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ARTERIOGRAPHIC INVESTIGATION OF THE HIP IN ADULT HUMAN SUBJECTS

A CLINICAL STUDY OF THE ARTERIES IN THE HEALTHY HIP, IN NECK AND PERTROCHANTERIC FRACTURES, AND IN NECROSIS OF THE FEMORAL HEAD

BY

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This thesis is based on the following publications:

I. *Müssbichler, H.:* Arteriographic studies of the normal hip in adults; evaluation of methods and vascular findings. *Acta radiol. (Stockh.)* 1970, in press.

II. *Müssbichler, H.:* Arteriographic studies in fractures of the femoral neck and trochanteric region; type and incidence of findings in pre- and postoperative examinations, relation to fracture dislocation and prognostic value. *Angiology* 1970, in press.

III. *Müssbichler, H.:* Arteriographic findings in necrosis of the head of the femur after medial neck fracture. *Acta orthop. scand.* 1970, in press.

In the text these papers will be referred to by their Roman numerals.

CONTENTS

INTRODUCTION

The blood supply of the femoral head has long been the subject of anatomical studies on cadavers and specimens (20, 33, 11, 31, 29, 14, 10, 26, 25). These examinations have shown that the femoral head is supplied by branches of the medial circumflex artery and its posterior collum branch. The supply of the femoral head is maintained mostly by the superior retinacular artery, the termination of the posterior collum branch. The inferior retinacular and ligamentum teres arteries play a smaller part but may in some measure compensate for a disturbance of the circulation in the superior retinacular artery (25). In Fig. 1 the vessels to and around the caput are shown schematically. The arteries are indicated by numbers which are also used in the arteriograms below.

Clinical investigation of the blood supply of the femoral head in living persons was stimulated by the attempt to predict the viability of the head after neck fracture. A reliable prognosis would make possible proper treatment of the fracture in each individual case. A solution to the problem has been sought either by direct demonstration of the vascular pattern of the hip by arteriography or by estimation of the circulatory state of the head carried out with several methods; the best known and/or important ones may be mentioned:

Intraosseous venography (12, 32) is based on the examination of the venous drainage from the femoral head after injection of contrast material into the head. Demonstration of one or several draining veins is presumed to indicate intact arterial supply of the caput, whereas the lack of venous filling suggests arterial damage. *Radioisotopes* are injected intravenously or into the femoral head in order to study the circulation to or from it (31, 6, 15, 7, 13). The circulatory state of the caput is calculated and its viability predicted from the access of the isotope into the general circulation or uptake in

the caput. Both intraosseous venography and the radioisotope methods are, as is obvious from the reports of their initiators, associated with a relatively high frequency of false and/or unconclusive results concerning the reliability of the prediction of the fate of the femoral head after neck fracture.

Direct registration of the circulatory state is possible by *intraosseous pressure* measurement *ad modum* Arnoldi and Linderholm (2) and by the use of the *oxygen tension test* devised by Woodhouse (34). Pulseless tracings from the femoral head as well as the lack of a rise in pO_2 in the caput after inhalation of 100 % oxygen is presumed to indicate avascularity. However, no prospective studies of these two methods have been published yet.

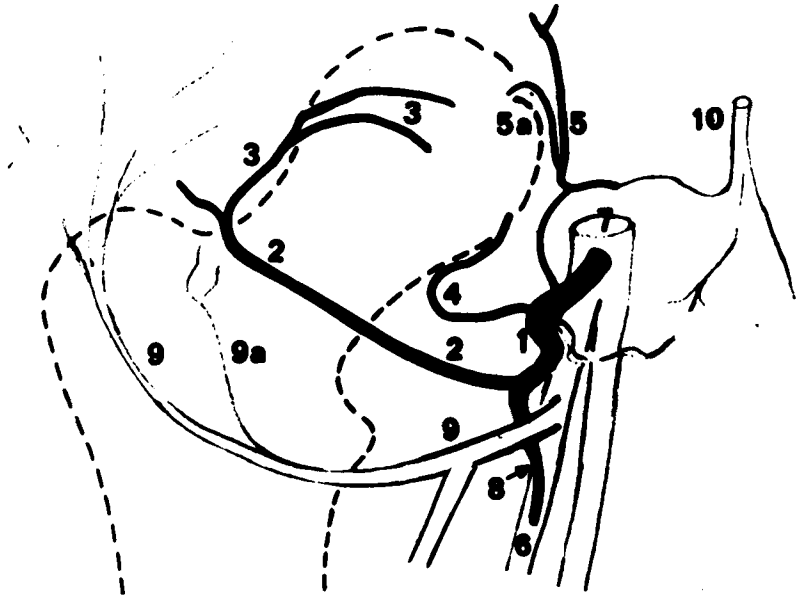

FIG. 1. Schematic drawing of the arteries to and around the femoral head: 1. medial circumflex art.; 2. posterior collum branch; 3. superior retinacular art.; 4. inferior retinacular art.; 5. acetabular art.; 5 a. ligamentum teres art.; 6. deep femoral art.; 7. common femoral art.; 8. inferior branch of the medial circumflex art.; 9. ascending branch of the lateral circumflex art.; 9 a. its superior branch; 10. obturator artery.

All the tests mentioned, used for prediction of the viability of the caput after neck fracture, are not, however, appropriate for study of the arteries themselves, which is possible by *arteriography*. This seems to be the method of choice for direct studies of the arteries in both normal, unaffected hips and in cases with fracture and femoral head necrosis.

Angiography in unaffected hips has already been carried out to a limited extent by Müssbichler (19), Hipp (10), and Brugger (8). Based on the findings of these examinations, arrested and/or delayed circulation in the posterior collum branch could be disclosed in neck fractures by Müssbichler (19). These findings were later confirmed by other authors (10, 8, 9, 17). Brünner et al. (9) showed additionally a close relationship between arrested circulation and development of femoral head necrosis as well as a relationship between normal circulation and healing of the fracture without necrosis. Femoral head necrosis has also been the subject of angiographic examinations. Müssbichler (19) noted delayed circulation in the posterior collum branch in 3 out of 4 cases examined. Lange and Hipp (16) reported on 6 cases and described a great variety of findings such as smallness, shortness, incomplete filling, and non-filling of the posterior collum branch or the femoral head vessels.

In the above-mentioned angiographic investigations many interesting questions were, however, left unanswered. The vessels of the unaffected hips, only examined as a complement to the studies of the vascular condition in affected hips, were not examined with regard to vascular details. Furthermore, in neck fractures the circulatory lesions were not studied in relation either to the type of dislocation or to reduction of the fracture. Systematic angiographic studies of fractures after nailing have not been carried out either. Angiographic studies of patients with pertrochanteric fracture or necrosis of the femoral head are restricted to only a few cases (19, 16, 10) from which, so far, no definite conclusions can be drawn.

Recent developments in angiographic techniques, such as the use of catheters, serial angiography with an automatic filmchanger, and the subtraction method (36) have made possible examination of the hip in different positions and have permitted far more reliable demonstration of the arterial circulation. These methods have to a great extent been used in the present investigation, the aims of which may be defined as follows:

A. To study the vascular pattern in healthy hips with regard to frequency of filling, origin, course, and ramification of the arteries most important for the nutrition of the hip joint and the femoral head in particular (I).

B. To study medial neck and pertrochanteric fractures angiographically with reference to the type of vascular lesion, their incidence, and relation to fracture dislocation, fracture reduction, and osteosynthesis; and furthermore to correlate the vascular findings from fresh and operated fractures with the fate of the caput as regards necrosis (II).

C. To study the type and occurrence of vascular changes in necrosis of the femoral head after medial neck fracture (III).

MATERIAL AND METHODS

Angiography was carried out in a total of 167 cases examined with one or several of the following methods:

A. *"General" arteriography* (I, II, III) with injection of contrast material into the common femoral artery in a retrograde direction carried out either through a blunt Seldinger cannula, in 34 cases, or through a polyethylene catheter, in 99 cases (Fig. 2 A).

B. *"Semiselective" arteriography* (I) with injection of contrast material into the common femoral artery in antegrade, i. e. in peripheral, direction. This was achieved either by use of a loop-formed Ödman-Ledin catheter (21), in 26 cases, or a straight polyethylene catheter, in 3 cases (Figs. 2 A', 3 and 7 *lower*). For the application of methods A. and B., the femoral artery was compressed at the thigh with a pressure cuff. The contrast medium (16 and 10 ml Urografin 76 % respectively) was injected for 2—3 seconds.

C. *Selective internal iliac arteriography* (I) with injection of 10 ml Urografin 76 % into the trunk of the internal iliac artery with a loop-formed, red Ödman-Ledin catheter (Fig. 4), in 14 cases; nine of them were part of the case material examined by method A. or B.

While methods A. and B. were used for evaluation of the vessels of the hip, C. was used in order to study whether and to what extent the internal iliac artery contributes to the blood supply of the femoral head.

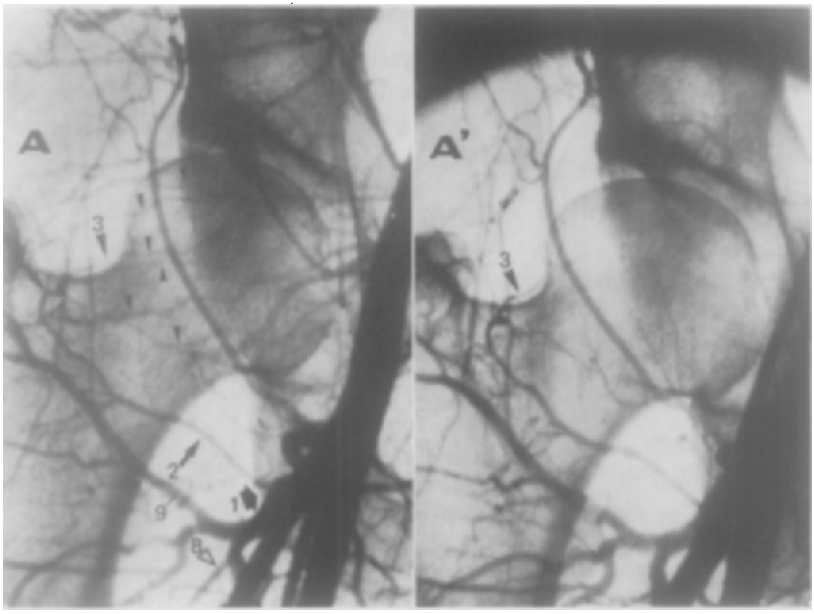

FIG. 2. One case examined with both general (*A*) and semiselective (*A'*) arteriography. In (*A*) gluteal branches (small arrows) are superimposed on the femoral head and its vessels, particularly the superior retinacular artery (3) whereas in (*A'*) the filling is limited to the external iliac art. and its branches only. Posterior collum branch (2) originating in the bifurcation (1) of the medial circumflex artery together with the inferior branch (8); ascending branch of the lateral circumflex art. (9).

In the 34 cases in which a Seldinger cannula was used, 20 ml Dijodon 50 % was injected and 4 exposures were taken over about 12 seconds. The examination with the cannula was performed in a-p projection with the hip in inward or outward rotation. In the remainder, in which a catheter was used, the examination was performed with injections of 10 or 16 ml Urografin 76 %, serial exposures, 1 per second for 15 seconds, and the subtraction method for evaluation of the angiograms.

In order to show the great range of individual variations, the diameters of the most important arteries were measured with the aid of a magnifying glass with a built-in mm scale.

FIG. 3. Subtraction angiogram from a semiselective examination illustrating the filling of the femoral head vessels except the superior retinacular art., the demonstration of which was, for some reason, not possible. Posterior collum branch (2), inferior retinacular art. (4); acetabular (5), and lig. teres art. (5 a) generated by the acetabular branches (small arrows) of the obturator and medial circumflex arts. respectively.

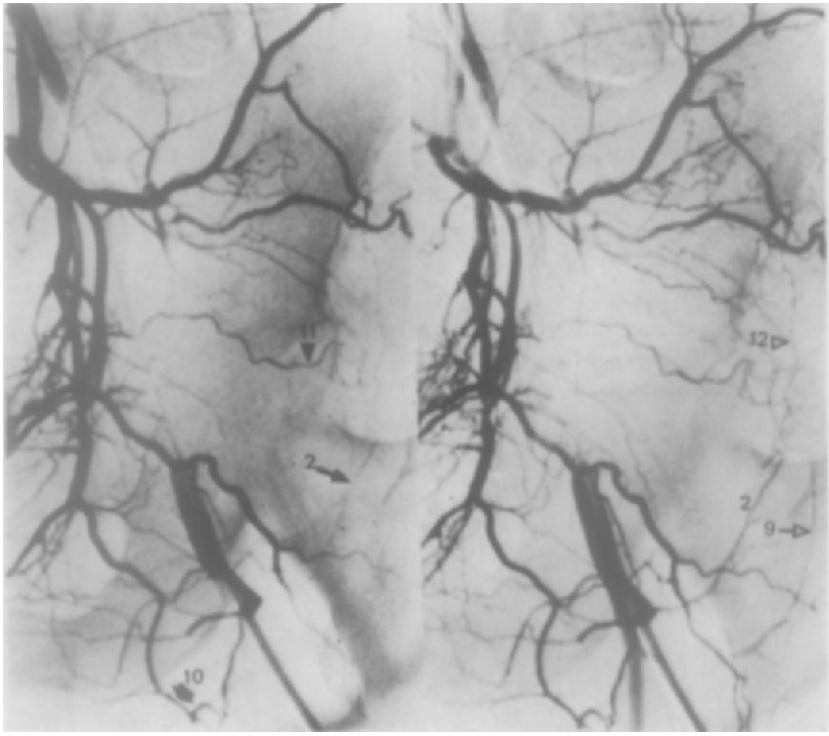

FIG. 4. Subtraction angiograms from selective internal iliac arteriography in different phases. The posterior collum branch (2) fills retrogradely via an anastomosis from the inferior gluteal art. (11), the medial circumflex artery fills via a branch (10) from the obturator artery. Anastomosis between the superior gluteal (12) and lateral circumflex (9) arts.

Complications (I, II, III)

Arteriography gave rise to thrombo-embolism in the femoral artery in one case with advanced atherosclerosis examined with a polyethylene catheter. Embolectomy was carried out and the patient recovered. In another case a transitory spasm of the external iliac artery occurred during catheterization with the loop-formed, red Ödman-Ledin catheter. The examination was interrupted and postponed until the next day, when it was successfully carried out with a polyethylene catheter without incidents. No other complications occurred.

RESULTS

Normal hips (I)

The vessels of the clinically and roentgenologically unaffected hips were studied in angiograms from 106 examinations in a total of 97 cases. Ninety-two were examined with general or semiselective arteriography and 14 cases with selective internal iliac arteriography; 9 of the latter were part of the material also studied with general arteriography.

The present investigation concerned evaluation of the anatomy of those arteries which directly or indirectly participate in the blood supply of the hip joint and of the femoral head in particular. They comprise branches of the medial and lateral circumflex arteries such as the posterior collum branch, the acetabular, ligamentum teres, inferior, and superior retinacular arteries, the ascending branch of the lateral circumflex artery, as well as arterial communications from the internal iliac artery to the femoral head (Figs. 1—7).

The results from general and semiselective arteriography were practically equal as regards the frequency of filling of the femoral head vessels, except for the acetabular artery in which the filling varied somewhat according to the method (see below).

The arteries of the hip known from the studies of anatomists (Fig. 1) could, in principle, be confirmed in living subjects by the present investigation (Figs. 2 and 3). Additionally, the present study revealed great individual variation as regards location of the origin, course and diameter of the vessels and their filling frequency. The most important variations concerned anomalies of the posterior collum branch such as hypoplasia in 3 cases (Fig. 5) and non-filling from the medial circumflex artery in 11 cases (Fig. 6), the latter was frequently found bilaterally. In 2 of these 11 cases, an ectopic origin of the posterior collum branch from the inferior gluteal artery was disclosed (Fig. 7), whereas in the remaining 9 cases the branch was not filled. The superior retinacular and acetabular arteries also varied individually in size and the incidence of their filling. The

FIG. 5. Semiselective arteriography carried out by insertion of a polyethylene catheter (K) into the common femoral artery in a peripheral direction. *Hypoplasia* of the posterior collum branch (2) terminating in small branches (white arrows) far from the trochanteric notch. Medial circumflex art. (1).

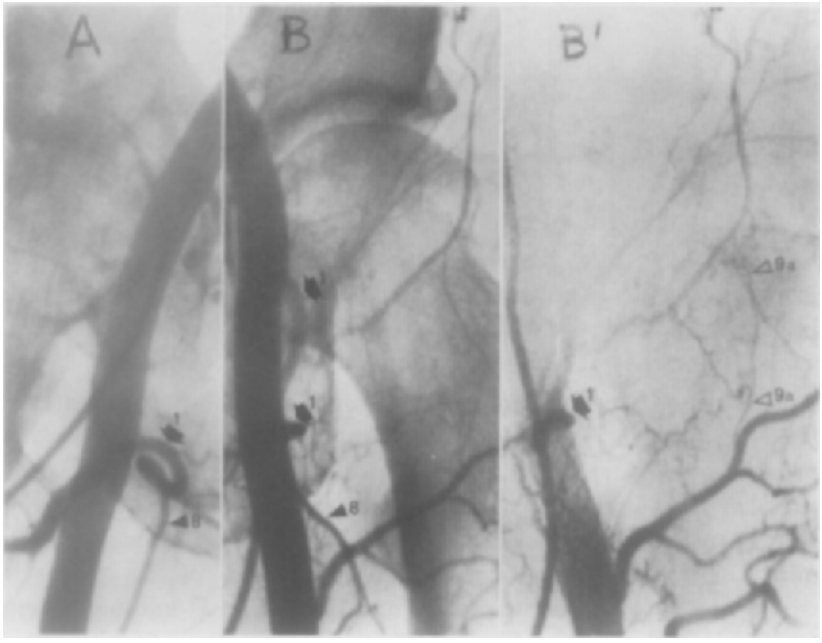

FIG. 6. Non-filling of the posterior collum branch due to anomaly. It is not derived from the medial circumflex art. (1) either in the arthrotic hip (*A*) or in the contralateral, healthy one (*B*). Good filling of the inferior branch (8) which was consistently present. Subtraction angiogram (*B'*) illustrates the superior branch (9 a) from the lateral circumflex artery-possibly replacing the posterior collum branch.

superior retinacular artery could not be demonstrated in any of the 14 cases in which the posterior collum branch was anomalous. In the remainder (78 cases), it filled with a frequency of 81 %. The incidence of filling of the other femoral head vessels, not influenced by anomalies of the posterior branch, was for the inferior retinacular artery 63 % and for the acetabular artery 27 % and 40 % when examined with semiselective and general arteriography respectively. The ligamentum teres artery was demonstrated in 2 cases only. Selective filling of the internal iliac artery disclosed, in addition to an ectopic origin of the posterior collum branch (2 cases), small anastomoses from the inferior gluteal artery to the posterior collum branch in 3 out of 14 cases (Fig. 4).

Atherosclerotic changes were found in the medial circumflex artery as well as in the posterior collum branch in some cases.

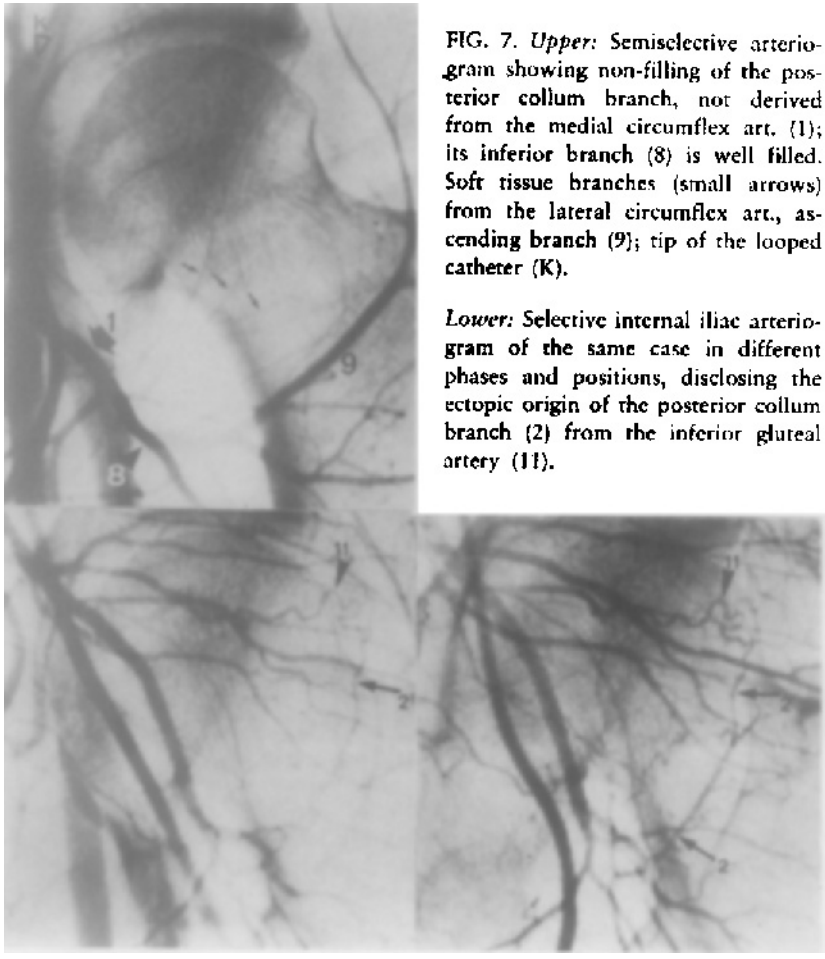

FIG. 7. *Upper:* Semiselective arteriogram showing non-filling of the posterior collum branch, not derived from the medial circumflex art. (1); its inferior branch (8) is well filled. Soft tissue branches (small arrows) from the lateral circumflex art., ascending branch (9); tip of the looped catheter (K).

Lower: Selective internal iliac arteriogram of the same case in different phases and positions, disclosing the ectopic origin of the posterior collum branch (2) from the inferior gluteal artery (11).

Forty-nine patients with fractures of the proximal end of the femur were examined with general arteriography. The fractures involved the medial part of the neck in 37 cases and the pertrochanteric region in 12. The examination concerned 37 cases with fresh fractures, 27 neck and 10 pertrochanteric, which were examined one to three days after the accident. Twenty-five of them (20 neck and 5 pertrochanteric fractures) were re-examined one to three weeks after nailing, and 12 (10 neck and 2 pertrochanteric fractures) were only studied after the operation.

Of the 37 cases with recent, unreduced fractures, the circulation in the posterior collum branch was normal in 19 cases and disturbed in 18. The latter comprised delayed circulation (Fig. 8) in 3 neck fractures; circulation was arrested (Figs. 9—12) in 12 neck and 3 pertrochanteric fractures. In 2 of the former the circulation was "intermittently" arrested only, i. e. the posterior collum branch was normally filled at the beginning of the arterial phase but circulation

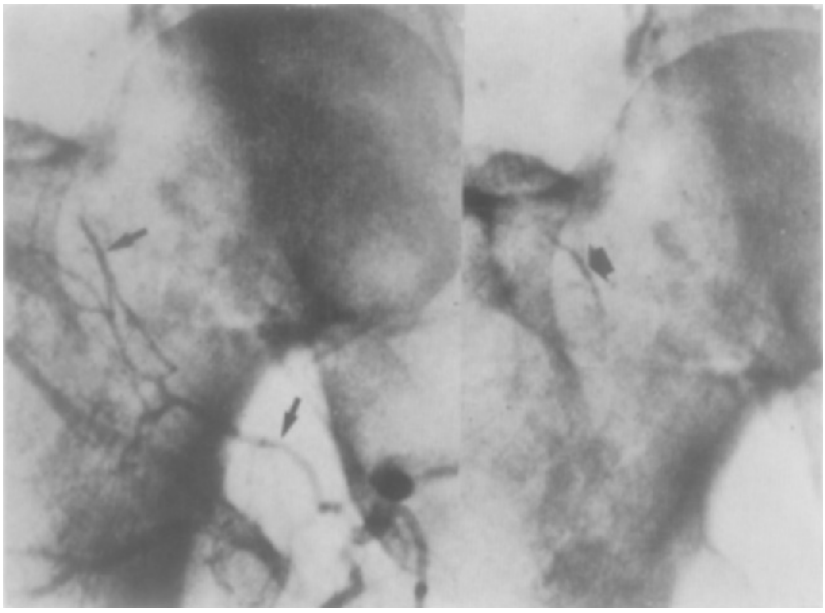

FIG. 8. Serial angiography of a recent neck fracture without dislocation. The posterior collum branch (arrows) is well filled (*left*) but the circulation through it is delayed which is indicated by pooling of contrast medium in its peripheral part (*right*, heavy arrow).

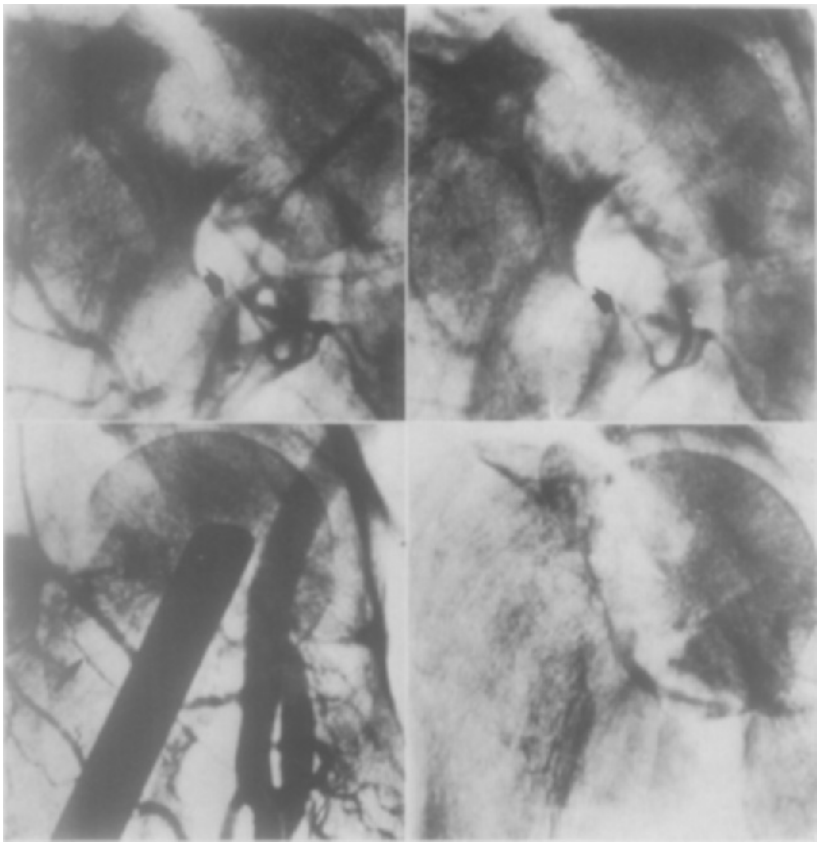

FIG. 9. *Upper:* Serial angiograms of a recent neck fracture in varus position. The circulation in the posterior collum branch is arrested (arrows) and contrast material is pooling in the intact trunk of the vessel.
Lower: After reduction and nailing the circulation is restored and the posterior collum branch re-filled (*left, arrow*); nevertheless necrosis of the femoral head occurred later (*right*).

in it became arrested in the later arterial phase. The superior retinacular artery did not fill in any of the cases when the circulation was disturbed in the posterior collum branch whereas the other femoral head vessels were not affected.

From correlation of the circulatory conditions in the posterior collum branch with the type of dislocation of the fracture, the following results were obtained: (*a*) circulation was disturbed only in

malrotated recent fractures (the findings concerned 15 neck and 3 pertrochanteric fractures), and (*b*) circulation was normal in 12 neck and 7 pertrochanteric fractures with malrotation present in only 3 and 1 cases respectively. The circulation was not affected by valgus or dorsal angulation up to 30 degrees.

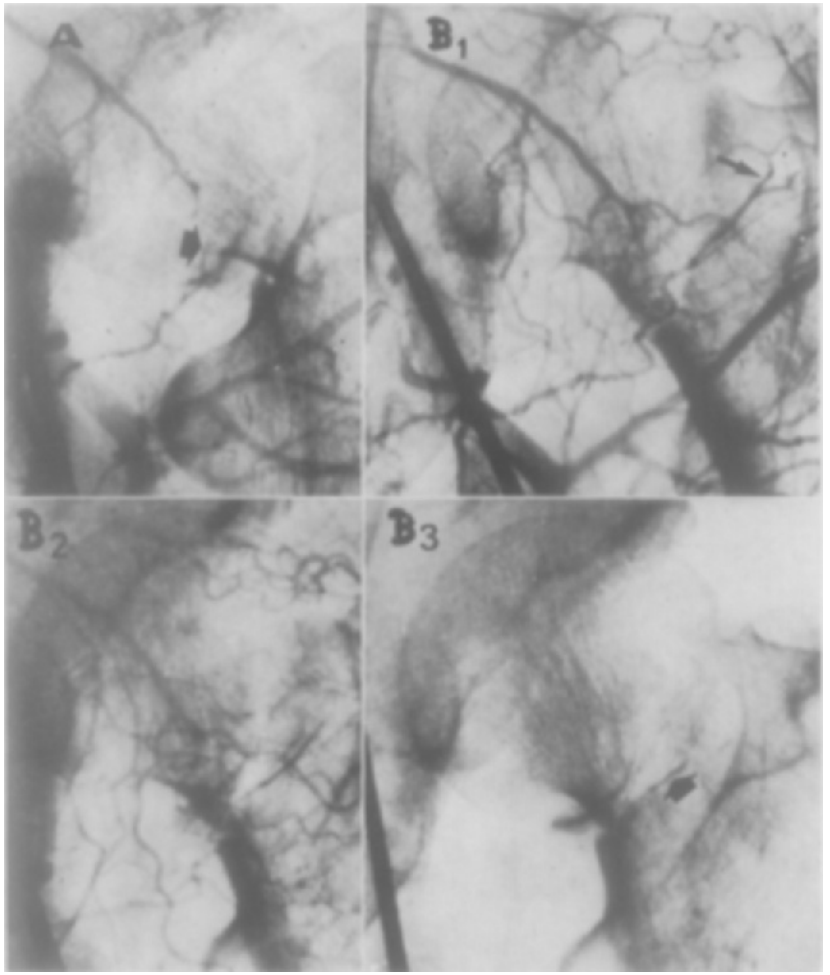

FIG. 10. *A:* Serial angiogram of a fresh, malrotated neck fracture with arrested circulation (arrow) in the posterior collum branch. *B:* Serial angiograms after reduction of the malrotation by forced inward rotation of the leg. Now a complete filling of the posterior collum branch is obtained (B^1, arrow); however, the circulation is somewhat delayed, visible from the pooling of the contrast material at the end of the arterial phase (B_3, heavy arrow).

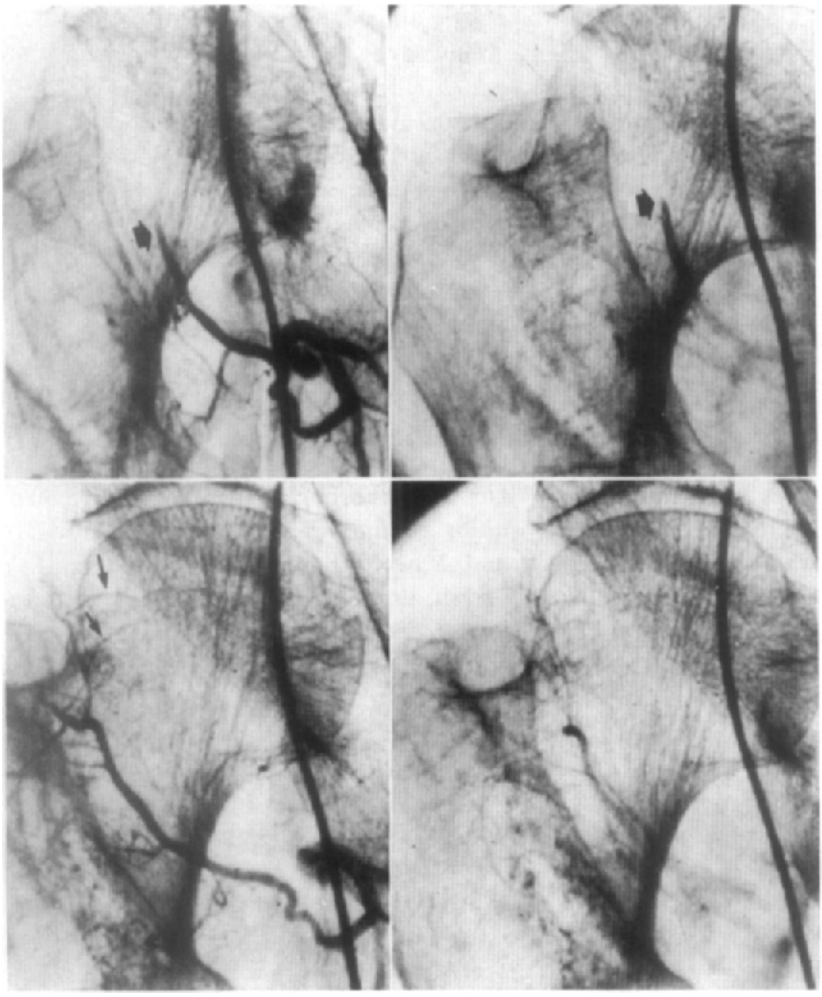

FIG. 11. *Upper:* Serial angiograms of a recent malrotated pertrochanteric fracture with arrested circulation (heavy arrow) in the posterior collum branch. *Lower:* After reduction of the malrotation by forced inward rotation of the leg, the circulation normalized and two branches of the superior retinacular artery also filled (arrows).

Reduction of malrotation by forced manual inward rotation of the leg was immediately followed by restitution of the circulation in the posterior collum branch (Figs. 10 and 11). This was noted in 5 cases in which the reduction manoeuvre was successful. Restitution in the posterior collum branch was accompanied by a filling of the superior retinacular artery in 2 cases.

Thirty-seven patients were examined after definitive reduction and nailing; in no case was arrested circulation observed. In the 13 cases with arrested circulation prior to operation, filling of the posterior collum branch was restored to normal in all cases (Figs. 9 and 12). However, in 4 of them, 3 neck and 1 pertrochanteric fractures, the circulation remained delayed.

Forced outward rotation of the leg also caused arrest of the circulation in the posterior collum branch in 2 pertrochanteric fractures even though they had been thoroughly reduced and nailed.

Non filling of the posterior collum branch due to an anomaly was observed in 1 neck and 2 pertrochanteric fractures (Fig. 13).

A follow-up study of 9 fresh, unreduced neck fractures with arrested circulation revealed later development of femoral head necrosis in 7 cases, whereas in the fresh fractures with normal or delayed circulation necrosis occurred in only 1 out of 9 cases. Out of the 24 neck fractures examined angiographically after nailing and followed-up, necrosis developed in 9 cases, in 2 of which the circulation had been delayed in the fresh fracture. In the remaining 15 cases, 1 with delayed and 14 with normal circulation, necrosis did not appear.

The superior retinacular artery was not filled in any of the 11 cases in which necrosis developed, whereas it had filled in 7 out of the 16 cases in which necrosis was not established at follow-up. No correlation was found between the incidence of filling of the other femoral head vessels and the ultimate fate of the caput.

Necrosis was not seen to develop in any of the 7 pertrochanteric fractures followed-up. In one of them, however, the circulation in the posterior collum branch was arrested prior to reduction.

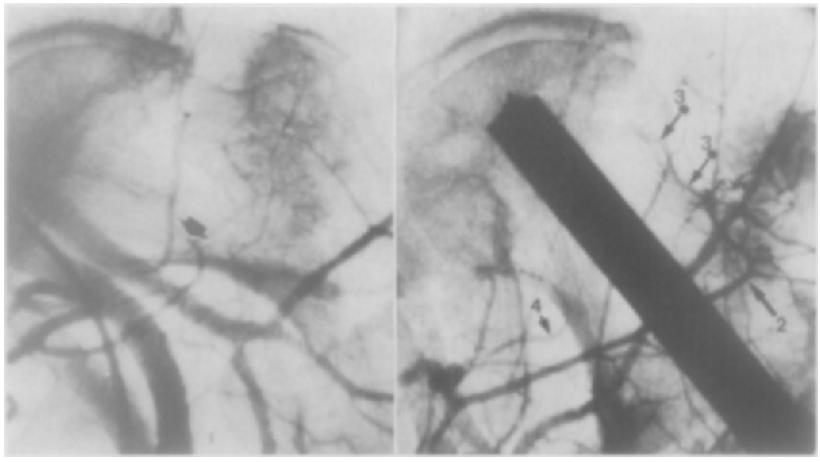

FIG. 12. Serial angiogram of a recent, malrotated, pertrochanteric fracture with arrested circulation in the posterior collum branch (*left*, heavy arrow). After reduction and nailing (*right*), the circulation normalized (2) and the superior (3) and inferior retinacular (4) arteries became well filled.

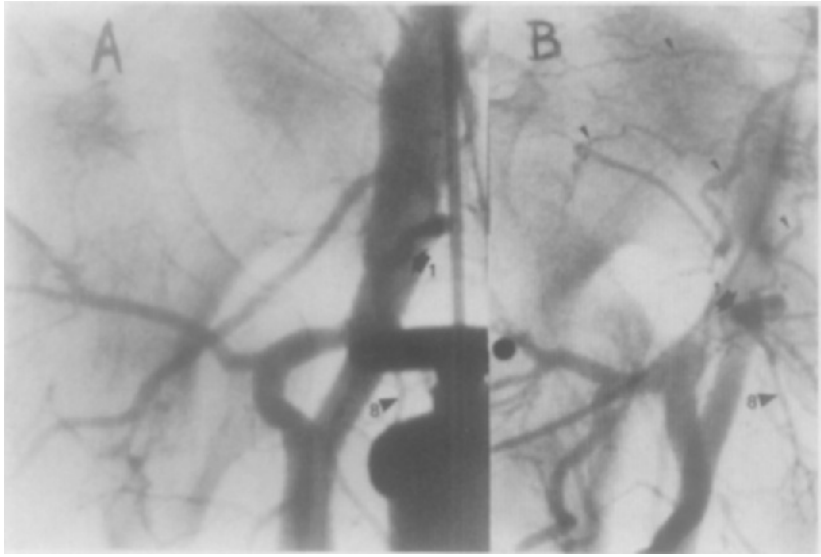

FIG. 13. Two cases (*A*, *B*) with pertrochanteric fractures. In both cases the posterior collum branch did not fill because of an anomaly. This condition should not be misinterpreted as a circulatory disturbance. Medial circumflex art. (1), inferior branch (8), ascending branch of the lateral circumflex art. (9), branches of the inferior gluteal art. (small arrows in *B*).

Necrosis (III)

An account is given of the arteriographic findings from 21 cases with necrosis of the femoral head after medial neck fracture. In agreement with previous observations (19), delayed circulation in the posterior collum branch was a frequent and typical finding evident in 13 cases (Fig. 14). Furthermore, the present examination disclosed that the superior retinacular artery did not fill in any of the cases with necrosis, indicating nutritional disturbance of the caput. On the other hand, the inferior retinacular artery was frequently enlarged (Fig. 15) and the acetabular and ligamentum teres arteries were both enlarged and more frequently filled than in the unaffected control hips. Moreover, hypervascular areas were found at the site of the old fracture and the less necrotic, medial portion of the femoral head in 14 cases (Figs. 14—16).

Rotation studies of the leg were performed in 14 cases. In inward rotation, the posterior collum branch was well filled in all cases, but circulation in it was interrupted in 4 cases when the leg was outwardly rotated by force (Figs. 15 and 17). All 4 cases were old, unhealed neck fractures which in the latter instance became malrotated.

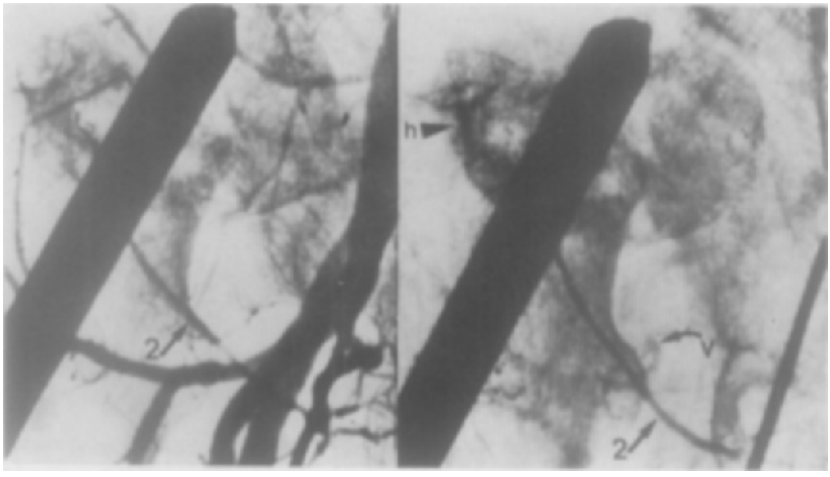

FIG. 14. Serial angiograms of a case with total necrosis of the femoral head. Good filling of the posterior collum branch (2) in which the contrast medium is pooling throughout the venous phase (*right*), vein (v), hypervascular area (h).

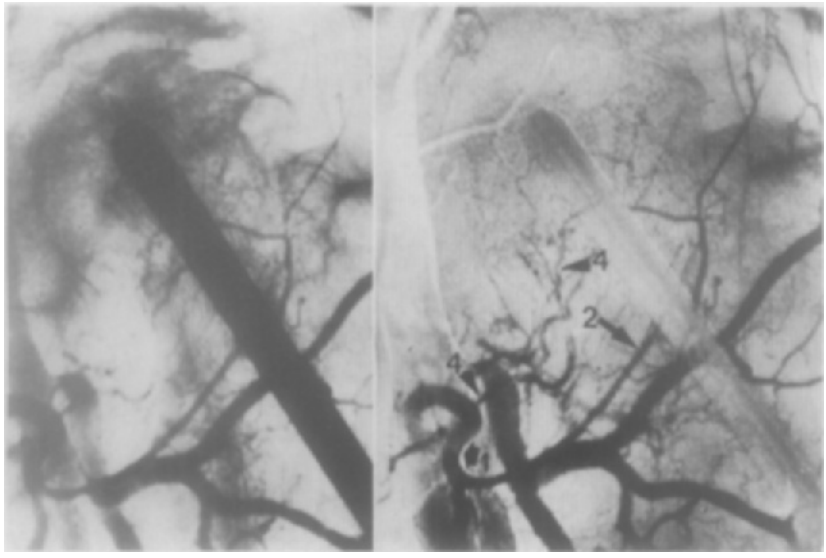

FIG. 15. Conventional and subtraction angiograms in necrosis of the femoral head. Enlarged inferior retinacular artery (4) hypervascularizing the medial, less involved portion of the caput. Medial circumflex art. (1), posterior collum branch (2) with arrested circulation in outward rotation of the leg.

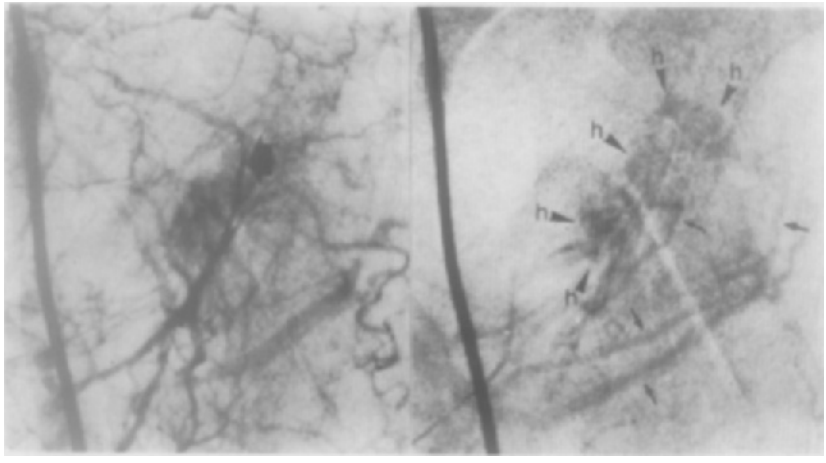

FIG. 16. Subtraction angiograms of a case with necrosis and non-united fracture. Posterior collum branch (heavy arrow). The fracture area is hypervascularized (h), optimally visible in late arterial phase (*right*). Venous drainage indicated by small arrows.

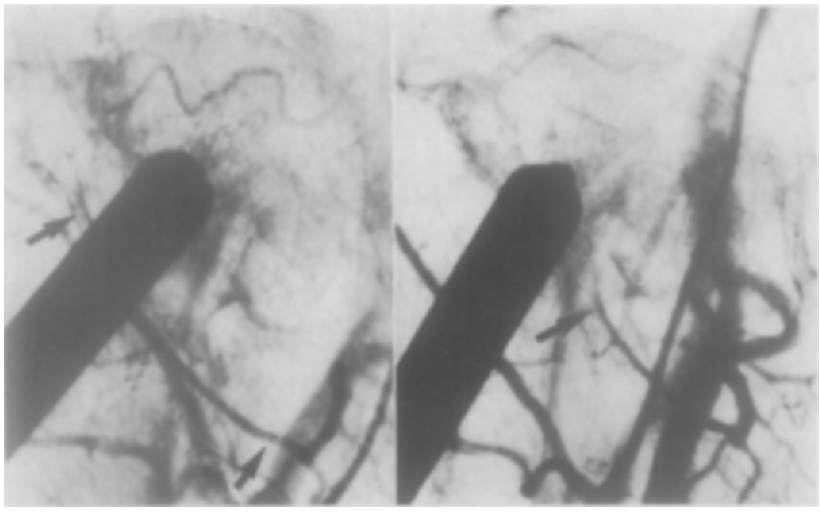

FIG. 17. Serial angiograms of a case with necrosis and unhealed fracture. Normal extension of the posterior collum branch (arrows) in inward rotation of the leg (*left*). The circulation became arrested when the leg was rotated outwardly (*right*, arrow).

DISCUSSION

The vascular supply of the head of the femur has been the subject of earlier angiographic investigations in living persons with healthy hips (19, 10, 8) as well as with neck fractures (23, 19, 10, 8, 9, 17) and femoral head necrosis (19, 16, 10). In these investigations contrast material was usually injected through a long sharp needle into the common femoral artery in a retrograde direction, a convenient method for arteriography of the whole leg used for several decades. Müssbichler (19) used exclusively the blunt Seldinger cannula 205 in order to reduce the risk of arterial wall damage by the sharp tip of the needle. In the present study cannulas have been replaced by catheters, the use of which allows free rotational movements of the hip joint during arteriography. In this way angiograms could be obtained in different projections, which is desirable for accurate and reliable identification of the vessels and for studying the influence of different positions of the leg on arterial circulation. With this procedure a close relationship between malrotation of fractures and arrested circulation in the posterior collum branch could be proved.

Earlier angiographic methods were additionally improved in the present investigation by using serial exposures with an automatic filmchanger, permitting better registration of the arteries than was the case with only 3—4 exposures. By injection of contrast material through the loop-formed, red Ödman-Ledin catheter, the vascular filling can be restricted to the external iliac artery and its branches which are responsible for the nutrition of the femoral head. For this reason this method was called "semiselective". The main advantage of this method was the avoidance of filling of the internal iliac artery, the branches of which are usually superimposed on the femoral head vessels. Application of the subtraction method, well established in other fields of angiography, is of great value for

reliable identification of small vessels and, not least, for the recognition of hypervascular areas such as were found in cases with femoral head necrosis.

In previous examinations of healthy hips, the vascular pattern, known from anatomical studies in cadavers and specimens, was to some extent identified angiographically. The examinations of Müssbichler (19) and Brugger (8) revealed in addition that the femoral head vessels could not be demonstrated in all cases examined. These observations are confirmed by the results of the present study, which further disclosed hypoplasia, ectopia, and non-filling of the posterior collum branch. In the last case the posterior collum branch was definitely not derived from the medial circumflex artery. As the latter as well as its inferior branch were well- and consistently filled with contrast medium, non-filling of the posterior collum branch cannot be due to technical errors. This is supported by the fact that this finding was frequently present bilaterally. Non-filling of the posterior collum branch is probably due to an undetectable ectopic origin or replacement of the branch by other sources of blood supply.

The absence of filling of the small femoral bead vessels, noted in many cases, may be due to a too low concentration of contrast material and not least, to the smallness of their diameters (0.3 mm is generally accepted as the lower limit of angiographic registration of vessels). These factors should be considered when filling of the femoral head vessels is not obtained.

Selective internal iliac arteriography disclosed only small collaterals to the posterior collum branch in single cases. Filling of the internal iliac artery seems, therefore, of no practical use in angiographic examination of the hip except to demonstrate the acetabular artery and an ectopic origin of the posterior collum branch.

Previous angiographic examinations of femoral neck fractures have mainly been made in an attempt to predict the fate of the femoral head as regards development of necrosis. Rook (23) concluded that "inadequate" or "poor" filling of the femoral, deep femoral, and circumflex arteries indicates reduced blood supply to the femoral head, and predicted a poor prognosis in such cases. The value of this observation, however, has not been checked by follow-up studies. Local disturbances of the circulation in patients with fresh medial neck fractures was demonstrated for the first time by Müss-

bichler (19), and later confirmed by the findings of Hipp (10), Brugger (8), and Maurer et al. (17). No differentiation between circulatory disturbances and anomalies, such as hypoplasia or non-filling of the posterior collum branch, or individual variations in the filling of the femoral head vessels has been made in the studies of these authors. It is obvious, however, that a clear differentiation between a circulatory lesion and normal, individual variations, including anomalies, is of the utmost importance for preventing misinterpretation of the findings.

The diagnosis of arrested circulation should be based on a visible interruption of the flow of contrast material, which usually pools in the intact trunk of the vessel. In the case of anomalous origin, no part of the vessel will be filled (Fig. 13) and in the case of hypoplasia, the vessel is narrow and short but otherwise normal. Atherosclerotic changes can also give rise to misinterpretation. They are not an uncommon finding either in affected or unaffected hips and are characterized by irregularities of the lumen caused by plaques attached to the arterial wall.

Trueta and Harrison (29) suggested from their anatomical studies that the superior retinacular artery is exposed to damage along the neck by varus fractures, whereas valgus fractures do not involve this artery which is the vessel most responsible for nutrition of the femoral head. This should explain the high frequency of femoral head necrosis after varus fractures. Backman (3, 4) contributed to this subject by experimental fractures in specimens of human hips as well as by follow-up studies of patients with neck fractures. He could demonstrate that malrotation of the fracture is responsible for extensive rupture of the superior retinaculum, where the superior retinacular artery runs, as well as for the development of femoral head necrosis. The deleterious role of malrotation upon the circulation to the femoral head could be definitely proved in the present study by angiography of malrotated fractures before and after reduction. It seems most likely that the immediate cause of the circulatory arrest is due to kinking or tearing of the posterior collum branch because of the malrotation of the fracture fragments. This assumption is supported by the successful provocation of circulatory arrest in old, unhealed fractures by outward rotation of the leg.

The superior retinacular artery may also be primarily affected, regardless of whether the circulation in the posterior collum branch

is arrested or not. Interruption of the superior retinacular artery has been demonstrated micro-angiographically after neck fracture in specimens of human hips (26). However, angiographic demonstration of lesions confined to the superior retinacular artery or the other femoral head vessels is not possible *in vivo* because of the high frequency of individual variation demonstrated by the present study of normal hips.

Prospective studies of angiographically examined neck fractures have been carried out by Brünner et al. (9). Their results agree with those of the present study, showing a close relationship between the circulatory condition in the posterior collum branch and the occurrence of necrosis. Isolated cases, however, deviated, thus indicating that additional factors may influence the fate of the femoral head: The most important being the *duration* of circulatory arrest. Its protraction is generally leading to arterial thrombosis with irreversible blockage. A similar process may, in the case of neck fractures, involve the superior retinacular artery e. g. the termination of the posterior collum branch.

From experiments on rabbits it is known that the osteoblasts of the femoral head may tolerate an interruption of the blood supply for up to 6 hours (34, 24). Postponed reduction of the fracture-dislocation maintaining circulatory arrest, may thus be responsible for the development of femoral head necrosis, whereas "early" reduction, advocated by several authors (5, 18, 27, 28), may protect or restore normal circulation and avoid the development of necrosis. Optimal effect in preventing necrosis of the femoral head may be expected from fracture reduction performed as an emergency as has been proposed by Strange (28). Forced inward rotation and fixation of the malrotated leg carried out as an emergancy could be an important link in the treatment of malrotated fractures.

Survival of the femoral head may also be helped by pre-existent collateral circulation within the caput, demonstrated microangiographically by Sewitt and Thompson (25) or by extraosseous communications between the trochanteric vessels and the superior retinacular artery (14) and/or between the inferior gluteal artery and the peripheral part of the posterior collum branch — shown in the present study of healthy hips. As one or several of these communications may exist, a reliable prognosis based on the circulatory

condition in the posterior collum branch alone cannot be made in each individual case.

While non-filling of the superior retinacular artery in individual cases is inconclusive, its filling, obtained in 7 fracture cases, seems to indicate viability of the femoral head, as no necrosis of the head was present at follow-up in any of these 7 cases. However, the prognostic value of this observation needs to be proved in a larger material and over a longer period before definite statements can be made.

The mechanism of circulatory arrest in pertrochanteric fractures, in which necrosis usually does not occur, may be different from that in neck fractures. The location of the pertrochanteric fracture, far distal and lateral to the posterior collum branch and particularly to the superior retinacular artery, makes it likely that the circulatory disturbance is actually less severe and therefore of a more transient character than in the case of neck fractures.

Delayed circulation in the posterior collum branch without circulatory arrest is thought to indicate impairment of emptying of this artery due to damage to its peripheral part or its main branch, the superior retinacular artery. Delayed circulation was found in 3 cases out of 27 with fresh fractures and in 13 out of 21 with established necrosis. In the latter condition, delayed circulation occurred not only more frequently but was also more pronounced than in recent fractures. This indicates that the degree of the circulatory disturbance progresses simultaneously with the development of necrosis. The consistent absence of filling of the superior retinacular artery throughout the whole necrosis material further emphasizes the nature of the nutritional disorder of the femoral head. Hypertrophy and/or increased filling frequency of the other femoral head vessels as well as the incidence of hypervascular areas point to the occurrence of a re-vascularization process at the fracture site and at the periphery of the necrotic head similar to that demonstrated histologically in humans subjects and experiment animals (26, 22).

GENERAL SUMMARY AND CONCLUDING REMARKS

The present angiographic investigation was concerned with the arterial supply of the hip in living persons. It comprised studies of (*1*) arteriographic methods, (2) the vascular anatomy of healthy hips, (*3*) the vascular anatomy of neck and pertrochanteric fractures, and (*4*) necrosis of the femoral head after neck fracture. The main results and conclusions of the investigation are summarized as follows:

ad 1. In the demonstration of the arteries of the hip, the following methods were applied:

A. A blunt Seldinger cannula was used in 34 cases in which 20 ml Dijodon 50 % was injected retrogradely into the common femoral artery. In 99 cases, 16 ml Urografin 76 % was injected through a polyethylene catheter into the common femoral or external iliac artery. These types of injection were termed "general arteriography" since, usually, both the external and internal iliac arteries filled.

B. A new catheter technique for semiselective visualization of the arteries of the hips was devised. It consisted of antegrade, peripheral injection of 10 ml Urografin 76 % either through a distally inserted polyethylene catheter (3 cases) or a loop-formed, red Ödman-Ledin catheter (26 cases). The purpose of this type of examination, only used in the normal material, was to avoid retrograde filling of the branches of the internal iliac artery superimposed on the vessels of the femoral head.

C. Selective internal iliac arteriography was carried out in 14 cases in order to study the contribution of this artery to the supply of the hip.

D. Other improvements comprised the use of an automatic film-changer taking 15 exposures over 15 seconds and application of the subtraction method.

The use of blunt Seldinger cannulas and catheters in particular as opposed to the sharp needles used by other authors diminishes the risk of arterial wall lesions. Catheters are to be preferred as they allow studies in different positions of the hip joint, which is desirable for reliable identification of vessels and of conditions of circulatory disturbance. Semiselective angiography with the red Ödman-Ledin catheter showed optimal results as regards identification of the femoral head vessels. The use of serial angiography and the application of the subtraction method further improved the registration of the arterial circulation and identification of vessels.

ad 2. Ninety-two healthy hips were examined angiographically. The findings revealed a great individual variation of the vascular pattern. This concerned particularly the posterior collum branch which was hypoplastic in 3 cases and of anomalous origin in 11. Demonstration of the superior retinacular artery in the total material of helathy hips was successful in about 69 % of the cases, of the inferior retinacular artery in 63 %, and of the acetabular artery in 40 % with general arteriography and in 27 % with the semiselective method. The incidence of filling of the other femoral head vessels was not influenced by the arteriographic method used. The existence of small anastomoses between the inferior gluteal artery and the peripheral part of the posterior collum branch was demonstrated by internal iliac arteriography in 3 out of 14 cases. Filling of the internal iliac artery also made possible confirmation of an ectopic origin of the posterior collum branch in the inferior gluteal artery in 2 cases.

Ignorance of these angiographic findings in healthy hips must necessarily give rise to misinterpretation of angiograms in fractures, necroses or other affections of the hip.

ad 3. A total of 49 cases, 37 with medial neck and 12 with pertrochanteric fractures, were examined. In 37 of them angiography was carried out before nailing (Paragraphs A—C below), 37 were examined after the operation (D), and in 27 cases with medial neck

fractures follow-up studies were made (E—H). The findings are listed below (A—G concern the circulation in the posterior collum branch).

A. In recent fractures the circulation in the posterior collum branch was normal in 19 cases and disturbed in 18. The latter condition comprised delayed circulation, 3 cases, and arrested circulation, 15 cases.

B. Circulatory disturbance was exclusively present in fractures which were in varus and dorsal angulation or in dorsal angulation of at least 40°.

C. Arrested circulation was restored to "normal" or "delayed" after reduction of the fracture during the angiographic examination. This was shown in 5 out of 12 cases.

D. After operative reduction and nailing, arrested circulation was not noted in any of the 37 cases examined. However, in 3 neck and 1 pertrochanteric fracture, the circulation remained delayed.

E. Follow-up studies could be performed in a total of 27 neck fractures, 18 of them angiographically examined before fracture reduction and 24 after operative reduction.

F. Femoral head necrosis developed in 7 out of 9 cases of fresh medial neck fractures in which the circulation was arrested before reduction, whereas necrosis was noted in only 1 out of 9 neck fractures with normal or delayed circulation. The probability of committing wrong decisions, according to the sign-test, rejecting the null hypothesis, P (necrosis) = 0.5, is less than 9 % and 2 % respectively.

G. Out of the 24 cases with neck fractures angiographically examined after operation, the circulation was normal in 21 cases and delayed in the remaining 3. At follow-up, necrosis had occurred in 9 cases, in 2 of which the circulation had been delayed and in 7 of which it had been normal.

H. The superior retinacular artery filled in none of the 11 neck fractures which later developed necrosis. It was, however, filled in 7 out of the 16 cases in which necrosis was not established at follow-up.

It is suggested that filling of the superior retinacular artery may indicate maintained circulation to the femoral head. However, its non-filling should in the individual case, not be interpreted as a circulatory lesion. It seems likely that the existence of an efficient collateral circulation, angiographically not demonstrable, may keep the caput alive in individual cases even though the circulation in the posterior collum branch or superior retinacular artery has been or still is arrested. This would explain the avoidance of caput necrosis seen in 2 cases with arrested circulation in the fresh fractures.

Reduction of the malrotation leading to restoration of the circulation in the posterior collum branch, suggests that this procedure should be carried out *as an emergency* in order to shorten the period of circulatory arrest. This may be a *valuable link in the treatment of malrotated neck fractures.*

ad 4. Twenty-one cases of femoral head necrosis after medial neck fracture were examined and associated with the following angiographic findings:

A. The posterior collum branch showed delayed circulation in 13 cases.

B. The superior retinacular artery was not filled in any case.

C. The acetabular and ligamentum teres arteries showed an increased frequency of filling and the inferior retinacular and acetabular arteries were enlarged, compared with the findings from the contralateral, healthy hip. Moreover, hypervascular areas at the fracture site and the medial, less-involved part of the caput were observed.

The arteriographic findings confirm the general opinion of avascularity of the necrotic femoral head but also show the occurrence of peripheral revascularization.

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