

A revision of the anatomy of the arteries supplying the upper end of the human femur

BY H. V. CROCK, MB.BS. (MELB.), F.R.C.S., F.R.A.C.S.

From the Anatomy Department, University of Melbourne and the St Vincent's Hospital School of Medical Research

Bone vascularization is now generally regarded as an anatomical subject of practical significance. However, it is not yet taught to undergraduates in medicine, nor even to specialist surgeons in training, though many of them become aware of certain publications in this field in the course of their reading.

In a recent leading article, the *Lancet* (1963), found it refreshing to note renewed interest in the blood supply of bone. The leader went on: 'All workers agree that the main source of arterial supply of a long bone is through the nutrient artery, with the perforating arteries of the metaphysis and epiphysis running it a close second. The direction of blood flow through the cortex of the diaphysis, and the contribution, if any, of periosteal arterial blood to the subjacent cortex are more contentious issues.' This suggests that the blood vessels of epiphysis and metaphysis have at last yielded up most of their anatomical secrets, while the cortex still defies the attempts of the best investigators to unravel its blood supply. The *Lancet's* commentary has prompted this revision, which indicates that there are wider and simpler areas for dispute than the narrow confines of the cortical bone of the diaphysis.

There is a remarkable similarity in the distribution of arteries to the epiphyses of long bones throughout the human skeleton. Different authors propose varying terminologies for these arteries, but there is no major disagreement between them when describing, for example, the arterial supply of the tibial epiphyses. An exception can be made in the case of the femur, where confusion still exists on the nomenclature of the arteries supplying the upper end. In English-speaking countries the description of the arterial supply of the human femoral head most widely quoted is that proposed by Trueta and Harrison in papers published in 1953 and 1957. There is scarcely a paper published on this subject which could be described as a pure work of anatomy. Most authors expound at length on the practical applications of the knowledge of this facet of anatomy to the understanding of fracture healing or to the localization of infective lesions or to the origin of Perthes's disease of the hip. Almost invariably, each makes some reference to most of the previously published work, if only to draw attention to faults in the use of techniques in the study or to errors of interpretation.

The purpose of this paper is to re-examine the anatomy of the arterial supply of the upper end of the human femur in an attempt to highlight the importance of establishing the correct terminology.

MATERIALS AND METHODS

For this paper, material has been injected, collected and processed personally from 136 post-mortems. Specimens from cases at the following ages were examined (the number at any one age being indicated in brackets). 5 days, 10 days, 6 weeks, 2 months, 2½ months, 3 months, 4 months, 2 years, 2½ years (2), 3½ years (2), 4 years, 5 years, 9 years 11 months, 11 years, 13 years (2), 15 years, 17 years (2), 21 years (2), 22 years (2), 27 years, 28 years (2), 39 years (2), 59 years (2), 60 years, 61 years, 63 years, 64 years (2), 65 years, 66 years, 68 years, 69 years, 70 years, 71 years, 75 years (2), 76 years, 80 years, 81 years, 90 years.

Many difficulties have to be faced when one attempts to obtain specimens of the upper end of the femur. Presuming that one can gain the necessary permission to remove the bone and that adequate assistance will be available for this operation, the technical difficulties of injection techniques remain to be overcome.

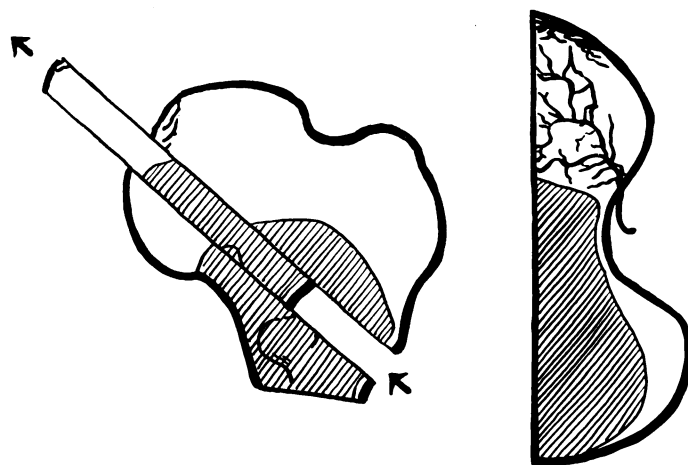
It is generally agreed now that bone injections are most likely to succeed when they are performed through major blood vessels in an otherwise undisturbed limb. The use of a tourniquet proximal to the injection cannula can be recommended especially when venous injections are attempted (Crock, 1962). In the case of the upper end of the femur no tourniquet can be applied proximal to the point of injection, so that the problem of reducing injection medium leakage into unwanted areas arises constantly. Under such circumstances only the larger calibre vessels entering the bone may be filled, as the pressure in the vascular circuit may never reach a level that will fill smaller branches. Failure to appreciate this point has led many authors to at least one false conclusion, namely, that no arteries enter the femoral head or neck anteriorly.

On examining five papers dealing with this subject, Harrison & Trueta (1953), Trueta (1957), Howe, Lacey & Schwarz (1950), Wolcott (1943) & Kolodny (1925), it was noted that not one provided satisfactorily detailed accounts of injection techniques. In one method which is commonly used, a narrow cannula of either metal or glass, is inserted and tied into the femoral artery. The vessel proximal to the cannula is ligated. The injection is then made by hand with a large syringe which is filled and emptied and refilled over the course of 5 or 6 min. There can be no argument but that the quality of injections obtained by this method can be excellent. On the other hand, it cannot be denied that a method which reproduces perfusion conditions is more likely to produce filling of all or most of the vessels penetrating the upper end of the femur, other conditions being equal. The following conditions should be satisfied to provide the best chance of obtaining a perfect injection of the arteries in the upper end of the femur.

- (1) The body should not be too cold.
- (2) The injecting cannula should be tied into the external iliac artery at groin level and the vessel should be separately occluded above it.
- (3) A tourniquet should be applied at about mid-thigh level if only the upper end of the femur is to be injected.
- (4) An injection apparatus which provides a free flow but with a variable pressure source should be used (Brookes, 1960).

(5) An adequate volume of injection medium must be injected under suitable pressure for an adequate time. The volume required varies with the nature of the medium used. For example, latex rubber 100 ml. injected at 10 lb. per square inch pressure for about 35 sec. will fill the extra-osseous vessels adequately to allow macroscopic dissection of small branches. The usual volume of Micropaque (Barium Sulphate Suspension 60% in water) required for an adult hip injection varies between 250 and 400 ml., injected at a source pressure of 6-7 lb. per square inch over 5-10 min., without interruption of the flow.

Having discussed briefly the problems of obtaining and injecting these specimens, one must turn to the difficulties of macroscopic dissection in this area and finally to the question of sectioning injected bones for the display and study of their contained

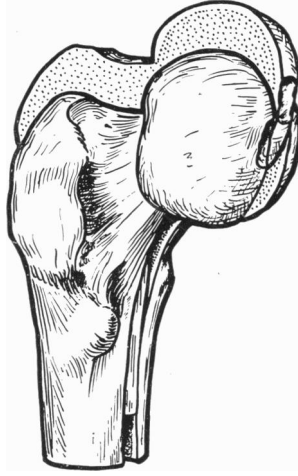


Text-fig. 1. A drawing of the posterior half of a coronal section of the upper end of the femur at birth, showing the site of removal of a section cut in the horizontal plane in the line of the femoral neck, together with a drawing representing the section thus obtained viewed from above. The outline of a posterior ascending cervical branch of the arterial corona of the femoral neck is shown terminating in the epiphysis of the head (Pl. 2. fig. 5).

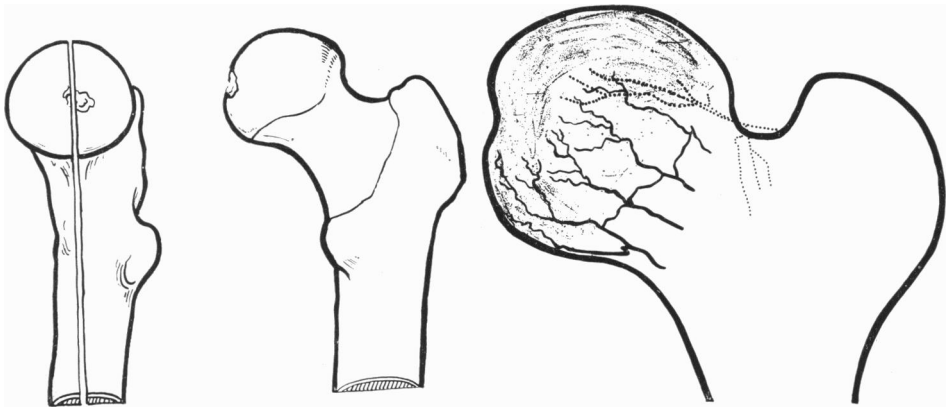
vessels. The paper of Howe *et al.* (1950), dealing with the gross anatomy of the arteries supplying the proximal portion of the femur and the acetabulum provides very detailed information. Yet even in this carefully prepared and beautifully illustrated work, the authors make no mention of their methods, or of the physical difficulties of dissecting fine vessels in relation to the dense thick fibres of the anterior capsule of the hip joint. They state that 'most investigators have found no arteries entering the femoral head or neck anteriorly'.

In Plate 1, figs. 1 and 2, in the present paper, a dissection of the arteries surrounding the neck of the femur is illustrated. In this specimen the arteries had been injected with latex rubber solution under high pressure (10-12 lb. per square inch) and yet, even then, many of the small vessels running up the femoral neck had been only partly filled with the medium. These were broken in the dense formalin fixed tissues early in the process of macroscopic dissection. In writing the description for Plate 1, fig. 2, one could say that a single vessel runs up the anterior aspect of the neck, this

would provide an accurate description of the photograph of the specimen, but the appendix, 'this was the only properly filled vessel to escape destruction at the time of the dissection', should be added.



Text-fig. 2. A drawing showing the site of origin of a coronal section from the upper end of the femur (Pl. 2, figs. 6, 7).



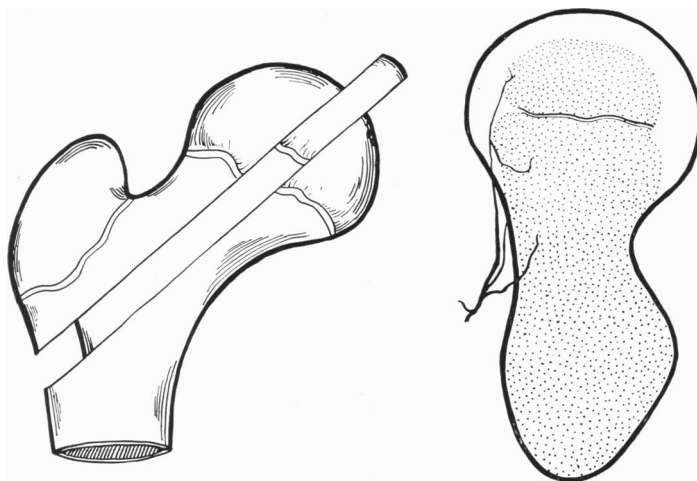
Text-fig. 3. A drawing of the upper end of an adult femur viewed from the medial aspect, showing the division of the bone into halves along the coronal plane, with a drawing of the posterior half of the specimen alongside, together with a detailed drawing of the posterior half of the femoral head with the outline of the articular cartilage shaded in. Outlines of the terminations of posterior ascending cervical arteries and their epiphyseal branches are marked in (Pl. 2, fig. 8).

The final barrier to the proper understanding of the intra-osseous distribution of these arteries lies in the appreciation of the importance of the planes of section of the specimens.

The Text-figs. 1-4, illustrate the sites from which sections have been cut in preparing the present material for analysis. Text-figure 1 shows a horizontal section

being removed from the posterior half of a femoral head at birth, with a view of the specimen thus obtained on the right side (see legend accompanying Pl. 2, fig. 5 for explanation). The remainder of these text figures are self explanatory.

The errors in previous papers appear to stem from the failure to appreciate fully the difficulties, limitations and importance of injection technique, and the necessity to examine the material in three planes, in coronal sections, in horizontal sections in the line of the neck, and in sagittal sections. The most striking information can be derived from the coronal plane sections and in the majority of papers on this subject, specimens are illustrated in this plane only. Many of the authors whose



Text-fig. 4. A drawing of the upper end of the femur during growth, showing the site of removal of a section cut in the horizontal plane in the line of the femoral neck, with a drawing of the specimen thus obtained alongside. An anterior ascending cervical branch of the arterial corona of the femoral neck has been drawn in. Note its division into epiphyseal and metaphyseal branches (Pl. 3, fig. 9).

works have been cited in this paper have concluded that vessels do not enter the front or back of the femoral head. These faces of the bone can be studied in horizontal sections in the line of the neck or by direct surface inspection, Lagrange & Dunoyer (1962). None of the relevant papers illustrates a specimen in horizontal section and this omission is the basis of an error in nomenclature which currently threatens to be perpetuated.

OBSERVATIONS

Origin of arteries supplying the upper end of the femur

The base of the femoral neck, at the level of the capsular attachments of the hip joint is surrounded by a ring of arteries. The posterior circumference of this arterial ring is usually formed by a large well-defined branch of the medial femoral circumflex artery, while anteriorly it is completed by branches of the lateral femoral circumflex artery (Pl. 1, figs. 1 and 2).

Branches arise from this ring at regular intervals. They penetrate the capsule of the hip joint along the inter-trochanteric line, and on the posterior aspect of the

femoral neck, pass beneath the orbicular fibres to run upwards beneath the synovial reflection towards the articular cartilage rim which demarcates the femoral head from its neck. From these branches arise the metaphyseal and epiphyseal arteries of the upper end of the femur.

The arteries of the round ligament of the femoral head usually spring from branches of the obturator artery, or from the medial femoral circumflex artery.

In the region of the trochanteric fossa the medial and lateral femoral circumflex arteries anastomose. At this site on the supero-lateral aspect of the femoral neck there is always a leash of branches extending along the neck (Pl. 1, fig. 1). This group of vessels is claimed by some authors to be the only source of the blood supply of the femoral epiphysis at certain stages of its growth (Trueta, 1957), but the findings in the material presented here do not support such a conclusion (Pl. 1, figs. 3, 4; Pl. 2, figs. 5, 8; Pl. 3, fig. 9).

Distribution of arteries within the femoral head and neck

At birth the upper end of the femur is almost entirely cartilaginous (Pl. 1, figs. 3, 4). As in the adult, the base of the femoral neck is surrounded by a ring of arteries, from which ascending branches pass up along the neck, around its circumference. They penetrate the cartilage of the head and each branch eventually terminates in a sinusoidal expansion.

The density of vessel distribution within the femoral head is such that a specimen must be sectioned into halves along the coronal plane of the neck in order to illustrate the vascular patterns clearly (Pl. 1, figs. 3, 4). When this has been done, it will be noted that there appear to be two distinct groups of vessels within the femoral head. These vessels have been described by Trueta (1957), as the lateral epiphyseal and the inferior metaphyseal groups respectively. However, if the specimens are examined in the horizontal plane it will be seen that the 'inferior metaphyseal group' (Trueta, 1957), springs from the same ring which gives origin to the lateral epiphyseal group (Pl. 2, fig. 5; Pl. 3, fig. 9).

The distribution of these arteries within the femoral head can be studied adequately in coronal and horizontal sections. In coronal sections each artery, on the anterior or posterior face of the femoral neck, is a single straight vessel with few side branches (Pl. 1, figs. 3, 4). The nature of its termination within the cartilage has been described above. When analysing this material, if reference is made to pictures of the whole femoral head divided into halves in the coronal plane, and to photographs of thin sections cut from the dividing face of one of the halves of the femoral head, then it can be concluded incorrectly that these vessels are metaphyseal arteries and not terminal epiphyseal branches of ascending cervical arteries. On the other hand in horizontal sections of the femoral neck, the ascending cervical branches from the arterial ring of the femoral neck can be seen lying on the surface of the femoral neck where they break up into metaphyseal and epiphyseal branches (Pl. 2, fig. 5; Pl. 3, fig. 9). In horizontal sections it will be seen that these arteries arch towards the centre of the femoral head, their many branches resembling the branches of a tree bending towards one side in a strong wind. This pattern of distribution is shown in Pl. 2, fig. 5, in which it will be noted that the tips of sinusoidal endings of the various branches of the main ascending cervical artery are aligned near the

mid-line of the specimen, the lowest sinusoid lying close to the ossified metaphysis, the highest of them lying near the arteries of the fovea centralis.

All the ascending cervical branches of the arterial ring of the femoral neck give rise to epiphyseal and metaphyseal branches (Pl. 2, figs. 6, 7, 8; Pl. 3, fig. 9).

From the supero-lateral aspect of the femoral neck metaphyseal branches descend vertically into the neck. This particular group of metaphyseal arteries is always well marked and it gives rise to branches which turn medially and horizontally and to others which turn laterally and horizontally. These various branches are then distributed towards the neck metaphysis and towards the growth line of the greater trochanter (Pl. 2, fig. 6).

In the epiphyses of long bones in man it has been observed that the gross vascular patterns, which are established at birth, remain unchanged throughout life (Crock, 1962). The upper end of the femur provides no exception to this rule (Pl. 1, fig. 4; Pl. 2, figs. 6, 7, 8). During growth the epiphyseal line of the upper end of the femur constitutes a barrier at all times between vessels within the metaphysis and within the epiphysis (Pl. 2, fig. 6). Although the scar of this epiphyseal line may remain after its closure, a free anastomosis of vessels develops across it at the end of the growth period (Pl. 2, fig. 7). It should be stressed, however, that there is always a free anastomosis between epiphyseal and metaphyseal arteries in the upper end of the femur upon its surface.

The analysis of the material presented in this paper indicates a need for revision of the nomenclature of the arterial supply of the upper end of the human femur. The following terminology is therefore suggested:

(1) *The arterial ring of the femoral neck*

The femoral circumflex arteries are the principal vessels forming the ring.

(2) *The ascending cervical branches of the arterial ring of the femoral neck*

These arteries give rise to metaphyseal and epiphyseal branches. All of these vessels and their branches may be described in further detail by using standard anatomical prefixes, such as: anterior, posterior, superior and inferior.

(3) *The arteries of the round ligament*

SUMMARY

1. A revision of the nomenclature of the arterial supply of the femoral neck and head is presented. This is based on the analysis of fifty specimens.

2. Details of injection techniques and of the preparation of specimens for analysis are discussed fully in relation to their bearing on the interpretation of the findings.

3. The importance of examining sections of the femoral head and neck in three planes is stressed.

4. Illustrations of sections cut in the horizontal plane along the line of the neck show that vessels currently described as 'inferior metaphyseal arteries' are in fact surface vessels running along the femoral neck.

5. The following nomenclature is suggested:

(a) The arterial ring of the femoral neck.

(b) Ascending cervical branches of the arterial ring of the femoral neck, each of which divides into metaphyseal and epiphyseal branches.

(c) Arteries of the round ligament.

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EXPLANATION OF PLATES

PLATE I

Fig. 1. A photograph of the posterior aspect of the upper end of the left femur. Male, aged 65 years. The arteries had been injected with red latex rubber solution. (Dissection by Dr S. Schofield.) The distribution of the medial femoral circumflex artery is shown, where it forms the posterior half of the arterial ring of the femoral neck. Some ascending cervical branches have been dissected and they can be seen springing from the ring on the postero inferior and superior aspects of the femoral neck. The first perforating artery can be seen in the lowest part of the dissection, with the upper nutrient artery of the femoral shaft arising from its inferior surface.

Fig. 2. A photograph of the anterior aspect of the left femur. (Same specimen as shown in fig. 1.) Branches of the lateral femoral circumflex artery are dissected forming the anterior portion of the arterial ring of the femoral neck. One of the anterior ascending cervical branches of this ring has been displayed. Note its relationship to the capsule of the hip joint.

Fig. 3. A photograph of the anterior half of the upper end of the right femur. Coronal section. Female child, aged 5 days. Arterial injection. Spalteholz cleared specimen. The upper shaft of the femur with its dense vascular injection is clearly demarcated from the femoral head and the greater trochanter. The distribution of arteries within the cartilaginous anlage is seen. The sinusoidal patterns of the terminations of the vessels, even at this low magnification, can be seen. $\times 3$ approx.

Fig. 4. A photograph of the posterior half of the upper end of the femur illustrated in fig. 3. The vessel seen at the centre of the femoral head terminates in the cartilage of the head just to the right of the vessels from the round ligament entering at the fovea capitis. This vessel is currently described as an 'inferior metaphyseal artery' (Trueta, 1957). A horizontal section cut from this specimen is shown in Pl. 2, fig. 5, in which it can be seen that the vessel in question lies on the

surface of the femoral neck. It is not therefore a metaphyseal artery, but is re-named in this paper as—a posterior ascending cervical branch of the arterial ring of the femoral neck. It is shown terminating in epiphyseal branches within the femoral head.

PLATE 2

Fig. 5. A photograph of a horizontal section cut from the specimen illustrated in Pl. 1, fig. 4. Spalteholz cleared specimen (see Text-fig. 1). $\times 3$ approx.

Fig. 6. A photograph of a coronal section (1 cm. thick) cut from the upper end of the left femur of a male child, aged 13 years (see Text-fig. 2.). Spalteholz cleared specimen. In the trochanteric fossa remnants of the arterial ring of the femoral neck can be seen. From these, the outline of superior ascending cervical branches can be seen passing upwards along the neck. Metaphyseal and epiphyseal branches can be seen entering the femoral neck and epiphysis of the head, respectively. Note also the anastomosis between the superior epiphyseal branches and the arteries of the round ligament. $\times \frac{1}{2}$ approx.

Fig. 7. A photograph of a coronal section (1.5 cm. thick) cut from the upper end of the right femur from a female, aged 59 years. Spalteholz cleared specimen. Note the pattern of distribution of major vessels within the head and neck of the femur. It corresponds precisely with the pattern already established at birth. The anastomosis between vessels across the site of the former growth plate, within the bone, is shown. $\times \frac{1}{3}$ approx.

Fig. 8. A detailed photograph of the posterior surface of the upper end of the femur from a male, aged 27 years (see Text-fig. 3). Spalteholz cleared specimen. The terminal portions of posterior ascending cervical branches of the arterial ring of the femoral head are high-lighted. Their fine epiphyseal branches penetrate the femoral head, to disappear out of focus at about its centre. The outlines of the superior ascending cervical arteries, with their metaphyseal and terminal epiphyseal branches are noted, out of focus in the depths of the specimen. $\times \frac{1}{3}$ approx.

PLATE 3

Fig. 9. A photograph of a horizontal section cut from the upper end of the femur of a male child aged $2\frac{1}{2}$ years (see Text-fig. 4). Spalteholz cleared specimen. On the anterior face of the femoral neck—lying on the left of the photograph, the course of a dissected anterior ascending cervical artery is shown. Note its metaphyseal and epiphyseal branches. On the posterior face of the femoral neck all superficial arteries and soft tissues have been removed. Only the partly filled stem of a terminal epiphyseal branch of the posterior ascending cervical artery can be seen traversing the cartilage of the head on the right side of the specimen. $\times 2$ approx.

