

# The venous drainage of nerves; anatomical study and clinical implications

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**Summary**—The venous drainage of the peripheral nerves was studied in the upper and lower limbs of two human fresh cadaver subjects after total body perfusion with a radio-opaque lead oxide mixture. Four patterns of extraneural drainage were identified in which the *venae nervosa* drained: directly to the *venae comitantes* of the neurovascular bundle; indirectly via nearby veins, derived usually from muscles; to the periarterial venous plexus; or, in the case of the cutaneous nerves, to the perivenous plexus.

The various patterns of the drainage along the length of the radial, median, ulnar, sciatic, anterior and posterior tibial nerves were identified. A rich longitudinal plexus of veins exists on and within the nerve which appears to be mainly free of valves. The large *venae nervosa* usually contained valves, whereas the tiny veins draining the nerves were valveless or exhibited a sentinel valve at their entry point into a larger venous channel.

The clinical implications of these results are discussed in relation to the mobilisation of nerves, the use of island nerve flaps, possible donor sites for free arteriolised neurovenous flaps and the compressive nerve syndromes.

It is now a century since Quénu and Lejars (1890) provided detailed and accurate observations on the anatomy of the blood supply of the peripheral nerves. They made the important observation that the vascular anastomoses on and within a nerve are so profound that they provide the basis for the development of a collateral circulation to the entire limb when a major arterial channel to the part has been interrupted. The venous anatomy of the nerves was examined as well, but it was not displayed radiologically nor were the site and orientation of the valves located. Indeed very little work has been done since that date on this important side of the vascular network. The pathogenesis of nerve degeneration and regeneration was the subject of much research. However the activity and contortions of the axons, their myelin sheath and the Schwann cells received so much attention that the information regarding their vascular lifelines languished on dusty bookshelves.

The two Great Wars reversed the situation. The profusion of nerve injuries that flowed from the battle front demanded a reappraisal of the blood supply to these structures and its importance in nerve repair. An aspiring surgeon, later to become a world authority on nerves and nerve injuries, rose

to champion the cause. Dr Sydney Sunderland, later to be knighted for his contributions, performed an extensive analysis of the vascularity of the peripheral nerves in adult specimens (Sunderland, 1945a, b, c). He concluded that “peripheral nerves are abundantly vascularised throughout their length by a succession of vessels which, by their repeated division and anastomosis within the nerve, form an unbroken intra neural vascular net.”

Nerve defects were common and many futile attempts had been made to bridge these defects with nerve substitutes. The importance of the blood supply in the process of nerve repair became obvious but with it came a dilemma which even today is the subject of some controversy. The choice lay between free non-vascularised nerve grafts and extensive mobilisation of the nerve ends to achieve coaptation. Both procedures address the problems of vascularity. One relies on a rapid revascularisation from the graft bed, the other involves the risks of devascularisation of the nerve ends. To solve this problem, the pedicled nerve flap was introduced by St Claire Strange in 1950 but its application was severely restricted by the limited availability of suitable donor nerves in the area. By now, information regarding the arterial supply of the nerves

was extensive but details of the venous drainage were still scanty.

In 1976 Taylor and Ham extended the concept of living nerve flaps to distant donor sites when they introduced the free vascularised nerve flap. Once again the blood supply of the peripheral nerves was re-evaluated and classified according to their potential for microvascular transfer (Fig. 1). The venous drainage of the nerves was studied by anatomical dissection and in animal experiments. This led to the arteriolised neurovenous flap (Townsend and Taylor, 1984) in an attempt to expand the available donor sites for free living nerve transfer.

Recently we have performed an extensive investigation of the venous network of the entire body (Taylor *et al.*, 1990). The veins were displayed radiologically and the site and orientation of the

valves were ascertained by dissection. An important revelation was the large number of valveless (oscillating) veins which link adjacent valved territories to form a continuous venous network between and within tissues. However, the venous drainage of the nerves was not studied in detail. This paper therefore focuses on this important void in our knowledge.

The consequences of an inadequate venous drainage on a skin or muscle flap, with the sequelae of oedema, infarction and ultimate demise, are common knowledge. Surely similar problems may be hidden beneath the skin when the venous drainage of a peripheral nerve is compromised. This study is designed to provide anatomical information which may help determine the safe length that different nerves can be mobilised in various regions. It may provide other donor sites

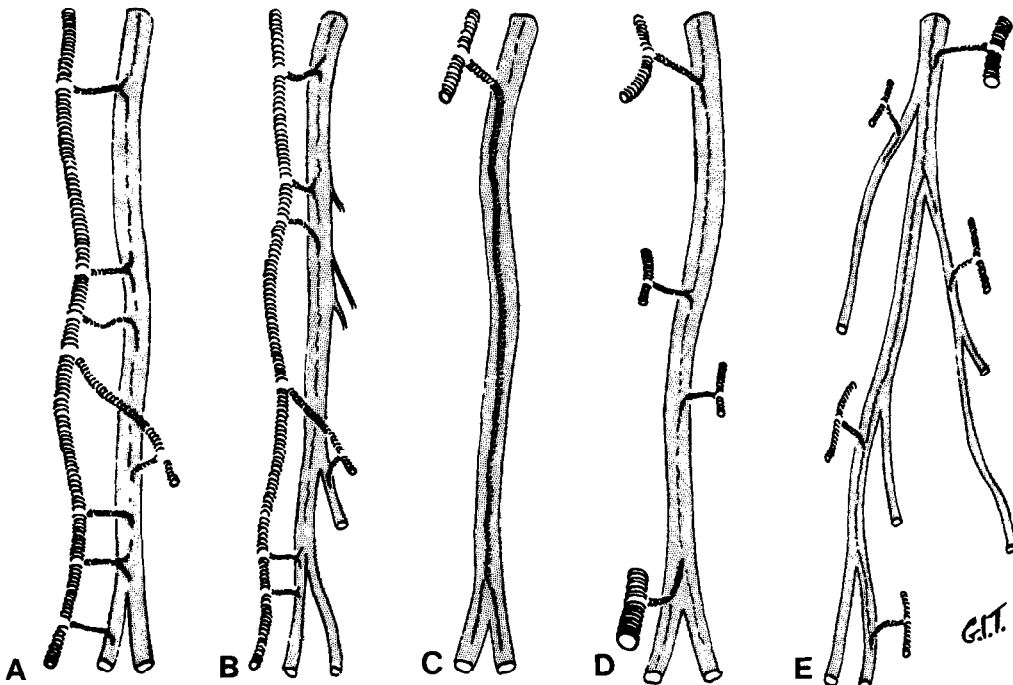


Fig. 1

**Figure 1**—Classification of the blood supply of peripheral nerves with special reference to their suitability for transfer. In type A an unbranched nerve is paralleled by a single artery which provides a segmental blood supply, *e.g.* the ulnar and superficial radial neurovascular bundles in the forearm. Type B is similar but the nerve is branched, *e.g.* the intercostal nerve and its accompanying artery. In type C a large nutrient artery (*e.g.* the median) courses for a long distance on the surface of an unbranched nerve. In type D the nerve is again unbranched but the blood supply is derived from multiple arteries, *e.g.* the sciatic nerve in the thigh, and in type E the nerve is branched and its blood supply is fragmented.

for vascularised nerve transfer and perhaps throw some light on the pathogenesis of such problems as the compressive nerve syndromes and Volkmann's ischaemia in the limbs.

### Materials and methods

The study was conducted in two middle-aged recently deceased female subjects and was confined to the limbs. Nine pairs of nerves were examined in the superficial and deep tissues, making a total of 18 studies. They were selected to encompass the various patterns of venous drainage and because of their clinical importance. They included the ulnar, radial, median, lateral and medial cutaneous nerves of the forearm in the upper limb and the sciatic, posterior tibial, anterior tibial and sural nerves in the lower extremity.

Both female subjects were injected with a lead oxide-gelatin mixture, modified from Salmon's (1936) original perfusate (Crosthwaite *et al.*, 1987). The venous injection technique is described elsewhere in detail (Taylor *et al.*, 1990) and involves the use of sequential tourniquets as described by Last and Tompsett (1962). The tourniquets have a back pressure effect which forces the mixture into the small venous radicles via collateral vessels and those veins which are devoid of valves.

The integument was detached and radiographed. The cutaneous nerves were removed from the subcutaneous tissues together with their large accompanying veins, the arteries and the surrounding connective tissue. Next, the neurovascular systems were dissected from the deep tissues. In the upper limb they were removed in continuity from the axilla to the palm of the hand and in the lower limb the dissection extended from the buttock to the toes. In each case the surrounding connective tissue sheath was included together with converging venous pedicles from the adjacent muscles and septa, where appropriate.

These long specimens were photographed and radiographed (Fig. 2). A meticulous dissection of the venae comitantes and their tributaries was performed with the microscope at magnifications from 6 to 40 times. The site and orientation of the valves, the entry of the venae nervora into the draining veins and the various patterns of drainage of the nerves were ascertained by dissection and photographed.

In some cases the venae nervora were well displayed with the lead oxide mixture, in other instances the filling was scanty. However, between

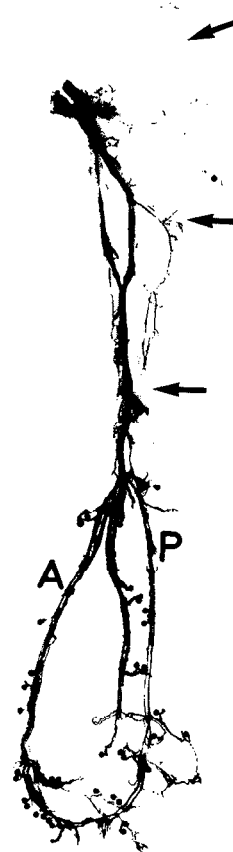


Fig. 2

**Figure 2** – Radiograph of the neurovenous system of the lower extremity injected with lead oxide. Lead beads locate the site of entry of the cutaneous perforating veins. Note the continuous arcade formed between the anterior (A) and posterior (P) tibial venae comitantes and the arcades draining the sciatic nerve (arrows).

the two cadavers sufficient information was obtained to enable us to classify the various patterns of venous drainage of the nerves and to show how these patterns varied along the length of each.

### Results

Locating the site and orientation of the valves in the accompanying superficial veins and the deep venae comitantes was a relatively easy task. The various patterns of drainage of the venae nervora were also well displayed. However, locating the valves in the small venous radicles of 0.1 mm or less was very difficult, even when filled with the

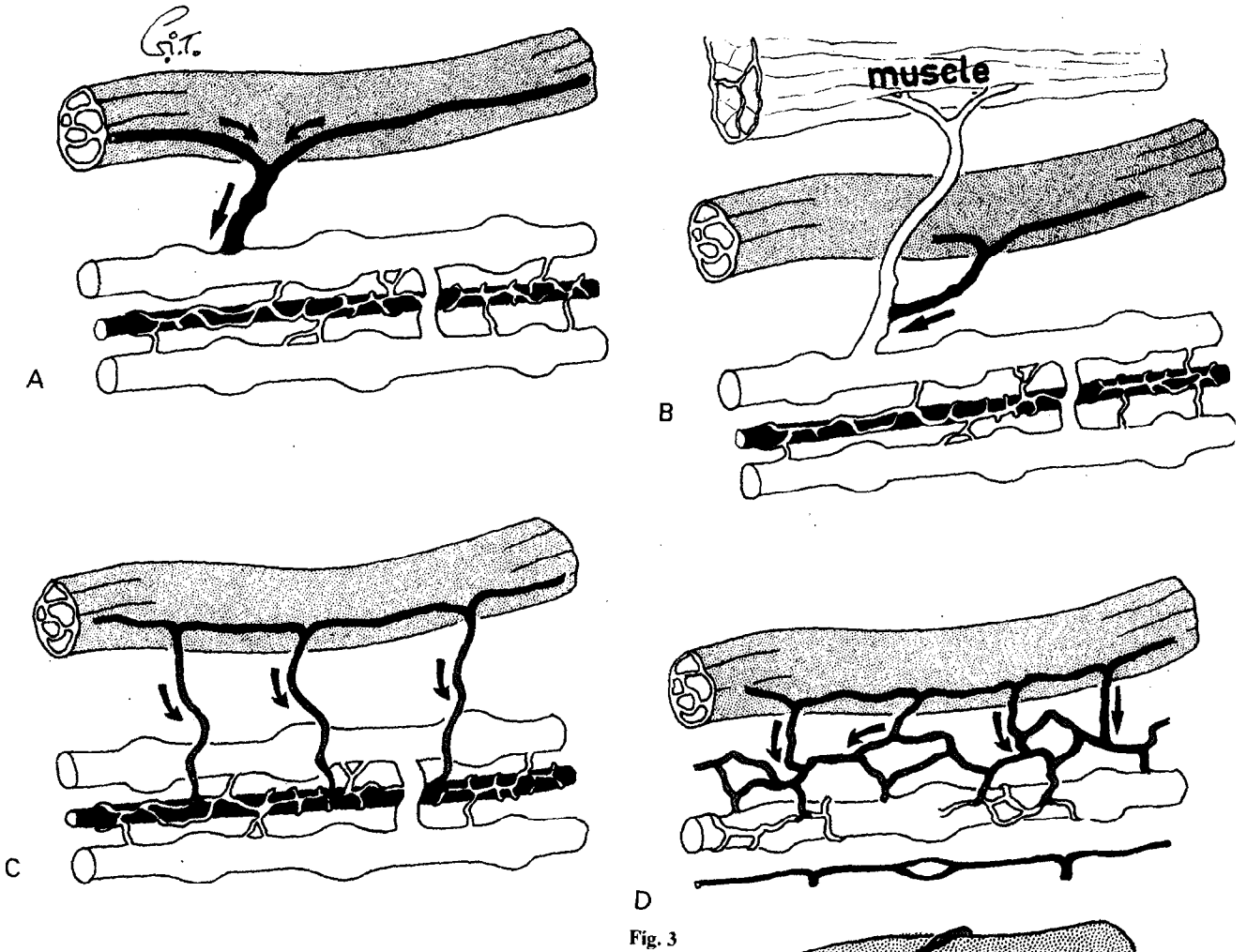


Fig. 3

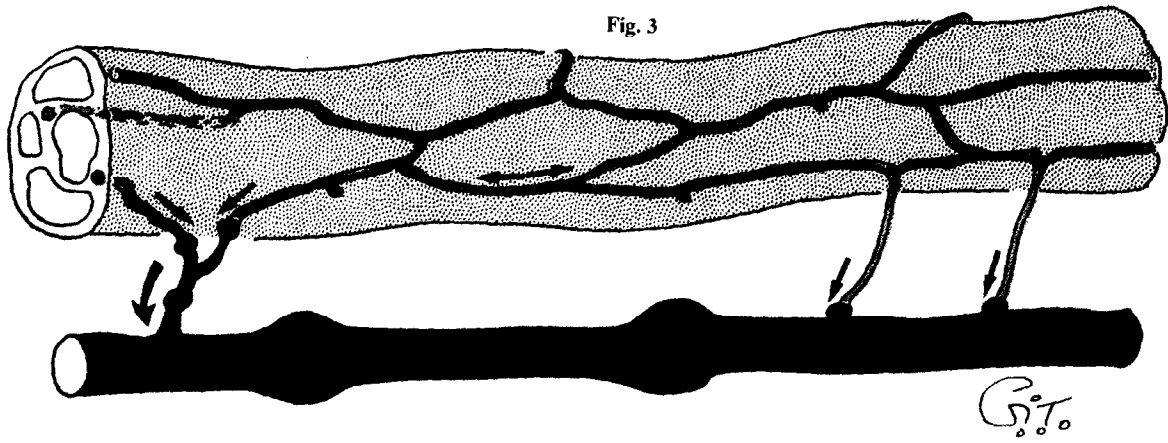


Fig. 4

Figure 3—Diagram of the patterns of venous drainage of a nerve. In type A the vena nervorum drains directly to the vena comitans of the artery; in B it drains indirectly via a muscular vein; in C the venous drainage of the nerve is to the periarterial venous plexus and in D the nerve drains to the perivenous plexus. Figure 4—Diagram of the avalvular (oscillating) veins on and within the nerve (coloured yellow) which link the venae nervora. Valved veins are coloured blue and two sentinel valves are illustrated.

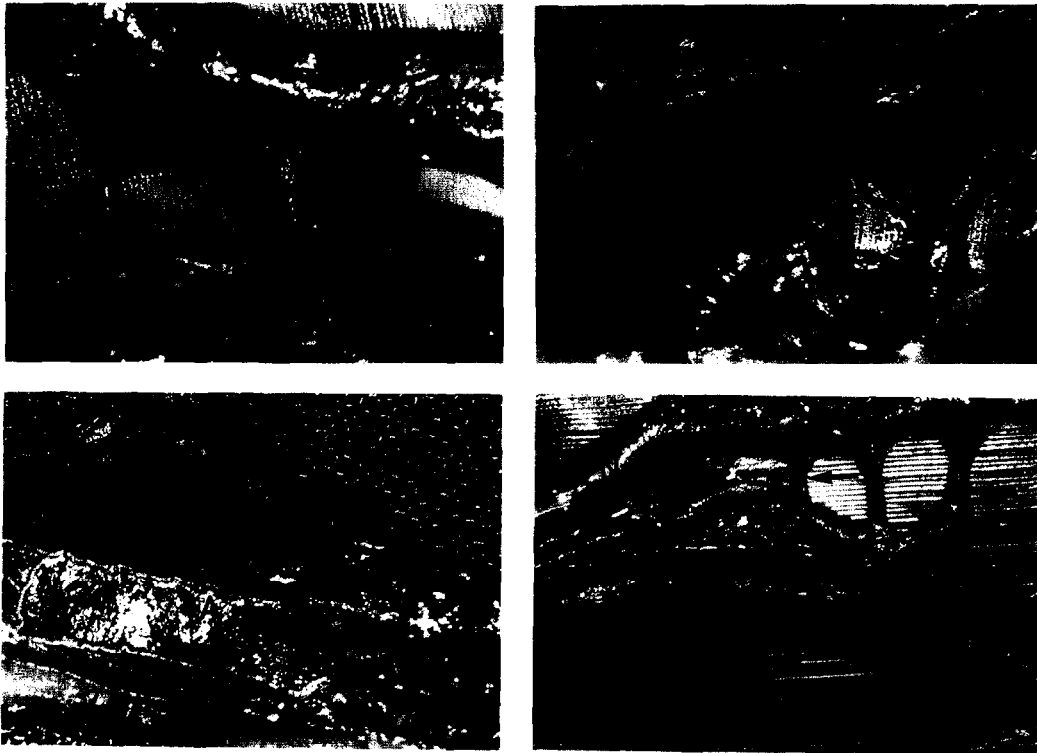


Fig. 5

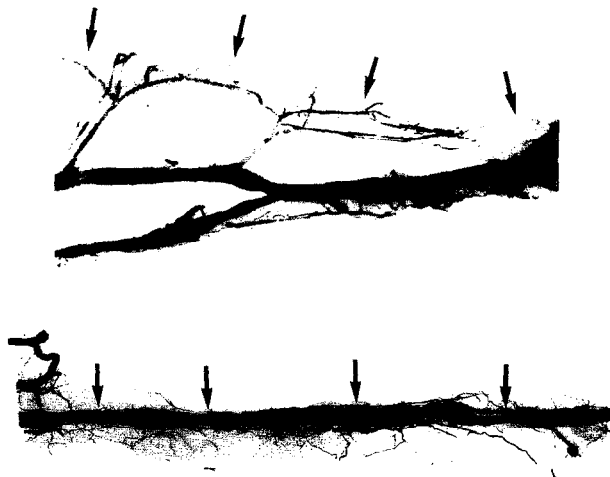


Fig. 6

**Figure 5**—Cadavar studies to compare with Figure 3. The nerve (N), artery (A), vein (V) and venae nervora (arrows) are labelled in each case. The veins have been injected with lead oxide. **Figure 6**—Radiographic studies of the venous drainage of the sciatic nerve (above) and the sural nerve (below). The nerves are located with arrows in each case. Note the epineural and intraneural veins of the sciatic nerve in the former study which link the venae nervora to form arcades and the rich perivenous plexus which surrounds the short saphenous vein in the latter study.

radio-opaque mixture. Where veins were devoid of the perfusate the task was impossible. The results are therefore presented within the feasibility limits of our dissections.

#### *Classification of the venous drainage of the nerves*

Four patterns of extraneural drainage were identified. Although many of the *venae nervora* were accompanied by nutrient arteries to the nerve, the number of veins exceeded that of the arteries. In general the *venae nervora* drained to the nearest vein or plexus of veins. The patterns are shown in Figures 3–6.

##### *1. Direct venae nervora*

This was the least common variety. In this instance a *vena nervorum*, usually large, drained directly from the nerve to the accompanying *vena comitans*. Characteristically these veins have a T-shaped configuration (Figs 3A, 5A and 6). Because of their size and site it seems likely that they are the dominant drainage of the nerves in the region.

##### *2. Indirect venae nervora*

These veins leave the nerve and “hitch-hike” with larger vessels which cross the nerve en route to the *venae comitantes*. In most cases these intermediate veins were derived from muscles; sometimes they drained the overlying integument and occasionally they were noted arising from bone. They are shown in Figures 3B and 5B.

##### *3. Periarterial venous plexus*

In the deep tissues the arteries travel with their *venae comitantes* and are surrounded by a very rich venous plexus, the *venae arteriosae*. This network of fine veins, which appear to be free of valves, communicates with the *venae comitantes* of the artery. They are not to be confused with larger veins which, like the rungs of a ladder, also cross the artery to interconnect the *venae comitantes*.

The *venae nervora* drain to the periarterial venous plexus which in turn drains to the *venae comitantes* of the artery. This is a very common pattern of venous drainage of the nerve and, perhaps, is to be expected since in many instances the artery lies between the nerve and the comitant vein. The pattern is shown in Figures 3C and 5C. Technically the architecture was difficult to demonstrate photographically as attempts to separate the artery from the nerve to display the *venae nervora* produced rupture of these tiny vessels.

By comparison, the *venae nervora* were usually

smaller than those seen in the previous two patterns. However, in the majority of cases the main vessels and nerves travel together in the limbs and hence this pattern of venous drainage is the commonest in the deep tissues.

##### *4. Perivenous venous plexus*

This pattern is typical of the venous drainage of the cutaneous nerves. A plexus of small veins, which are free of valves, courses parallel to, surrounds and communicates with the large subcutaneous veins. The *venae nervora* drain to this perivenous plexus, often travelling for several centimetres before entering it. Sometimes we were able to record tributaries which left the nerve and communicated with cutaneous perforating veins and the plexus on the deep fascia (Sunderland, 1972). In general the *venae nervora* were small and are shown in Figures 3D, 5D and 6.

##### *Site and orientation of the valves*

Wherever possible the *vena nervorum* was opened with microscissors to identify the valves. In the first two patterns the direct and indirect *venae nervora* were of a size which allowed us to identify the valves in most cases. However, where they drained to the periarterial and perivenous plexi their diameters were 0.2–0.1 mm or less (Figs 3 and 5). Attempts to slit these veins open with scissors yielded irregular tears, making recognition of valve cusps impossible.

Where the *venae nervora* were large, for example the median vein draining the median nerve in the proximal forearm, the ulnar collateral veins draining the ulnar nerve in the arm and the venous arcades draining the sciatic nerve in the thigh, valves could be identified and their direction verified. Valves were noted in the main stem of the *vena nervorum* and sometimes in its collecting channels. Beyond these collecting vessels the epineural veins on the surface of the nerve were devoid of valves. These avalvular or oscillating veins connect adjacent *venae nervora*, vessels whose valves are orientated in opposite directions, to form a continuous network surrounding the nerve. The point of entry of the *venae nervora* into the *venae comitantes* of the artery bore no fixed relation to the site of the valves in these comitant veins. In most cases they entered just before or just after the valves.

Although we were unable to dissect the tiny *venae nervora*, we sometimes noted that they exhibited a sentinel valve where they communi-

cated with a larger vein (Fig. 4). It is our impression that valves are absent in the network peripheral to the sentinel valve when the latter exists. This is based on the observation that the epineural network was often displayed with the lead oxide mixture, and the characteristic bead-like appearance that identified the valve sites was absent.

Thus it seems, within the limitations of our study, that the venous drainage of a nerve is not unlike that of a muscle with multiple territories. It is drained segmentally by *venae nervora* which range from small closely related vessels to large veins or groups of veins which are spaced well apart. The *venae nervora* and their tributaries contain valves when they are large but, when small, may or may not exhibit a sentinel valve at their entry point into their draining vein. These *venae nervora* are linked together by a rich unbroken plexus of longitudinal epineural veins which surround the nerve (Figs 4 and 6).

#### *The intraneural veins*

In most cases the tiny radicles of the intraneural veins were not displayed, probably because of the molecular size and viscosity of the lead oxide gelatin mixture which set prematurely. However, where this was possible a rich network of interconnecting longitudinal venous channels was noted which followed the connective tissue framework of the nerve (Fig. 4). This pattern of distribution of the veins is similar to that of the arterial supply (Sunderland, 1972).

#### *The venous drainage of individual nerves*

The results of our studies are shown in Figure 7. Since the venous drainage of the limbs is quite variable this was reflected in the number, site and size of the *venae nervora* for each nerve. However, as a given nerve passed from one region to another, the *pattern* of venous drainage was relatively constant. For example the ulnar nerve exhibited usually a type A and B pattern of drainage in the arm and at the elbow whereas in the forearm a type C pattern predominated.

A striking feature was the predominance of direct *venae nervora* (type A) in relation to the joints, especially the elbow and knee. They were usually large and long to allow mobility of the nerve and they drained to fixed sites near the joints.

### **Discussion**

It is difficult to define, and thus compare the precise diameters of the *venae nervora* since they are thin-

walled and easily distended. Their appearance varies to some extent with the success of the perfusion. Occasionally they were clearly over-distended with the mixture, in other instances they were collapsed with poor filling. To provide some guide as to the relative importance of each *vena nervorum* we have divided them arbitrarily into three sizes:

- Large (greater than 1 mm)
- Medium (between 0.1 and 1 mm)
- Small (less than 0.1 mm)

#### *Dominant venous drainage sites*

The direct *venae nervora* were the largest variety. They predominate in the vicinity of the elbow and knee and in certain regions of the arm and thigh (Fig. 7). They often span for long distances on the nerve before they communicate with the *vena nervorum* in the next territory.

In most instances the direct *vena nervorum* is accompanied by an *arteria nervorum* which executes a similar course and distribution to the nerve. In the same way that a long skin or muscle flap can be elevated on a dominant arteriovenous system, the stage is set anatomically for a nerve to be mobilised in either way, provided the dominant pedicle is not violated. The burning question is, for what distance can this be performed with safety?

There are several observations, both clinical and anatomical, which when combined would suggest that it is the pattern of blood supply and venous drainage of the nerve which is important, not an arbitrary nerve length in centimetres.

In our anatomical studies, which led to the angiosome concept, we came to the conclusion that when a flap was raised the territory of an adjacent angiosome could be captured with safety and that necrosis occurred when attempts were made to capture the next or subsequent territory. On the arterial side the choke arteries, which link adjacent territories, provide anatomical strictures to blood flow and dilate when a flap is delayed. Our recent studies of the venosomes of the body reveal valved territories on the venous side which must be negotiated in a similar way as blood returns to the base of the flap.

If, for example, one examines the vasculature of the ulnar nerve from the distal axilla to the wrist, it crosses three territories and is supplied and drained segmentally from each. These territories are in sequence: the superior ulnar collateral in the upper arm; the ulnar recurrent at the elbow; and the ulnar

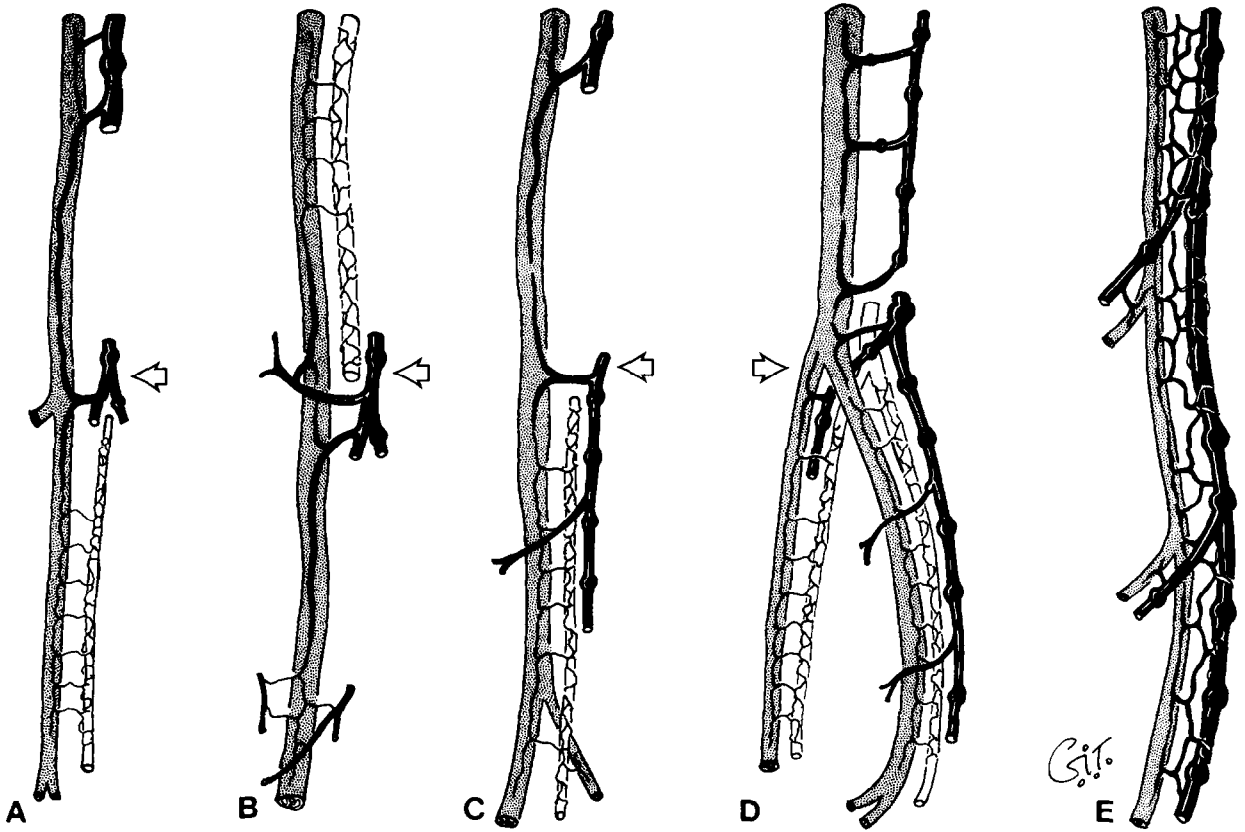


Fig. 7

**Figure 7**—Schematic diagram of the venous drainage of the radial, median, ulnar, sciatic and cutaneous nerves. Arrows designate the level of the elbow and knee. From proximal to distal the dominant venous drainage of: (A) The radial nerve is by direct *venae nervosa* to the axillary vein and the *profunda venae comitantes* in the arm, the anterior radial recurrent vein at the elbow and in the forearm the superficial radial nerve drains to the plexus around the radial artery. (B) The median nerve is to the plexus around the brachial artery and via muscular veins in the arm. In the forearm the dominant venous drainage is provided by the median vein. (C) The ulnar nerve is provided by the superior ulnar collateral vein in the arm, the ulnar recurrent at the elbow and to the plexus around the ulnar artery in the forearm. (D) The sciatic nerve is via the perforators of the profunda system in the thigh and directly to the popliteal vein at the knee. In the leg the anterior and posterior tibial nerves drain predominantly to the plexus around their accompanying arteries as well as to muscular veins. (E) The cutaneous nerve is to the perivenous plexus of the accompanying vein.

in the forearm. Clinically the ulnar nerve is detached from its nutrient branches in the forearm when an island skin flap is raised on the ulnar vessels, a distance of perhaps 15–18 cm in an adult. Complications are rare since the nerve is left *in situ* and is supplied and drained by vessels of the adjacent angiosomes, proximally at the elbow and distally in the hand. But, if either the ulnar or median nerves are divided in the distal forearm and mobilised across the elbow joint into the arm for a similar

distance to facilitate a primary repair, necrosis and fibrosis of the nerve is not uncommon (Sunderland, 1972).

In this situation the proximal nerve stump has been disconnected from its distal blood supply. When either nerve is mobilised into the arm its vasculature is interrupted across two angiosomes. In the case of the ulnar nerve these branches are detached in sequence from the ulnar and then the inferior ulnar recurrent vessels. The main supply

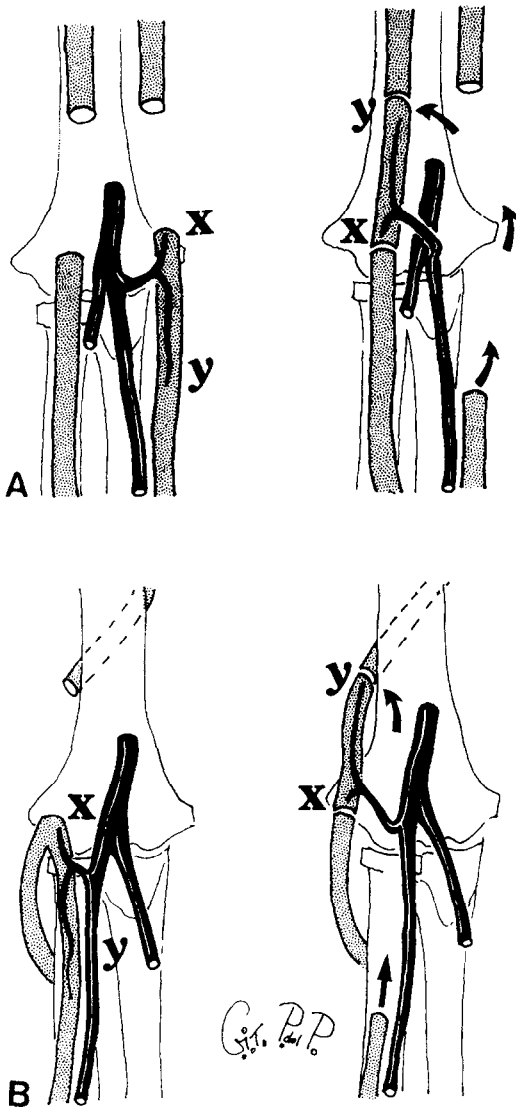


Fig. 8

Figure 8—Schematic diagrams of possible island nerve flaps at the elbow using the disrupted ulnar nerve to repair a defect of the median nerve in (A) and the superficial radial nerve to repair a defect of the main trunk in (B).

and drainage of the nerve is now dependent on the superior ulnar collateral vessels, vessels which arise beyond the axilla. Similarly the contribution from two angiosomes are violated when the median nerve is mobilised for a similar distance, namely the median branches of the ulnar system and the inferior ulnar recurrent vessels.

However, the ulnar nerve can be mobilised proximally and distally on the superior ulnar

collateral vessels (Taylor 1978; Briedenbach and Terzis, 1987) or the superficial radial nerve on the radial vessels (Taylor and Ham, 1976), to provide viable nerve segments in excess of 25 cm. In each instance just one angiosome is added proximal and distal to that of the pedicle.

Hence necrosis of a nerve appears to be related to the site of division of its nutrient vessels and not to an arbitrary length of mobilised nerve. It would seem that the nutrient vessels to a transected nerve can be divided with safety within one angiosome but interrupting those of an adjacent angiosome should be viewed with caution. In particular, care should be taken when mobilising a nerve in relation to a major joint especially the elbow and the knee.

*Island nerve flaps*

In the same way that viable nerve segments can be isolated on an arteriovenous pedicle for free transfer, these island nerve flaps can, within the restrictions of the pedicle, be used in one stage to repair defects in the local region (Fig. 8). Terzis (1985) has applied this technique around the knee to repair defects of either the lateral or medial popliteal nerves using island flaps of the sural nerve. This modifies the procedure of St Claire Strange from a two-stage operation to a one-stage procedure.

*Arterialised neurovenous flaps*

This technique was described by Townsend and Taylor (1984) in an attempt to expand the available donor sites for free vascular nerve transfer. It was applied to those nerves which have a type 4 pattern of drainage, namely the cutaneous nerves. The technique was tested in the pig and then the short saphenous vein-sural nerve complex was transferred in a series of patients in which the vein was reversed and interposed between two arteries. Subsequently the technique has been verified by Gu *et al.* (1985) and Rose *et al.* (1989). Our anatomical studies provide other donor sites such as: the saphenous neurovenous system in the leg; the musculocutaneous nerve in the distal leg and foot with accompanying veins; and the medial and lateral cutaneous nerves of the forearm with the basilic and cephalic systems respectively. In each case it would seem important anatomically to include a cuff of loose connective tissue around the neurovenous pedicle so as to capture the fine network of veins that connect the vasa nervorum to the vein conduit.

Circumstances may arise where it is prudent to

select a donor nerve from the deep tissues, but to omit the accompanying artery from the nerve flap. In these situations it may be possible to dissect the periarterial venous network from the artery to provide a neurovenous flap. Rose used this technique when he selected the terminal segment of the anterior tibial nerve and a vena comitans of the dorsalis pedis artery as his donor flap. This was used to repair defects of digital nerves in the hand, interposing the vein segment between the digital artery stumps.

#### *The compressive nerve syndromes*

This is an obvious area for further research and it is hoped that our venous studies will provide some basis for these investigations. Clinically we have noticed on numerous occasions an interesting sequence of events that occurs when the median nerve is decompressed in the hand for a carpal tunnel syndrome. Done under a tourniquet, the nerve is initially white when decompressed. Soon a flush of fine vessels appears at the site of stricture which is then followed by a vein which fills on the surface of the nerve. This would suggest that the condition is associated with some compromise to the venous drainage of the nerve in the carpal tunnel. Obviously further work needs to be done in this interesting area of research.

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