Venous drainage of the hind limb in the monkey
(Macaca fascicularis)

C. R. CHAPPLE AND B. A. WOOD
Department of Anatomy, The Middlesex Hospital Medical School,
Cleveland Street, London W1P 6DB

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INTRODUCTION

Most of our knowledge of the venous anatomy of the hind limb of primates is based on observations made on humans.

The veins of the legs in humans are usually divided into superficial and deep systems, with the plane of the deep fascia as the boundary (Dodd & Cockett, 1976). The two networks communicate not only where the two main superficial veins, the long and short saphenous, drain into the deep system, but also via numerous ‘perforating’ veins which pierce the deep fascia, either alone, or in company with an artery (Gundersen, 1966; Thomson, 1979). Direct observation and histological examination suggest that these perforating veins contain valves, whose cusps are orientated to allow blood flow from superficial to deep veins (Cotton, 1961; Thomson, 1979). On the other hand, evidence from dynamic studies suggests that blood flow is bidirectional, with the net flow being inwards (Bjordal, 1977).

There is little doubt that human leg vein anatomy has received this attention because of its importance in the aetiology and operative treatment of varicose vein disease. A search of the literature has failed to reveal any reference to varicose changes in the hind limb of non-human primates, and indeed it is often alleged that varicose veins are one of the results of the shift during human evolution from a quadrupedal to a bipedal gait and posture. In order to examine critically any hypothesis which seeks to associate human varicose vein disease with posture, or with a particular pattern of vein distribution, we considered it prudent to review and examine venous drainage patterns in non-human primates.

There are few reliable descriptions of the hind limb veins of pongids. Raven (1950), writing about a single dissection of Gorilla, and Sperino (1897), who cited the work of Gratiolet on Pan, both reported that these taxa have a short saphenous vein of the human type, but they do not have an autonomous long saphenous vein of the human type; instead it is replaced by venae comitantes accompanying an arteria saphena. The artery and venae comitantes remain beneath the deep fascia in both taxa until just proximal to the knee. Studies of hind limb venous anatomy of the Catarrhini (Old World monkeys) differ in their conclusions. Lineback (1933), Williams (1954) and Hill (1971) described both short and long saphenous veins of the human type in Macaca, whereas the studies of Zaluska & Urbanowicz (1969) and Szebenyi (1969) on Macaca, and Ananthanarayana Ayer (1948) reporting his findings on Semnopithecus, all stressed the lack of a human type long saphenous vein. Swindler & Wood (1973) reported on the results of twenty six specimens of Papio and six of Pan. They stated that Pan possesses both saphenous veins, as in
the human, but that in addition there are venae comitantes accompanying the saphenous artery. In *Papio* the long saphenous vein is apparently ‘normally absent’, the usual drainage pattern on the medial side being venae comitantes accompanying the saphenous artery; they deny the presence of an autonomous short saphenous vein. Only a single reference could be found to hind limb venous drainage pattern in the Platyrhini (New World monkeys); in this report Beattie (1927) noted that the arrangement corresponded to the ‘general primate pattern’. Williams (1954) and Góscicka (1967) are the only authors to have made specific comments on the presence or absence of valves in non-human primate veins; Franklin (1937) discussed the distribution of valves in the veins of animals, but made no special mention of primates.

In this study, detailed observations were made on the venous drainage pattern in a series of specimens of a generalized quadrupedal Catarrhine monkey, *Macaca fascicularis*, the ‘crab-eating’ macaque, which lives among the mangrove swamps and tidal creeks of coastal regions. It is one of the smallest species of macaque, with an average body weight of 3 kg. Its predominant mode of locomotion is quadrupedal walking and climbing (Napier & Napier, 1967).

Detailed observations on *Macaca* were supplemented by dissections of one hind limb of an immature chimpanzee, *Pan troglodytes*, and both hind limbs of a mature male gorilla, *Gorilla gorilla*.

**MATERIALS AND METHODS**

The hind limbs of twenty adult *Macaca fascicularis* were used in this study; detailed dissections were carried out on twelve limbs. The carcasses were kindly made available by the Wellcome Research Laboratories. Fixation was carried out at the Laboratories by whole body intra-arterial perfusion with 10% formol acetate. The lower part of the trunk and the hind limbs were separated from the rest of the carcass, and then stored in 10% formol saline.

Naked eye dissection, supplemented where necessary with a ×7 dissecting microscope, of the superficial veins and their connections was performed on all the limbs, and in five limbs, the dissection was carried through to include the deep veins. In two limbs, the arteria saphena, with its venae comitantes, and the short saphenous vein were both dissected along their whole length and removed, cut into 15 mm segments and examined histologically. Each segment was dehydrated in a series of alcohols, cleared and then embedded in paraffin wax. Each blocked segment was cut into 15 μm thick serial sections. One in five sections was mounted and stained using Verhoeff and Van Gieson’s staining method. All sections were examined under the light microscope noting the presence of tributaries and the location of valves. In six limbs the whole length of a constant ankle perforator was removed for histological study. In two limbs the muscles of the flexor compartment below the knee were removed en bloc, along with the associated vessels. The muscle masses were cut into 15 mm thick transverse slices, and were examined histologically. The sections obtained were studied for any evidence of the intramuscular venous sinuses of the type described in humans by Cotton & Clark (1965).
RESULTS

The general pattern of distribution of the main venous channels, based on the results of all the dissections, is given in diagrammatic form in Figure 1. The central thin solid line above the knee joint represents the plane of the medial intermuscular septum and below the joint it corresponds to the interosseous membrane. Deep fasciae covering the anterior and posterior aspects of the limb are depicted as dotted lines to the left and right of the diagram. Thick solid lines correspond to venae comitantes and the bold dashed lines to autonomus veins. The results of the superficial dissections of each of the twelve hind limbs, with the location of the main superficial and perforating veins, are shown in diagrammatic form in Figures 2 and 3. A description of the main superficial, deep and connecting venous channels is presented below followed by the results of the histological studies.

Dissection

Superficial veins

Drainage of the posterolateral aspect of the leg is by an autonomous vein which corresponds to the human short saphenous vein. The vein arises from the lateral side of the dorsum of the foot and passes up the posterior surface of the leg, receiving tributaries from the sole of the foot. It also receives a fairly constant tributary on its medial side which passes proximal to the medial malleolus and connects the short saphenous vein with superficial veins on the medial aspect of the leg. The short saphenous vein usually terminates by passing through the deep fascia and joining with the popliteal vessels, but in two cases it entered the venae comitantes accompanying the arterial supply to gastrocnemius.

The main drainage of the anteromedial aspect of the leg is by venae comitantes accompanying branches of the arteria saphena. The arteria saphena arises from the femoral artery in the lower part of the thigh and passes through the deep fascia just distal to the knee joint between the insertions of sartorius and gracilis (Fig. 4a). The main trunk of the arteria saphena continues distally in the superficial fascia and usually ends by penetrating the deep fascia at the base of the first metatarsal space; small veins connect these venae comitantes with the short saphenous vein. In 11 of the 12 detailed dissections a branch of the artery is given off some 4 to 7 cm above the medial malleolus. Running distally it re-enters the deep fascia 2 to 4 cm above the medial malleolus (Fig. 4a, b). In eight of the 12 specimens an additional branch of the artery is given off posteriorly at the same level, or a little higher, as the anteriorly directed branch. In two cases (Figs. 2e, 3d) this vessel (Fig. 4b), with its venae comitantes, was seen to pass through the deep fascia; in the remaining six cases the vessel became too small to trace by dissection. Significant anomalies of the distribution of the arteria saphena were noted in two animals. In one case (Fig. 3c) the main branch re-entered the deep fascia just proximal to the level of the medial malleolus to communicate with the deep branch of the artery. In the hind limb of another animal (Fig. 2d), the anterior branch which usually re-enters the deep fascia was absent, its place being taken by the passage of the main branch through the deep fascia over the anterior aspect of the ankle joint. In both these anomalous cases the superficial venous drainage of the dorsum of the foot was mainly into the short saphenous vein.
Fig. 1. Distribution of main venous channels in hind limb of *Macaca fascicularis*. Horizontal interrupted lines indicate planes of knee and ankle joints. Heavy dashed lines represent autonomous veins and the solid lines, venae comitantes. Diagram not to scale: (a) femoral vessels; (b) venae comitantes of main trunk of arteria saphena; (c) popliteal vessels; (d) short saphenous veins (s.s.v.); (e) medial tributary of s.s.v.; (f) lateral tributary of s.s.v.; (g) main continuation of venae comitantes of arteria saphena; (h) venae comitantes of posterior branch of arteria saphena; (i) venae comitantes of anterior or deep branch of arteria saphena; (j) vessels accompanying superficial peroneal nerve; (k) homologue of peroneal vessels; (l) posterior tibial vessels; (m) muscular vessels; (n) dorsalis pedis vessels. (A) Constant perforator connecting lateral tributary of short saphenous vein (f) with venae comitantes of the deep branch of the arteria saphena. (B) Constant perforators connecting short saphenous vein with venae comitantes of the posterior tibial artery.
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Deep veins

The majority of the deep venous channels are in the form of venae comitantes accompanying arteries. The arteries generally correspond to the pattern of distribution in humans except in two places, the thigh and the anterior compartment of the lower leg. In none of the dissections of the thigh could a profunda femoris artery be demonstrated; its place was taken by a series of muscular branches. In the lower part of the leg there was no evidence of an anterior tibial artery arising as a branch of the popliteal vessels, or of a peroneal artery of the relative size seen in humans. The place of the anterior tibial artery was taken in each case by the deep
Fig. 3. Diagrammatic representation of the main superficial and perforating veins of six right hind limbs of *Macaca fascicularis*. Horizontal interrupted lines indicate planes of knee and ankle joints. Venae comitantes are represented by double lines and autonomous veins by single lines. Passage of perforating veins through the deep fascia is indicated by circles. Labelling as in caption to Fig. 1. Diagram not to scale.

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Fig. 4. (a) Superficial dissection of the medial aspect of the left hind limb of *Macaca fascicularis*. The edge of the reflected superficial fascia is shown to the left of the specimen. (b) Close up of the same specimen with anterior (i) and posterior (h) branches of the arteria saphena dissected out. Labelling as in the caption to Fig. 1 with the addition of (o) saphenous nerve. Arrows indicate sites where arteries and venae comitantes pass through the deep fascia.

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Fig. 5. Superficial dissection of the lateral aspect of the ankle of the right hind limb of *Macaca fascicularis*. Arrowheads mark the edge of the deep fascia. Single arrow indicates the passage through the deep fascia of a constant perforator connecting the lateral tributary of the short saphenous vein (f) with the venae comitantes of the deep branch of the arteria saphena. Labelling as in the caption to Fig. 4 with the addition of LM, lateral malleolus; D, dorsum of foot.
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4(a)

4(b)

5

11-2
branch of the arteria saphena which continued onto the dorsum of the foot as the dorsalis pedis artery. This vessel communicates with small, deeply situated, arteries, one of which follows a course corresponding to that taken by the relatively much larger human peroneal artery. In several cases, a small artery passed from the anastomosis between the diminutive peroneal artery and the anterior tibial homologue, through the interosseous septum, to communicate with the posterior tibial artery. The arterial supply, and corresponding venous drainage to the soleus and gastrocnemius muscles are particularly rich. Arteries, along with their accompanying venae comitantes, arise at the lower border of the popliteal fossa and pass into the gastrocnemius muscle. Initially, these vessels run in the intermuscular septa, but by the middle third of the leg they pass into the substance of the gastrocnemius and soleus muscles. In the lower two thirds of the leg an additional supply to soleus comes from a vascular arcade formed from the posterior tibial vessels; these arteries are also accompanied by venae comitantes.

**Connecting and perforating veins**

The largest venous channels which connect the superficial and deep venous systems are the venae comitantes accompanying the branches of the arteria saphena, the main one usually re-entering the deep fascia 4-7 cm proximal to the medial malleolus. The majority of the remaining connections are perforating veins associated with the short saphenous system. They are located in three sites:

1. A large constant vein (marked ‘A’ in Figs. 1, 2, 3) passes between the lateral tributary of the short saphenous vein and the venae comitantes of the deep branch of the arteria saphena. It perforates the deep fascia over the anterior aspect of the ankle joint (Fig. 5).

2. Two or three veins (marked ‘B’ in Figs. 1, 2, 3) usually connect the medial or lateral tributary of the short saphenous vein with venae comitantes accompanying the posterior tibial artery.

3. Small veins (marked ‘C’ in Figs. 2, 3) pass between the lateral tributary of the short saphenous vein and veins in the gastrocnemius and soleus muscles.

In addition to these sites, small and inconstant perforating veins are found along the margins of the sartorius muscle, as venae comitantes of an artery accompanying the superficial peroneal nerve and making direct connections with the venae comitantes of superficial branches of the arteria saphena.

**Histological studies**

*Venae comitantes of the arteria saphena*

The location of valves, cross connections and tributaries of the venae comitantes of two animals is shown in Figure 6a, b. In each case, the vertically running vessel is the main branch of the arteria saphena from its emergence between sartorius and gracilis to where it passes through the deep fascia at the base of the first metatarsal space.

There seems to be no relationship between the position of the valves and the location of cross connections between the venous channels. Direct comparison of the two specimens which were studied in detail shows that there is considerable variation in the number and location of valves; thirteen in the main channels in one specimen (Fig. 6a) compared with four in the other (Fig. 6b).
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Fig. 6 (a) and (b). Diagrams showing location of valves in the venae comitantes of the arteria saphena and its branches. (c) and (d). Diagrams showing location of valves in the short saphenous vein and its main tributaries. Horizontal interrupted line indicates plane of deep fascia. Labelling for (a) to (d) as in caption to Fig. 1. Diagram not to scale.

Short saphenous vein

The distribution of valves in two specimens of the short saphenous vein and its tributaries is shown in diagrammatic form in Fig. 6 c, d. The plane of the deep fascia is indicated by the horizontal broken line. In one specimen (Fig. 6 c), the valves are concentrated in this part of the vein, whereas in the other, the valves are more evenly distributed. The line of attachment of the valve cusps was in most cases parallel to the skin surface.

In both the venae comitantes and the short saphenous system the valves are orientated so that they allow the blood to flow centripetally. Valves in tributaries are preferentially located near the ostium and are orientated so as to allow flow from the tributaries into the main venous channels.
Constant ankle perforator

The large and constant perforating vein which connects the lateral tributary of the short saphenous vein with the venae comitantes of the artery saphena was examined histologically for the presence of tributaries and valves. The results are presented in diagrammatic form in Figure 7. In all the specimens there are only three direct channels connecting superficial and deep veins which are unguarded by valves, and nearly all the small tributaries of the perforating veins have valves near their opening into the main vessel. All valves are orientated to allow blood to flow from superficial to deep veins.

Intramuscular veins

The flexor muscles of two limbs were sectioned to search for intramuscular venous sinuses of the human type. Relatively large, thin walled, venous sinuses were found in the plane of the intrafascicular fibrous septa in both soleus and gastrocnemius muscles. They were most marked midway between knee and ankle joints at the point of the maximum cross sectional area of the muscles, and appeared to communicate with the venae comitantes of the arteries supplying these muscles.
DISCUSSION

These findings in a series of dissections of Macaca fascicularis confirm the studies of Anathanarayana Ayer (1948), Zaluska & Urbanowicz (1969) and Szébenyi (1969) in which they demonstrated that a long saphenous vein of the human type is absent in the monkey. The only hint of a vessel in the 12 specimens of Macaca which may be homologous with the thigh segment of the long saphenous veins in humans was in a single leg. In this specimen a vein connecting with the femoral vein passed through the deep fascia over the distal part of the sartorius, ran superficially for 5 cm, and then re-entered the deep fascia in the proximal part of the thigh to rejoin the femoral vein. The form of the short saphenous vein in this study corresponds to earlier brief descriptions in the literature; there was remarkably little variation and it is noteworthy that there was no evidence of any drainage into the sciatic or gluteal veins, a pattern which was considered primitive and which is a rare anomaly in humans (Kosinski, 1926).

The distribution of the main branches of the arteria saphena noted in this study has been recorded before by Manners Smith (1912), Lineback (1933) and Szébenyi (1969), but none of these authors recorded the presence of the posterior branch which occurred in eight of the twelve dissections in this study although Swindler & Wood (1973) noted a posterior branch in Papio. An arteria saphena (called arteria saphena magna) has been noted in adult humans (Manners Smith, 1912; Senior, 1919; Aasar, 1939), and in these cases, as in Macaca, it can act as the major feed for the dorsalis pedis, in which case the anterior tibial artery is small or absent. The anastomosis in the lower part of the anterior compartment of the leg between the deep branch of the arteria saphena and smaller deep vessels may provide the means by which the vascular pattern such as is found in the monkey could be modified during evolution into the human pattern.

The careful survey of the venous pathways connecting the superficial and deep system made in this study is the first in a non-human primate. In the human, perforating veins have been classified into 'direct', when they pass from a superficial vein straight into a main deep vein or venae comitantes, and 'indirect', when they connect the subcutaneous venous plexus with muscular veins. This classification has been utilized in many studies (Sherman, 1949; Gundersen, 1966; Dodd & Cockett, 1976; Thomson, 1979).

A comparison of the distribution of perforating veins in humans and Macaca suggests that many vessels may have homologues in both forms. In the macaque, the major perforating veins are associated with the short saphenous vein. The direct perforator, ('A' in Fig. 1), connecting the lateral tributary of the short saphenous vein with the venae comitantes of the deep branch of the arteria saphena occupies the same position which in humans is occupied by the 'premalleolar vein' noted by Green, Griffiths & Lavy (1958), and the perforator number 7 of Kuster, Lofgren & Hollinshead (1968). The group of direct perforating veins which links the short saphenous vein with the posterior tibial venae comitantes, ('B' in Fig. 1), in Macaca is in the same position as veins described as the 'internal ankle perforators' (Linton, 1938; Sherman, 1949, p. 221; Cockett, 1955) or 'medial ankle perforators' (Thomson, 1979). In the human these vessels are described as usually connecting with the posterior arch complex, but in a few cases they are reported as connecting with a tributary of the short saphenous vein (Thomson, 1979). The group of indirect perforating veins on the posterolateral aspect of the leg, ('C' in Fig. 2), in Macaca
corresponds in humans to a group of perforators identified by Sherman (1949, p. 223) and by Thomson (1979) as ‘calf perforators’. Perforating veins noted by Green et al. (1958) on the anterolateral surface of the lower leg in humans may correspond to the veins accompanying the superficial peroneal nerve in *Macaca*, and occasional perforating veins noted in the thigh in *Macaca* are in the position of the ‘Hunterian’ perforators in humans (Sherman, 1944; Thomson, 1979). Several workers have noted that perforating veins are usually accompanied by arteries and although the monkey does not have a long saphenous vein, perforating veins in humans may be the homologues of sites where the arteria saphena passes through the deep fascia in lower primates. Haeger (1977) has claimed that there are at least 90 connections between the deep and superficial systems in humans. While we have been unable to demonstrate that number in *Macaca* hind limbs, it is clear that perforating veins are well developed in this representative of the non-human primates.

The results of this investigation partially corroborate the findings of Williams (1954) who was the first to make a detailed search for valves in the hind limb veins of non-human primates. Williams claimed that valves were placed at 6 cm intervals; the short saphenous veins of *Macaca fascicularis* are about 12 cm long, so the prediction would be that two valves would be found. In the two short saphenous systems examined in this study, however, ten valves were found in one specimen, and five in another. The different results probably reflect the greater accuracy of the serial sectioning technique.

The numbers of valves in these *Macaca* short saphenous veins correspond to valve counts in the human short saphenous vein where the average number is seven or eight per vein (Kosinski, 1926). The number of valves in the venae comitantes of the arteria saphena was nine and six in one specimen, and one and four in the other. These are significant differences in total number, but within the range noted by Cotton (1961) when counting the valves in human long saphenous veins. In a series of 75 cadaver veins, Cotton found that the average number of valves was seven, with a range from one to thirteen. The position of valves in the main vessel seemed to bear no particular relation to the entrance of tributaries, though such a relationship was noted in the human by Bardeleben (1880) and Ludbrook (1962).

The variations in the number of tributaries, and in the number and location of valves in the constant perforating vein on the lateral aspect of the ankle are illustrated in Figure 7. In a study of the valves in human perforating veins, Kuster et al. (1968) demonstrated that perforators in the distal part of the leg and foot showed considerable variation in the number and direction of the valves. Whereas all the valves in this vein in *Macaca* are orientated to allow flow from superficial to deep, Kuster et al. found that in the homologous ‘premalleolar’ vein of the human, valves occurred in only two of seven veins examined. The valves that do occur in this perforating vein in *Macaca* are located near to the deep veins, a point emphasized by Pirner (1956) in his study on human perforators.

Full details of the histology of veins in *Macaca* will be presented separately but it is worth recording that several valves showed folding of the endothelium at the valve agger, of the type noted by Cotton (1957). The venous sinuses which have been demonstrated within the soleus and gastrocnemius muscles resemble those described in humans by Cotton & Clark (1965) and Abramova & Chilaya (1967). They contain flaps of endothelial tissue, but it is difficult to demonstrate that they act as effective valves.

One of the objectives of this study was to determine whether any features of the
venous network of the human leg could be claimed as an unique human specialisation, and not merely a common feature shared with non-human primates. It is tempting to conclude from the evidence of *Macaca* that a superficial venous channel running the full length of the limb on the medial aspect is a derived feature of humans, but other evidence suggests that this is not so. A number of mammals, e.g. cat, dog, horse and ox, possess a single venous channel, not venae comitantes, which accompanies the arteria saphena as it emerges into the superficial tissues proximally in the thigh (Grossman, 1938), but an autonomous medial superficial venous channel is less common. The results of the superficial dissections of an immature chimpanzee (*Pan troglodytes*) and an adult gorilla (*Gorilla gorilla*) provide a link between the monkey and human conditions. In *Pan*, venae comitantes accompany the arteria saphena which passes through the deep fascia between the insertions of sartorius and gracilis, and, as in *Macaca*, it has a deep branch which feeds the dorsalis pedis on the dorsum of the foot. No superficial venous channel was found on the medial aspect of the thigh; these findings agree with observations made by Gratiolet and cited by Sperino (1897), but contrast with those of Swindler & Wood (1973) who report the presence of both long and short saphenous veins in *Pan*.

The *Gorilla* hind limb is perhaps the most interesting of all for it shows a combination of features which have been noted in human and monkey specimens. At the junction of the distal and middle thirds of the thigh, the arteria saphena pierces the deep fascia accompanied by venae comitantes. The artery continues distally and, as in *Macaca* and *Pan*, has a deep branch which feeds the dorsalis pedis artery. A separate vessel, and autonomous vein, runs up onto the medial aspect of the thigh and just after it is joined by two tributaries it passes through a defect in the deep fascia to enter the femoral vein. This defect corresponds to the position of the saphenous opening in humans and careful dissection of the saphenofemoral junction in *Gorilla* showed that the entrance of the superficial vein is guarded by a valve. The distribution of perforating veins in *Gorilla* resembles that in *Macaca*. More specimens need to be dissected before these interesting differences between *Pan* and *Gorilla* can be confirmed. None the less, the evidence presently available suggests that modern humans and a range of non-human primates have many features of the venous drainage of the hind limb in common, and it casts doubt on suggestions that structures such as perforating veins, and venous sinuses in the soleus and gastrocnemius muscles, are peculiar to modern humans and arose as functional adaptations to the upright posture.

**SUMMARY**

Detailed dissection and histological examination of the hind limb veins in twelve adult limbs of *Macaca fascicularis* confirm that the main superficial venous channels are a short saphenous vein and the venae comitantes of branches of the arteria saphena. Three sets of constant perforating veins were located, and the number and location of valves in these and the main superficial venous channels were noted. Venous sinuses were found in gastrocnemius and soleus muscles. Dissections of the superficial veins were made in single specimens of *Pan* and *Gorilla*, and in the latter a long saphenous vein of the human type was found. Possible homologues between the non-human and human venous systems are proposed.
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