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THE ARTERIAL SUPPLY TO THE FEMORAL HEAD IN CHILDREN

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The epiphysis of the femoral head begins as an island of bone entirely surrounded by cartilage at about the age of four to six months. This island condition continues until the growth cartilage disappears at puberty. In the fovea, where the round ligament of the head is placed, connective tissue instead of cartilage is found.

The arteries supplying the epiphysis have previously been studied using arteriography (Hipp 1962, Müssbichler 1970) or arterial injections combined with microradiography and clearing of the specimens according to the method of Spalteholz (Trueta 1957, Crock 1967). In these investigations the femoral head has been halved or sliced before study and description. It is difficult, however, to perform a three-dimensional study on arteriograms even with the use of stereoscopy and it is impossible to visualize the arteries inside the epiphysial bone.

This study is an attempt to achieve a better description of the topography of these arteries by investigating the total upper femoral end after injection and clearing by the method of Spalteholz.

MATERIALS AND METHODS

Injections were carried out at autopsy in children 8–24 hours after death. Thin polyethylene catheters were placed in both external iliac arteries and if possible in the obturator arteries. The superficial and deep femoral arteries were then ligated just below the circumflex arteries. The vessels were infused for 10 minutes with a 0.9 per cent saline solution using a constant pressure of 90 mmHg. Without interruption and using the same constant pressure Microphil®* was then infused

* Microphil® (Canton Bio-medical Products Inc., P.O. Box 154, Swartmore, Pa. 19081 U.S.) consisted of 32 ml compound and 40 ml diluent. To this was added 7.2 ml duroliopaque and just before injection, 4 ml curing agent.

for 10 minutes. Thirty minutes later both hip joints including the upper end of the femur and the lower part of the pelvis were carefully removed.

This block was fixed in a 4 per cent solution of formaldehyde for 30 days and then minutely dissected, special care being given to the deep branch of the medial circumflex artery and its relationship to the tendon of the external obturator muscle. The entire upper end of the femur including the lower part of the fibrous capsule and the round ligament of the head formed the final specimen, which was re-fixed in formaldehyde. In order to obtain a short decalcification period, some of the specimens were decalcified in a mixture of formic and hydrochloric acid using electrical ionization (Preece 1965). The degree of decalcification was checked frequently by X-ray tests and was complete after 100–150 hours. Results were acceptable but the method was found to be a little coarse. The other specimens were decalcified in Tetrasodium edetate (Gussen & Donohue 1965). This technique gave very fine results but the process was quite slow, taking 2–4 months.

When decalcification was finished the specimens were bleached in 3½ per cent hydrogen peroxide for two days. They were then dehydrated in increasing concentrations of alcohol up to absolute alcohol using an automatic tissue processing machine with a bath change every 24 hours. Clearing was performed in two parts of methyl salicylate (Wintergreen oil) and one part of benzyl benzoate. Before studying the specimens in a stereoscopic microscope (magnification 6–40) air was driven out using a vacuum chamber.

A total of six children were studied. Their ages were: A: 4 months. B: 1 year, 2 months. C: 3 years, 10 months. D: 5 years, 2 months. E: 6 years, 3 months. F: 9 years, 11 months.

In child E injection of the left side failed because of damage to the pelvic arteries during autopsy. The right femoral head in C was damaged by decalcification and injection was insufficient in A's right and D's left. Thus eight specimens were available for study of the arterial supply to the epiphysis of the head of the femur. None of the children were known to have had signs or symptoms in the hips before death.

Causes of death: A: Congenital heart disease, Down's syndrome. B: Acute gastroenteritis. C: Pneumonia after measles, leucaemia. D, E and F: Cerebral contusion or dilaceration.

Nomenclature and brief gross anatomy

The small arteries surrounding the femoral head have been given various names. In the present communication the Paris Nomina Anatomica (PNA) will be used, according to Hipp (1962).

The deep branch from the medial circumflex artery, ramus profundus (RP) passes behind the neck of the femur in close relationship to the capsule and the external obturator muscle. This artery ends as lateral branches to the epiphysis: rami nutricii capitis proximalis (RNCP). Fine retinacular branches from RP pass medially and a little behind the neck towards the head: rami nutricii capitis distalis (RNCD). From arteries in front of the neck, retinacular branches pass

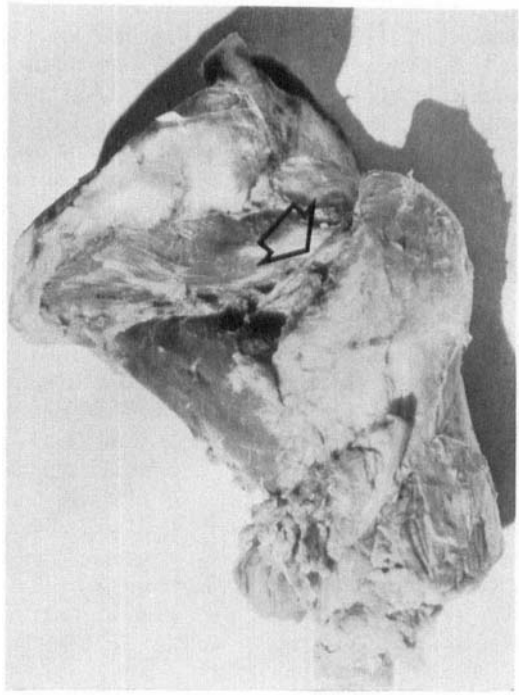

Figure 1. Right hip specimen from E, six years old, seen from behind in the extended position. The deep branch of the medial circumflex artery curves snugly around the tendon of the external obturator muscle (arrow).

to the anterior part of the head: rami nutricii capitis anteriores (RNCA). Finally the artery in the round ligament of the head: arteria ligamenti capitis femoris (ALCF) supplies the head from the opposite side.

The different specimens will be named Ar (right specimen from A), Bl (left from B) etc.

RESULTS

Macroscopic dissections

This could not be done in A. In all the other specimens a normal course of RP just below the external obturator muscle close to the adhesion of the fibrous capsule to the back of the femoral neck was found. In every case the artery crossed superficially to the tendon of the muscle as it passed round the tendon before turning to the lateral side of the neck (Figure 1). When the hip joint was extended the external obturator was tense and the artery was found to be stretched over the tendon. In internal rotation of the hip this tension and stretching was even more marked. When the hip was flexed the muscle

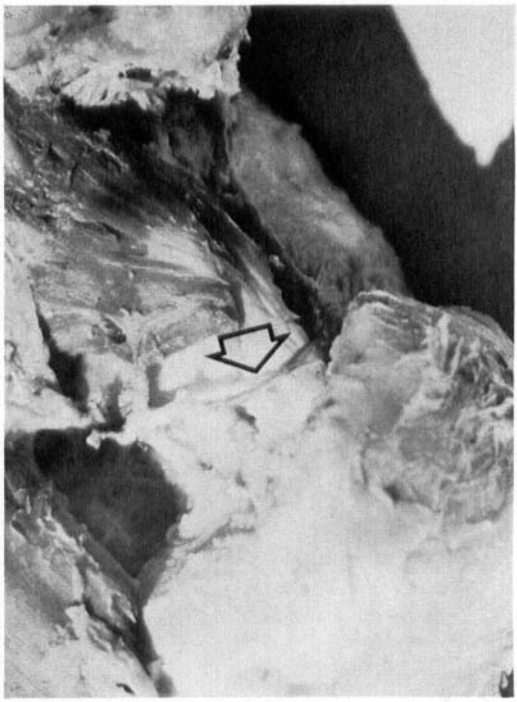

Figure 2. Same specimen as Figure 1, increased magnification. The hip is flexed and the shadow of the deep artery on the obturator tendon shows that the artery is slack (arrow).

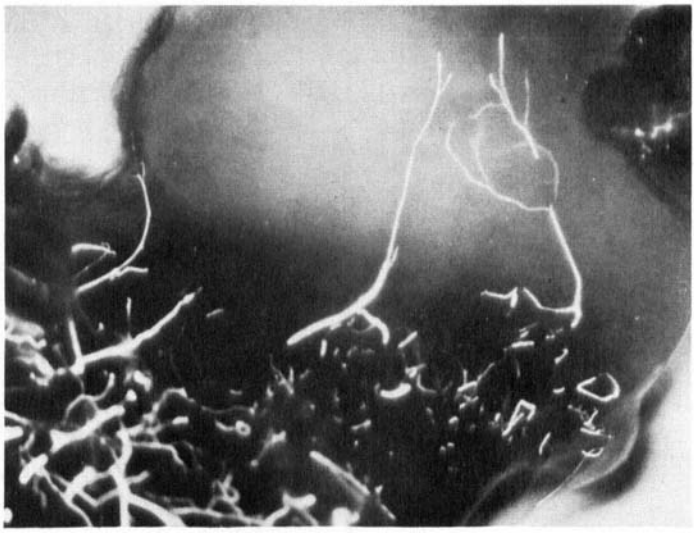

Figure 3. Left head of A seen from behind. Two arteries appear ascending from the sparse metaphysial network into the cartilaginous ball. The small vessels in the ligament of the head (top right) are confined to the ligament itself.

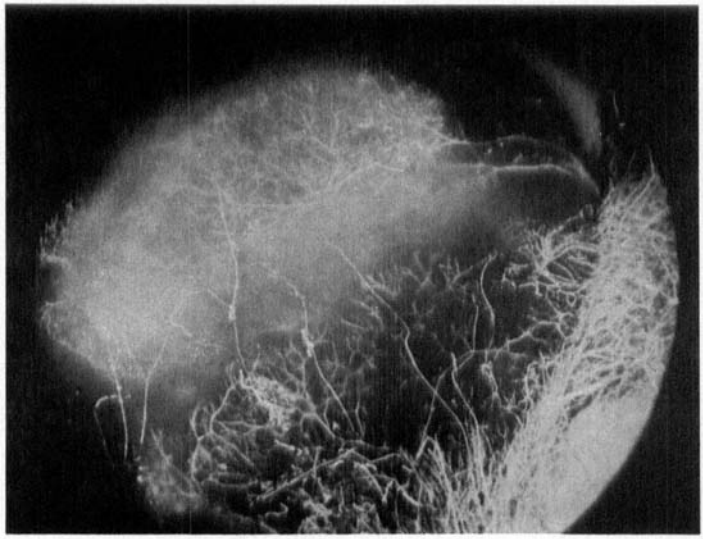

Figure 4. Left femoral head of C seen from in front where several thin anterior retinacular arteries (RNCA) traverse the periphery of the epiphysial cartilage. Two of the four lateral arteries (RNCP) are seen to the right bending into the epiphysis.

and artery were completely relaxed and even more markedly so if the joint was outwardly rotated in addition (Figure 2).

In Dl a contusion haemorrhage laterally at the neck at the side of RNCP was found. These vessels were thrombosed along their entire course. In spite of this the epiphysis was injected in this specimen (Figure 8).

Microscopic findings

Al (aged 4 months) showed two arteries from the metaphysis emerging to the head (Figure 3). Laterally an artery ascended a short distance but did not pass into the cartilaginous head. ALCF was seen only in the ligament and did not pass into the head.

Br (aged one year) showed a well-vascularized epiphysis supplied from a large RNCD, a small RNCA and a few small RNCP. The ALCF supplied a small area in the fovea but no vessels passed into the epiphysis.

Cr and Cl (aged nearly four years) showed richly supplied and well-vascularized epiphyses from which small, scattered arterial branches passed into the deepest layers of the covering cartilage. Four RNCP

Figure 5. Same specimen as Figure 4. The network in the fovea and ligament is anastomosing with two of the small branches ascending from the epiphysis into the basal layer of the cartilage (arrow).

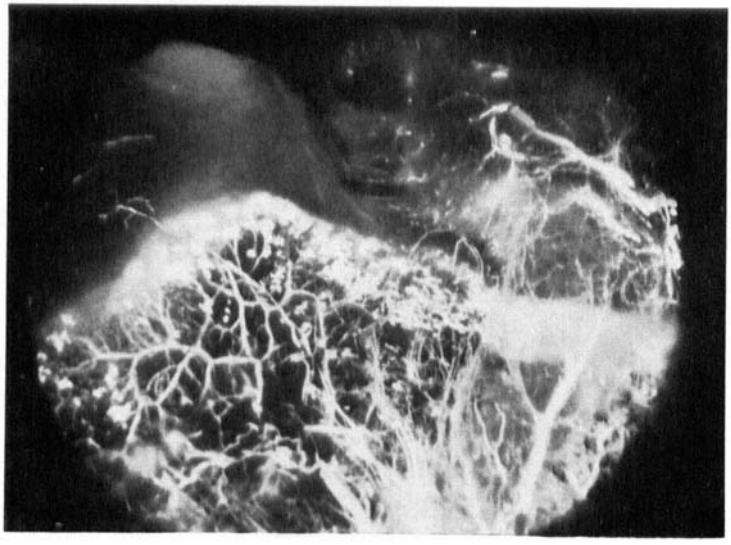

Figure 6. Left hip specimen of D seen from in front. The greater trochanter is seen to the right. The head to the left is poorly illuminated. The upper border of the metaphysial networks runs as a uniform band from the head to the trochanter.

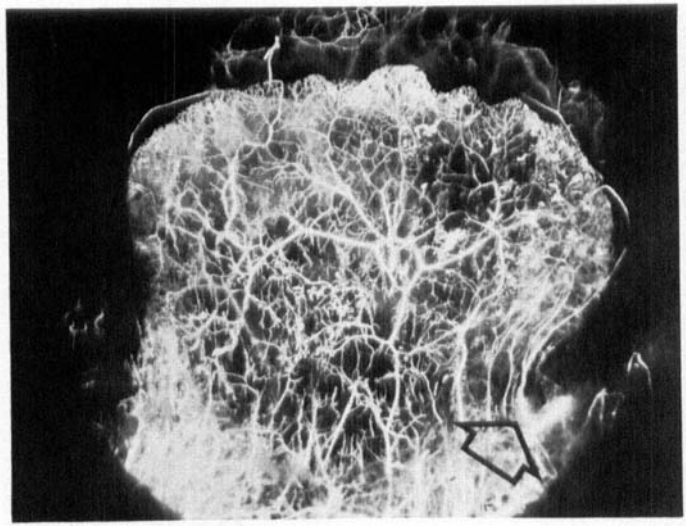

Figure 7. The metaphysial network of D's right hip seen medially. At the bottom is seen the dense arterial network of the synovial pouch. Here the arteries turn (arrow) before running along the neck into the metaphysis and further up into the epiphysis which is barely seen above the dense surface of the metaphysial network.

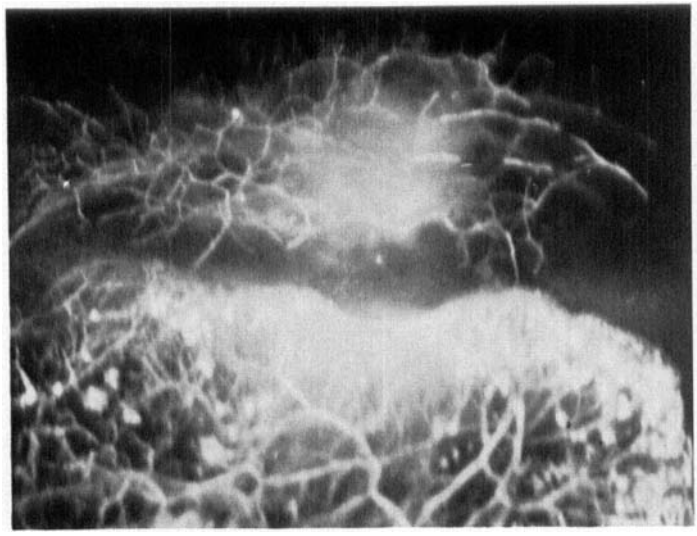

Figure 8. The epiphysis of D's left hip seen from in front is well filled through the inferior and anterior retinacular arteries, although no injecting material could pass the lateral arteries (right). These were thrombosed outside the cartilage, but some retrograde filling was present.

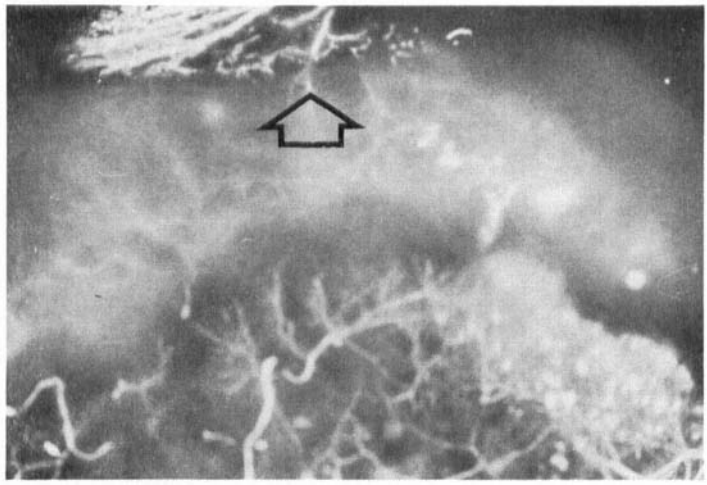

Figure 9. Right hip of E. The fovea is seen tangentially (top). One very small anastomosis passes down into the epiphysis (arrow).

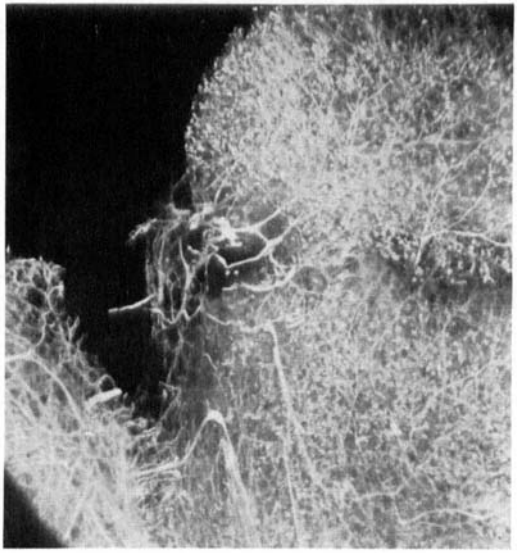

Figure 10. The lateral part of the right femoral head of F, who was nearly ten years old, seen from in front. A lateral synovial network ending in several RNCP is seen. All of the bone is well vascularized.

from the synovial arterial network lateral to the neck entered the epiphysis at an angle of 100–110°. A large RNCD and not less than six small RNCA were present (Figure 4). The ALCF supplied a rich network of vessels in the fovea, and from here some very small anastomoses with the epiphysial network were seen (Figure 5).

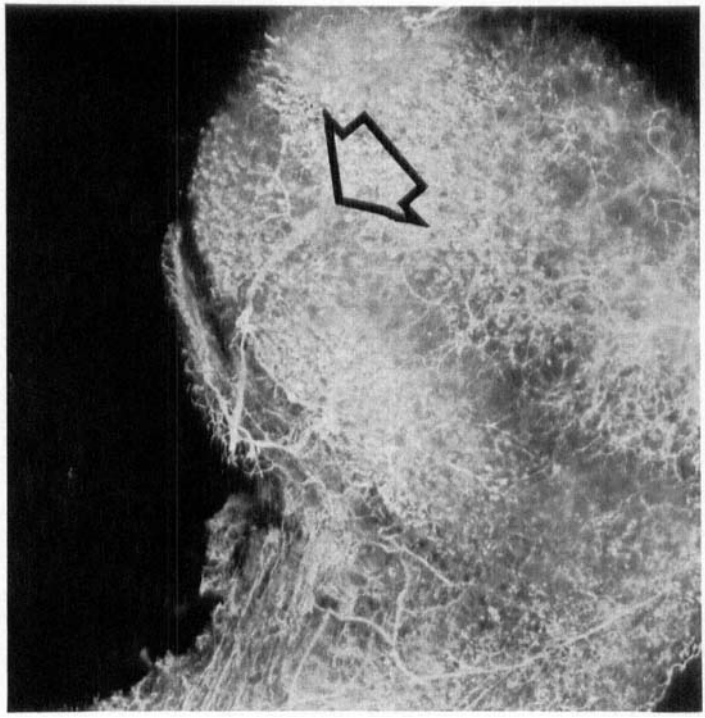

Figure 11. The medial part of the same specimen as in Figure 10 showing a RNCD arising from the synovial network outside the neck and passing the epiphysial cartilage (arrow) into the epiphysis.

Dr and Dl (aged five years) showed an extensive arterial network in the metaphysis which was particularly dense just below the epiphysial cartilage. This "surface" of the metaphysial arteries continued as a uniform band along the lateral border of the neck to the trochanteric part of the metaphysis, and its presence supports the supposition that the growth in the upper end of the femur takes place from a total surface (Figure 6). From a ring of closely packed small arteries at the bottom of the synovial membrane, the retinacular arteries arose and ascended outside the neck, supplied the metaphysis, but ended in two RNCD and one RNCA to the more sparse epiphysial network (Figure 7). In Dr two well-developed RNCP were seen but in Dl, where these arteries were thrombosed due to the contusion, the terminal ends of the RNCP evidenced retrograde filling from the epiphysial arteries to the cartilaginous border. The epiphysis was primarily filled through a large RNCD (Figure 8). Neither in Dr or Dl were any ALCF found.

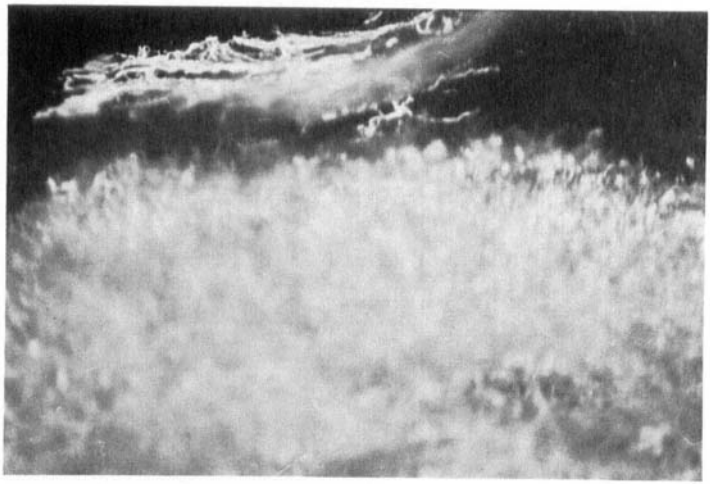

Figure 12. Same specimen as Figures 10 and 11 showing no communication between arteries of the fovea and the underlying dense epiphysial network.

The most likely explanation is that injection of the obturator arteries failed in this patient.

Er (aged six years) showed a increasing number of arteries in the epiphysis which were filled mainly from the RNCP but one RNCD was seen. The ALCF to the foveal vessels showed in this specimen a small but distinct anastomosis between the arteries in the fovea and those in the epiphysis (Figure 9).

Fr and Fl (aged nearly 10 years) showed the increasing importance of the RNCP in vascularization of the epiphysis. From a true network laterally in the synovium 7–10 arterial branches entered the epiphysis (Figure 10). At the opposite end, just medially, both specimens showed a RNCD also arising from the synovial network and entering the epiphysis (Figure 11). With the exception of these latter vessels no anastomoses between the epiphysis and the metaphysis were seen. The ALCF supplied the fovea only and had no communication with the epiphysis itself (Figure 12).

Generally speaking the arterial network in the metaphyses was found to be more dense than in the epiphyses. The metaphysial vessels were supplied from both the diaphysial (the nutritient artery system) and the synovial network and from arteries entering the bone below the capsule. The network in the epiphysis of the greater trochanter was mainly filled by arteries entering the trochanter from the lateral side.

DISCUSSION

In the macroscopic part of this investigation it is made clear that the RP is tighted over the tendon of the external obturator muscle when the hip is extended and even more if it is rotated inwardly too. According to arteriographic investigation (Müssbichler 1970) great individual variation in the course of the RP exists. Supposing the artery in some cases is placed deep to the tendon it will then be compressed between the tendon and the capsule in the extended position of the hip, for example in normal standing. Among the hips in the present study no such case was found, but this supposed deep localization might explain the findings of Hipp (1962) who observed closure of the RP in patients with Perthes' disease.

As to the microscopic part of the investigation the results are admittedly defective due to technical reasons in particular. The results are primarily dependent on successful removal of the blood from the vessels followed by complete filling of the arteries with injected material.

Of the 12 hips, eight have been sufficiently prepared to give some evidence about the position and relationship of the arteries to the upper end of the femur. This small material obtained from children aged four months to 11 years is hardly representative enough to draw general conclusions but it can be compared with other investigations. Preparing the upper femoral end in one whole block gives the advantage of not destroying any of the arteries. This will happen when the blocks are sawn into halves or slices. With this technique the total block can be placed in any position while studying the arteries from different angles under the microscope. As a whole block all diffusion to and from the epiphysis has to pass the cartilage and this will prolong the time needed to decalcify and prepare the blocks. In these larger blocks it is impossible to study the finer structure of the vessels inside the bone as Trueta & Morgan did in 1960 in a study of the vascular contribution to osteogenesis.

In general this investigation has confirmed the findings made by other investigators. In a child of four months not as many small arteries to the epiphysis were found as by Trueta (1957) and Crock (1967). In the youngest children the anastomoses between the networks in the fovea and the epiphysis did not follow exactly the same pattern as in the investigation of Trueta. These anastomoses were found at the age of three but not at the age of nearly ten in the present study. Trueta found the lateral epiphysial arteries (RNCP) to be the only

arterial supply to the epiphysis after the age of six years, whereas in this study a medial retinacular artery (RNCD) was found passing to the epiphysis at the age of nearly 10 years. This study agrees with Wolcott (1943) and Tucker (1949) in that the vessels in the round ligament of the head (ALCF) primarily supply connective tissue in the fovea and have little importance for vascularization of the epiphysis. In the present preparations the anterior retinacular arteries (RNCA) passed more constantly to the epiphysis than reported by other investigators. It is the author's opinion that the lateral, the distal and the anterior retinacular arteries (RNCP, RNCD and RNCA) belong to the synovial network which is more clearly seen with increasing age. Possibly this is what Harty (1953, 1966) described as two ring anastomoses. The retinacular arteries arise from this synovial network and follow it to the border of the cartilage from whence they continue along the border between metaphysial bone and surface cartilage giving off branches into the metaphysial bone before entering the epiphysis as they pass obliquely through the edge of the epiphysial cartilage. The lateral arteries (RNCP) become increasingly dominant in the blood supply to the epiphysis with increasing age. If the blood supply through these arteries is stopped, the epiphysis will undergo ischaemia, especially in children more than 5–6 years of age. This condition persists until the rest of the smaller arteries have grown sufficiently to compensate.

SUMMARY

A method used to inject Microphil® into the arteries of the hip region in children of various ages at autopsy is described. By macroscopic dissection and microscopic investigation particular attention was given to the blood supply to the epiphysis of the femoral head. The findings are discussed in relationship to those of others. The deep branch of the medial circumflex artery terminated as the lateral arteries to the epiphysis. With increasing age these latter arteries were found to be of increasing importance with regard to the blood supply of the epiphysis. The artery in the round ligament of the femoral head was found to have little if any importance to the epiphysial blood supply in children.

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