among these patients there was a large number of complications, mainly in the form of non-union, found in a total of 10 patients. Three also had necrosis of the femoral head, and another 3 developed necrosis of the head, but the fracture had united.

From these figures, however, nothing can be deduced concerning the absolute incidence of these complications. Presumably, the total num-

FIG III



RELATION BETWEEN DISAPPEARANCE RATE T/2 OF XENON^{133} INJECTED IN THE FEMORAL HEAD IN 23 CASES OF RECENT FRACTURE OF THE FEMORAL NECK AND THE SUBSEQUENT COURSE WITH A MINIMUM OF 2 YEARS OF OBSERVATION TIME.

ber with non-union among the 37 primary survivors corresponds approximately to the actual incidence, as re-displacement is often already ascertained during the primary stay in hospital causing, like pseudarthrosis, considerable symptoms and a severely compromised walking function. On the other hand, capital necrosis gives rise to more delayed and often less severe symptoms. Among the patients who died during the follow-up period or among those who were not included in the follow-up, there were probably, therefore, some cases of capital necrosis. It is worth emphasizing that two cases of necrosis were not detected until at follow-up, both with fairly modest symptoms, and no previously unknown non-united cases were discovered.

It is obvious that the T/2 value affords no reliable guidance in respect to the occurrence of complications. As might be expected, the incidence is highest in the group where the vascularization is presumed to be poorest. Among patients in whom the T/2 exceeded 400 minutes, 6 out of 7 developed complications, including necrosis in 3, whereas one fracture united without complications. Reversely, there were 3 cases of necrosis among those who were apparently well vascularized. In two there was co-existent pseudarthrosis.

In 4 out of the 10 cases with non-union, the reduction at operation had been difficult or had not been fully satisfactory. In 3 of these patients the T/2 was shorter than 400 minutes. In the remaining cases the appearances at osteosynthesis cannot explain the occurrence of complications.

3. *I^{131}-labelled Antipyrine*

In a small series of a total of 8 tests I^{131}-labelled antipyrine was used. The technique was the same as that of the Xenon tests, and the results were expected to be in approximate conformity with these tests, as the substance is low-molecular and is not bound to bony tissue and not broken down in the tissues (Lindbjerg 1967).

A. This series includes 3 patients aged 64 to 81 years with trochanteric fractures. T/2: 45, 57, and 53 minutes. Two of these patients had severe co-existing osteoarthritis, and at follow-up 3 years later the third one had developed severe osteoarthritis in the hip.

B. 5 patients 59 to 91 years of age had transcervical fractures. T/2 was 63, 136, 180, and 316 minutes, and ∞. These patients with T/2 values of 136 and 180 minutes were seen at follow-up. The fractures had united without capital necrosis. The patients having T/2 of 63 and ∞ had died at the time of follow-up. The patient with a T/2 of 316 minutes developed re-displacement at the end of 4 months. She was tested again, and now the T/2 was only 54 minutes.

DISCUSSION

The object of this study was to ascertain whether it was possible — by the present methods which proved easily practicable and devoid of complications — to separate *a priori* those patients in whom fracture of the femoral neck is followed by such compromised circulation in the femoral head that complications are sure to arise, either in the form of capital necrosis or non-union.

A presupposition of using tests of circulation for this purpose is of course that reduced circulation is the main cause of these complications. This is generally assumed in the case of capital necrosis. The reduced circulation may be due to tearing of vessels in and along the femoral neck. However, Claffey (1960) has demonstrated that the lateral vessels along the femoral neck may be anatomically intact despite considerable displacement of the fracture. In such cases, clamping or kinking may be imagined to play a role, and may presumably soon lead to thromboses. In that event, it is important to perform prompt pri-

mary treatment, including reduction and application of traction. Another factor too may be operative, viz. possible compression of the vessels due to accumulation of intra-articular fluid (Soto-Hall et al. 1964, Woodhouse 1964). The measurements were not done until one or more days after the fracture, when these factors must be presumed to have exerted their effect, so that the vascular injury present at that juncture would be permanent. It has been demonstrated in animal experiments by Woodhouse (1964) that necrosis occurred in all cases after 12 hours' anoxia of the femoral head. However, the vascular injury may become aggravated during the operation. For instance, the insertion of the nail may cause major or minor vascular injuries in the femoral head, presumably in the main of anastomoses from the vessels in the ligamentum teres which are usually intact and which may be decisive in supplying the head after interruption of the supply from other vascular areas. At least, it has been demonstrated by Sewitt (1964) that a wedge-shaped area above the nail is frequently the seat of necrosis, whereas Claffey (1960) found no major vascular injury, not even where the tip of the nail was in touch with the fovea. Naturally, this possible cause of necrosis cannot be demonstrated in a preoperative investigation.

A factor of uncertainty in the present method is the possibility that the injected fluid may escape through the puncture canal or the surface of the fracture to the hip joint. After injection of X-ray contrast medium, the medium has been seen to distribute rapidly in the femoral head (Forson et al. 1966, Hulth 1956, Matumoto 1966), and in some cases penetrates the surface of the fracture, reaching the joint. In such cases, however, the volumes have been several millilitres. With the small volumes used in the present study, i. e. 0.3–0.5 ml, the escape into the joint must be assumed to be slight, but in return the distribution in the femoral head is perhaps limited, there being a possibility that it is deposited in a limited necrotic area which possibly may undergo complete revascularization. This leads to the problem concerning the significance of revascularization: We know that revascularization takes place, and the extent to which it takes place must be of great importance to the clinical course. Here, again, is a factor which cannot be assessed by tests done early in the course. In this connection, it may be mentioned that in autopsy materials the incidence of capital necrosis has reached as far as 80 per cent (Sewitt 1964), i. e. far exceeding the clinical incidence. Therefore, revascularization must be a decisive factor in many cases.

It is even more difficult to predict the occurrence of non-union. In this respect, the accuracy of the reduction and the efficacy of the fixation no doubt play a decisive role. Cassebaun & Nugent (1963) felt that the course of union could be predicted with great accuracy on the basis of the operative result. However, lacking blood supply to the femoral head may be able to affect the course unfavourably. It is well known that fractures of the femoral neck may unite in spite of necrosis and that non-union may occur without necrosis, but frequently both complications co-exist. Gradually, as numerous pseudarthroses are being treated by prosthetic arthroplasty, it has been discovered that microscopic examination of the femoral head often shows extensive necrosis, although there have been no radiographic signs thereof. Indeed, this was observed in several cases of the present material.

All these theoretical reflections would play no major role if a method had been found for predicting the complications and if that method were in complete agreement with the course. However, this did not apply to the present technique. True, there was a preponderance of complications in the group in which vascularization was presumed to be poorest, but in one out of 7 cases the course was completely devoid of complications. Reversely, complications occurred in 7 out of the 16 better vascularized cases, predominantly in the form of non-union, but there were also 3 cases of capital necrosis. Thus, the method is not applicable as a basis for therapeutic indications. If T/2 values exceeding 400 minutes in the Xenon test were considered an indication for primary prosthetic arthroplasty, several patients would nevertheless develop complications; a considerably smaller number of patients would be fitted with a prosthesis if the course without a prosthesis had been uncomplicated. In this respect it is a factor of importance how the patients with complications fare. It must be emphasized that a large proportion of the patients with capital necrosis, probably about half (Boyd 1963, Manninger et al. 1967, Spotoft 1944), manage tolerably, so that prosthetic arthroplasty is far from being necessary in all cases. It must also be borne in mind that all patients do not manage equally well with a prosthesis, even when it has been inserted primarily.

Thus, although the result of the present studies was negative when considered in the light of the primary approach, certain findings deserve to be emphasized:

1. Patients with osteoarthritis usually have ample vascularization of the femoral head, cf. the previously mentioned studies of Harrison et

al. (1953) which showed an increased vascularization of the head in osteoarthritis of the hip.

2. In transcervical, as well as in trochanteric fractures, the vascularization of the head seems to deteriorate with advancing age.

3. Among patients with trochanteric fractures, too, there was surprisingly quite a number with very slight vascularization of the femoral head, judging by the present methods. This might be assumed to be due to failure of the methods. It must be emphasized at this site that in none of the cases was there a suspicion of misplacement of the needle in the test. Incidentally, Bloch (1962), in a study using intravenous administration of P^{32} in a small series of 6 trochanteric fractures, found one patient with very slight vascularization of the head, but he took it for granted that this must have been an erroneous determination. Shermann & Selakowich (1957) reported that in apparently normal bones there might be major or minor necroses, increasing in extent in the presence of peripheral vascular disease. For instance, he found subchondral necroses in the femoral head of an 86-year-old patient with a recent trochanteric fracture.

4. The most surprising result is probably that the vascularization of the femoral head appears to be approximately the same after trochanteric and transcervical fractures, although in the latter it would be expected to be more compromised due to vascular injury. This finding seems rather inexplicable. Is the reason that in fact the methods used do not afford any definite information concerning the circulation in the head? This appears to be improbable. At any rate, Xenon has been used with satisfactory results for determinations of circulation in other tissues, with local injection and determination of clearance, *inter alios* by Lassen et al. (1964), and by Lindbjerg (1967) also in fatty tissue. In this connection it must be borne in mind that the femoral head contains predominantly yellow bone narrow. Another possibility is that perhaps the vascular injury does not affect the course as much as has been assumed. In particular, it might be imagined that the efficacy of the revascularization is the decisive factor.

SUMMARY

Fracture through the femoral neck is followed by necrosis of the femoral head in about 25 per cent of the cases. The explanation is assumed to be damage to the vascular supply of the head. The vascularization of the capital fragment must also be assumed to influence the occur-

rence of non-union. If the occurrence of these complications could be predicted with reasonable accuracy, the primary treatment could be decided accordingly, so that secondary prosthetic arthroplasty could be avoid. Various methods for determining the circulation in the femoral head have been tested, *inter alia*, arteriography, venography, and in particular injection of radioactive isotopes, either directly into the femoral head determining the elimination rate, or intravenously determining the uptake by the femoral head. The accuracy of the methods is around 80 per cent, but many results are unassessable.

The rate of elimination of radioactive Xenon^{133} from the femoral head was determined in 45 cases of recent transcervical fracture and, for comparison, in 35 patients with trochanteric fractures. At follow-up a minimum of 2 years later, which included 23 out of the 45 cases of femoral-neck fracture, capital necrosis and/or non-union were found in 6 out of 7 patients in whom the vascularization was presumed to be poor, but also in 7 out of 16 patients with satisfactory vascularization. Therefore, the method is considered inapplicable as a basis for deciding the therapeutic indication.

Patients in whom osteoarthritis of the hip co-existed were found to have, on the whole, ample vascularization of the femoral head. After transcervical as well as trochanteric fractures, the vascularization was less satisfactory in patients over than under 70 years of age. The degree of displacement of the transcervical fracture did not influence the vascularization. Strangely enough, a group of patients with trochanteric fractures, which are not supposed to affect the capital blood supply, were found to have a highly impaired vascularization, and on the whole capital vascularization was the same after transcervical and trochanteric fractures. This finding perhaps indicates that vascular injury is not as important an aetiological factor in these complications as previously assumed.

Smaller series were tested by injecting into the femoral head I^{131}-labelled albumin or I^{131}-labelled antipyrine by the same technique as used in the Xenon^{133} studies; the results were the same.

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