THE BLOOD SUPPLY AND LYMPHATIC DRAINAGE OF TENDONS

By D. A. W. EDWARDS, *Anatomy School, Cambridge*

The surgical care of tendons presents many difficulties. Their behaviour as a tissue is largely dependent on the peculiarities of their blood supply, yet there is no available account of the anatomy and physiology of their vascular pattern. Kölliker (1850) said that tendons had practically no blood vessels; Schäfer, in Quain's *Anatomy* (1912, pp. 115, 343), gave a brief description of the blood vessels of muscle and tendon, and quoted Ludwig & Schweigger-Seidel (1872) as having described lymphatic vessels on the surface of tendons draining the muscle sheath. Mayer (1916) gave an outline of the vascular pattern and some details of the arrangement of mesotendons. The following study was undertaken to provide a fuller description of the vascular pattern of tendon.

MATERIAL AND METHODS

Flexor and extensor tendons, crossing the metacarpals and metatarsals, of cow, calf, adult human subjects, guinea-pig and dog were used. Indian ink or Winsor and Newton's water-colour vermilion cream was injected into blood vessels and lymphatics, and sodium nitroprusside-benzidine was used to delineate the blood vessels by Pickworth's method (1934). The Winsor and Newton water-colour cream gave a good pattern for the moment, but faded rapidly when treated with alcohol and clearing agents. Sodium nitroprusside-benzidine preparations were also suitable for immediate use only.

Blood vessels were injected via the metacarpal or metatarsal artery, or as they lay in the mesotendon, at a pressure of 100–250 mm. mercury. Lymphatics could only be injected satisfactorily in a disto-proximal direction, and it was sometimes necessary to make several attempts to get the needle into the superficial plexus. For this purpose it is best to use a no. 20 (S.-B.) needle with long bevel, to pass the needle as parallel to the tendon as possible, and to exert only gentle pressure. The warmer, fresher and younger the material, the better the results; old or cold tissue is unsatisfactory. Occasionally blood vessels are entered, but the pattern produced is different.

Double injection preparations were also made, blood vessels being injected with Indian ink and, following this, the lymphatics with vermilion cream. All preparations were verified by histological examination of injected areas, and in all cases the main lymphatic channel was traced back along the artery and vein to the carpo-metacarpal joint. In all cases but one there was no doubt that the injection had entered the lymphatics only; in one case both lymphatic and blood channel became filled with the injection medium, as was clearly proved under the binocular microscope. Injection preparations of either blood or lymph vessels alone are much more satisfactory than those in which both systems are injected.

OBSERVATIONS

The unit of tendon structure is the tendon fascicle. This consists of closely packed collagen fibres with their parent cells, the fascicles being bound together by a layer of fine connective tissue, the interfascicular tissue or endotenon. The cross-sectional area of the fascicle is variable but lies within certain limits (0·125–0·375 sq.mm.). The interfascicular tissue is probably largely nutritional in function, and the characteristic limit to the area of the fascicle is probably related to nutritional requirements. The interfascicular tissue may also be compared with the packing of a laminated spring and facilitates internal movement of the tendon. Where it has no synovial sheath the tendon is surrounded by loose fatty areolar tissue, the paratenon, which fills the interstices of the fascial compartment in which the tendon is situated.

In the simplest form of musculo-tendinous junction the muscle fibres are continued as collagen bundles, and each group of muscle fibres enclosed in perimysium continues as a tendon fascicle, the perimysium being continuous with the interfascicular tissue. Where the muscle fibres join the tendon obliquely this arrangement does not always hold, but there is a close correspondence between the grouping into bundles of muscle fibres and the grouping into tendon fascicles. At its insertion, the tendon becomes intimately connected with the bone and periosteum. The majority of the collagen fibres of the tendon are continued into the bone as the perforating fibres of Sharpey and the interfascicular tissue becomes continuous with the periosteum.

The tendon has a uniform structure throughout. The fascicles run from end to end, separated from each other and bound into a whole by connective tissue, continuous on the one hand with that of the muscle, on the other with the periosteum. The fascicles are roughly hexagonal in cross-section and show interfascicular grooves. In the interfascicular

tissue run blood vessels and lymphatics. The blood vascular system is simple and is uniform throughout the tendon, consisting of a series of longitudinal channels and a regular series of transverse anastomotic vessels (Pl. 2, figs. 4, 6).

Each fascicle is surrounded by a series of longitudinal arterial vessels, some of which can be seen in the interfascicular grooves on the surface of the tendon (Pl. 1, fig. 1). These longitudinal vessels are arteriolar in size, with a well-marked tunica media and a uniform lumen. They are fed from the surface vessels by transversely running channels of the same size which thread their way around and between the fascicles, linking the longitudinal vessels into a uniform plexus. Accompanying each arterial channel are two veins with the characters of large venules. They lie on each side of the artery, communicating frequently: their communication usually lies in the immediate neighbourhood of a branch or tributary (Pl. 2, figs. 4, 6).

Arising from the arterial bed is a series of capillary vessels which form loops draining into several capillary venules. This gives the impression of many more venous tributaries than arterial branches. The capillary plexus is intra-fascicular and does not appear to penetrate the collagen bundles. The loops may run from one longitudinal channel to another, or back to the parent channel.

Double injection preparations of blood and lymph vessels within the tendon were not satisfactory, but injections of lymphatics alone gave good results. These lymphatic channels follow the same course as the arteries. By the examination of stained sections of injected material the lymph vessels are seen to be closely associated with the blood vessels. The lymphatic plexus is quite characteristic and readily distinguished from the venous. It consists of several large vessels, usually two or three, of very irregular bore, with many interconnexions giving the appearance of a close meshwork surrounding the artery and veins (Pl. 2, fig. 5). The tributaries of the plexus are difficult to determine, but appear to be short, blindly ending capillaries lying in the interfascicular tissue and not extending very far from the main stem.

Connexions of this internal intratendinous blood, and lymph vascular system with the external are located at four sites: (1) at the musculo-tendinous junction, (2) at the osteo-tendinous junction, (3) in the extra-synovial region, (4) in the intra-synovial region.

(1) *At the musculo-tendinous junction.* Each collagen fibre represents a muscle fibre. Each muscle fibre is surrounded by a capillary network fed from larger vessels lying in the perimysium. Where the muscle cell becomes a collagen fibre the capillary network ceases and of the vessels within the muscle only those of the perimysium continue into the tendon as the interfascicular vessels. These vessels, coursing from the muscle to the tendon, are the same size as those in the rest of the tendon, and there is no suggestion that the tendon derives much of its blood supply from the muscular arterioles. The vessels of the muscle sheath become continuous with those of the tendon sheath.

No deep lymphatic connexions across the musculo-tendinous junction have so far been displayed, but lymph vessels on the surface of the tendon can be traced into the muscle sheath, and a few into the perimysium. So far there is no satisfactory evidence that the deep lymph vessels of the tendon are continued into the perimysium, but the possibility exists.

(2) *At the osteo-tendinous junction.* Here the interfascicular vessels do not increase in size and do not receive any increased blood supply, but merely continue on their way, anastomosing with the rather scanty periosteal vessels. In some places branches may be seen passing through to the cortical layers of the bone. The vessels are small, few and irregularly distributed. Whilst the collagen fibres continue into the bone, the interfascicular tissue merges with the periosteum and takes its blood vessels with it. The vessels turn at right angles into the plane of the periosteum and become part of the periosteal network. The osteo-tendinous junction is not an important source of blood supply to the tendon. As with the musculo-tendinous junction, the fate of the lymph vessels in this region has not been ascertained.

(3) *Where the tendon has no synovial sheath* it is surrounded by very loosely woven connective tissue, so allowing considerable movement of the tendon; this has been called paratenon (peritenonium externum). Its function is that of an elastic sleeve which gives the tendon free movement against the surrounding tissue, at the same time maintaining its continuity with the tissues (see Mayer, 1916).

At frequent and regular intervals small vessels may be seen coursing through this areolar sleeve towards the tendon. They arise from vessels which lie in the vicinity and do not appear to have a specific origin and course. On approaching the tendon the vessels branch several times in the direction of the longitudinal axis of the tendon, lying in the interfascicular grooves. It is from these surface vessels that those within the tendon arise at regular intervals by transversely running branches threading between the fasciculi (Pl. 1, fig. 1). This loose areolar tissue and the layer of more condensed tissue around the tendon are continuous with the outer intermuscular tissue and the muscle sheath respectively. Vessels, of a size comparable with those approaching the tendon along its length, may be seen running in the muscle sheath and intermuscular tissue, becoming continuous with the surface vessels of the tendon. The paratenon is also continuous with

the loose areolar tissue on the surface of the periosteum, and surface vessels of the tendon are seen to pass off the tendon into this tissue. Some of these vessels may be quite large, e.g. those of the vincula brevia. Whilst the deep vessels are not large, the surface vessels of the osteo-tendinous and musculotendinous junctions may be significant in the maintenance of the nutrition of the tendon.

So far it has not been fully determined what happens to the lymphatic efferents on the surface of the tendon. There is no doubt that some of them pass alongside the entering arterial channels. Nothing has been found of their course at the osteo-tendinous junction except that relatively large lymph vessels can be seen running out in the loose tissue on the surface of the periosteum, apparently draining the area. It may be that they are communicating with the deeper channels of the tendon, and in view of the apparent lack of lymphatics in bone and periosteum it is reasonable to expect that the deeper lymphatics of the tendon drain to the surface vessels at the region of the osteo-tendinous junction, and from this surface network back along the main vascular channels of the region. This, however, remains to be demonstrated.

(4) *Where the tendon lies within the synovial sheath.* Within the synovial sheath the tendon has the same structure and vascular pattern as elsewhere. Instead of being surrounded by paratenon, the tendon is enclosed in a thick sheet of very vascular fibroelastic tissue, the visceral layer of the synovial membrane. The visceral layer is continuous with the parietal layer at the ends of the sheath, and the two may be connected by sheets or cords of tissue known as mesotendons. These mesotendons may be compared with the mesentery, and serve to convey blood vessels to the visceral layer, which is also vascularised by continuity from the parietal layer. The parietal layer is vascularised from the surrounding tissue.

In man mesotendons of the sheet type are found at the wrist and ankle, carrying several vessels often in a fan formation. Cord-like mesotendons are found in the digital sheaths where they are known as vincula longa, carrying one artery, two veins, and usually four lymphatics.

The synovial blood vessels show (1) a very fine capillary network on the surface of the synovial membrane, and (2) a deeper and much larger plexus of arteries and veins. The capillary network consists of fine vessels looping up to the surface from the arterioles and venules below. In some regions they may lie in small villi projecting from the surface. These loops are all of the same order of size; they are single and connect arterioles to venules (cf. Davies, 1946).

In the deeper layers of the synovial membrane lies the very rich plexus of larger vessels; it is with this plexus that the surface interfascicular vessels of the tendon communicate by short anastomotic channels, these short channels taking the place of the vessels of the paratenon.

The blood and lymph vascular systems of the synovial membrane will now be considered in more detail.

In the cow the deeper blood vascular plexus of the synovial membrane is virtually a continuous network of vessels, both arterial and venous. On the visceral layer there are direct anastomoses between the vessels in the various mesotendons, on the parietal layer between the large vessels entering the membrane, and round the ends of the sheath the larger vessels of the visceral and parietal layers anastomose. From this wide network of large vessels so formed, a series of loops arises, and from these loops, a subsidiary series of arcades, this process continuing until four to six generations of progressively smaller loops and vessels have been formed (Pl. 1, fig. 2). Each of these series of loops anastomoses with adjacent members of its own generation. Within the areas of each small arcade is a plexus of arterioles and venules from which arise the capillary loops of the surface layer.

The large vascular bundles contain a single arterial stem, branching only to form large vessels, and giving rise infrequently to small local vessels. This arterial stem is of fairly uniform bore within the limits of its own arcade and may be readily identified by this character. Running parallel with this artery, and placed one on each side of it, are two veins, one usually considerably larger than the other, and connected to each other by regular anastomosing channels of the same order of size as the larger. Both veins receive many local tributaries draining the perivascular plexuses previously mentioned. Anastomoses between the veins occur almost always at the entrance of a pair of tributaries. Examples of this may be seen in Pl. 1, fig. 2 and Pl. 2, fig. 6.

The two venae comitantes are evenly spaced from the central artery, and in preparations in which the blood vessels only have been injected the parallel venous channels are plainly seen, surrounded by a clear space. In this space runs a fine network of very small vessels which appear to be mainly venous and to drain regularly into veins. Arterial connexions cannot be seen in the injection preparations and are difficult to interpret on sections. The site of this plexus suggests that it may be perilymphatic, but this is difficult to make out from sections, and in double injection preparations of blood vessels and lymphatics, the fine plexus does not stand out clearly. In general the lymphatic vessels run with the blood vessels. From the periphery to the mesotendons they are multiple longitudinal channels,

acquiring valves shortly before they arrive at the mesotendon. In the mesotendon there is usually one artery and four lymphatics, but within a few centimetres of the mesotendon the four lymphatic channels fuse to a single vessel which may become double for short distances.

From the mesotendon to the periphery the lymphatic vessels are closely associated with the blood vessels. The larger lymph vessels have a corresponding pattern, lying always between the artery and veins, and on the outer side of the veins, so that each artery is accompanied by two veins and four lymphatics. These four lymph channels are intimately connected by a rich network of lymphatic capillaries, which pass on both sides of the blood vessels, enclosing them in a lymphatic plexus. This plexus follows the blood vessels in all their branching down to the smallest arcades (Pl. 1, figs. 2, 3). The terminations of the lymphatic capillaries appear to be short, blindly ending vessels with either convex or concave, slightly bulbous tips (cf. Davies, 1946). The concavity or convexity may well depend on the degree of distension of the vessel. The deeper plexus gives off these blindly ending lymphatic capillaries to the surface of the synovial membrane and communicates frequently with the interfascicular vessels of the tendon beneath.

The characteristic differences between lymphatic and blood vessels may be summarized as follows:

(1) Lymphatic capillaries are larger in bore than blood capillaries. This is true also of the more proximal vessels, and is probably due to the lack of muscle tissue in their walls.

(2) The lumen of the lymphatic vessel is irregular, giving it a moniliform appearance; the lumen of the blood vessels is regular.

(3) Rarely are lymphatics seen as single vessels; they are almost always in the form of a network of parallel vessels with frequent anastomoses producing a mesh with irregular spaces.

(4) The ultimate lymphatic vessels appear to be end vessels, i.e. they end blindly.

The actual site of the valves in the lymph vessels rests largely on deduction. Injection of lymphatic capillaries disto-proximally from the tendon is easy. Once a capillary lymphatic has been opened to the needle very gentle pressure of a few centimetres of water suffices to pour ink into the vessels, which fill rapidly along their course to the main channels. This free and rapid flow proximally from the tendon is constant. As well as a disto-proximal flow, there is always a local spread in all directions, adjacent channels fill and a large area of the synovial membrane can be injected from one insertion of the needle. Vessels can be seen running from the area to several mesotendons. This demonstrates that a lymphatic anastomosis exists, comparable with the blood vascular anastomosis and that no valves are present in the synovial network itself, neither are they seen under the binocular microscope, nor in histological preparations. This may be due to one or both of two factors: (1) if the lymphatic is not distended the valves are not readily visible, (2) if the lymphatic is distended with injection fluid, the valves are obscured.

In histological preparations, however, valves could be seen within a few millimetres of the mesotendon, in the mesotendon, and in the vessels proximal to this from the tendon. These facts agree with the results of attempted proximo-distal injection of lymphatics by inserting a needle into the vessels at the mesotendon or proximal to this. All these attempts have failed. No flow has occurred distally, and if the vessel has been clamped proximally, the vessel wall frequently breaks before the competence of the valves has been overcome.

We may assume therefore that valves do not exist in the synovial lymphatic network itself, but only proximal to this, and that here the valves are competent.

DISCUSSION

The literature abounds with papers on the nature of tendons, treatment of tenosynovitis, and the rupture of the extensor pollicis longus, but studies undertaken on the basis of the anatomy and physiology of tendons are rare.

For the surgeon, tendon has certain characteristics: (1) it appears to be practically avascular, (2) it is destroyed very slowly by inflammatory processes, (3) it may be cut and transplanted with impunity, (4) it is very difficult, if not impossible, to suture tendon within a synovial sheath without a high incidence of adhesion, (5) healing and sequestration of infected tendon is extremely slow.

In marked contrast to other tissues, tendon is virtually 'dead' during life. Almost the whole of the tendon is made up of collagen fibrils closely packed together, and apparently undergoing little or no metabolic activity. The living part of the tendon consists of the tendon cells lying between the bundles of collagen fibrils they have produced, and the interfascicular connective tissue. It is these living tendon cells which require a blood supply, but their proportionate volume is small, so that the vascular needs of the tendon as a whole are very small. Hence its apparent avascularity to the naked eye, and the scanty but regularly spaced plexus of vessels described above. It is interesting to note that of all the purely organic tissues of the body, tendon withstands the processes of decay longest. Because of the large proportion of 'dead' tissue, autolytic and bacterial destruction is slow. In the large sloughing ulcers of the foot which sometimes occur as a result of wet gangrene, the extensor tendons may be seen stretched across a bag of pus

and necrotic tissue, and whilst their surfaces are covered with purulent exudate, the central parts of the tendons show a relatively healthy appearance in cross section. Bacteria quickly gain a hold upon the connective tissue sheath of the tendon, and may penetrate a short distance down the interfascicular septa. This hold is shallow, however, and further penetration and extension of the eroding process is very slow.

Coupled with this slow rate of erosion of the tendon substance is the very slow rate of sequestration of dead material. Union of clean-cut tendon surfaces is a little slower than that of other connective tissues, but the process of organization of the fibrin film between the approximated tissues is not grossly delayed (Garlock, 1927; Mason, 1940).

The suture of tendon outside a synovial sheath is easy and, as the tendon is already adherent to the adjacent tissue, the functional result is good. Suture within a synovial sheath is difficult. Healing of the adjacent ends of the tendon is good, and the blood supply is virtually unimpaired as a result of the excellent longitudinal anastomoses and the frequent feeding of these by vessels from the synovia. But the methods of tendon suture at present in vogue do not consider the synovia as a separate structure, and no attempt is made to invert the edges of the synovia in the way that is customary in sewing a rent in the peritoneum. If this could be achieved it is possible that the incidence of adhesions might be reduced. The visceral synovia of the flexor tendons of the hand, however, is so thin and so firmly adherent to the underlying tendon, that this method of approach seems doomed to failure from the technical point of view.

Tendon may be transplanted or transposed with relative ease and the certainty that healing of the transplant will occur (Garlock, 1927). This is largely due to the low metabolic requirements of the tissue which can obtain sufficient blood supply from its longitudinal anastomoses until such time as vessels have developed in the new paratenon.

The arrangement of arteries, veins, and lymphatics in a tendon is interesting and typical and affords a further confirmation of the view that the lymph vessels tend to run in close proximity to the arteries (Harris, 1937). The tendon and its synovial sheath have one artery in the centre, on each side thereof a vein, and the lymphatic vessels disposed as four main channels one on each side of each vein and connected with one another along their whole extent by an intricate system of transverse vessels which surround the artery and veins. The veins are paired, with interconnecting branches in the immediate neighbourhood of the junction of tributaries, suggesting a mechanism for ensuring that the blood returns one way or the other and that venous pressure is evenly distributed.

There are no valves to be seen in the veins or lymphatics on the visceral synovial membrane, though they occur in the mesotendons. The flow of injection media is free in either direction in both the lymphatics and veins in the synovial membrane and in the vessels within the tendon substance. The arteries and their smaller branches have a thick wall of muscle and elastic tissue, and though no direct evidence of pulsation of these small vessels has been seen, it is reasonable to suppose that such pulsation does occur. Where valves are present in the lymphatics it is easy to visualize a pumping mechanism making use of transmitted pulsation from the artery. As a pulse wave passes through the artery, the lymph channel is compressed locally, and by means of the frequent valves, flow of lymph occurs in a disto-proximal direction from the periphery. Where valves are not present, the pulse wave produces local pressure, but the flow is not necessarily unidirectional. This pulse wave, much flattened in these relatively small peripheral vessels of the synovial membrane, may be of significance in promoting the flow of lymph to the mesotendons, where the valved pumping system takes over. The absence of valves and the rich anastomosis permits the easy flow of fluid towards any communication with the surrounding tissues, and so guarantees continuous good drainage in spite of any local pressure. There is evidence to suggest that lymphatic vessels contain no valves where they lie in or on a relatively firm, non-yielding tissue, but that valves occur where local tissue resistance is low, e.g. in loose folds of synovial membrane.

SUMMARY

1. A method of injecting the lymphatic vessels of the visceral synovial membrane of tendon sheaths is described.

2. The structure of the tendon, the musculo-tendinous junction and the osteo-tendinous junction is given, with their blood supply and lymphatic drainage.

3. The vascular pattern of the tendon and its sheath is described with special reference to their nutrition.

4. The observations are discussed in the light of the surgical pathology of tendons.

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EXPLANATION OF PLATES

PLATE 1

Fig. 1. Digital extensor tendon of calf outside a synovial sheath. The blood vessels are injected with Indian ink. Note the arteries with their venae comitantes appearing from one side of the tendon, the longitudinal anastomoses formed in the interfascicular grooves, and the vessels running deep into the tendon from these. (× 12.)

Fig. 2. Synovial membrane of superficial digital flexor tendon of calf. The blood vessels are injected with Indian ink. Note the arterial channels with their venae comitantes and the arcades of decreasing size which they form. (× 12.)

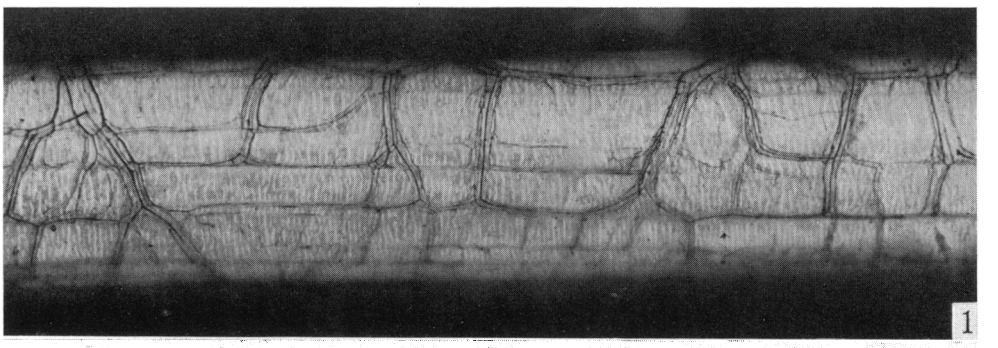
Fig. 3. Synovial membrane of superficial digital flexor tendon of calf. The area corresponds to that of fig. 2, and the lymphatic vessels have been injected with Indian ink. Note the arrangement of four parallel vessels with clear spaces between, where the artery and venae comitantes are to be found. (× 12.)

PLATE 2

Fig. 4. A projection drawing of intra-tendinous blood vessels injected with Indian ink. Note the longitudinal arrangement of arteries and venae comitantes with transverse anastomoses. These vessels lie in the interfascicular tissue. (× 20.)

Fig. 5. A projection drawing of intra-tendinous lymphatics containing Indian ink, to the same scale as fig. 4. Contrast the size and shape of the vessels with those in fig. 4. The distribution of the vessels is seen on section to be perivascular. (× 20.)

Fig. 6. A diagrammatic reconstruction of a tendon fascicle to show the longitudinal and transverse arterial channels and their venae comitantes.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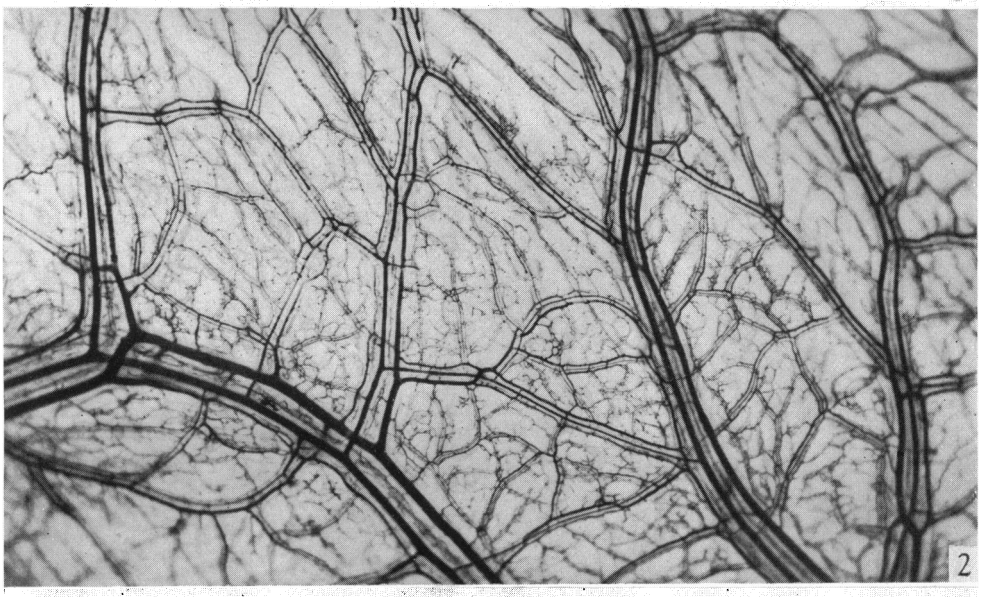
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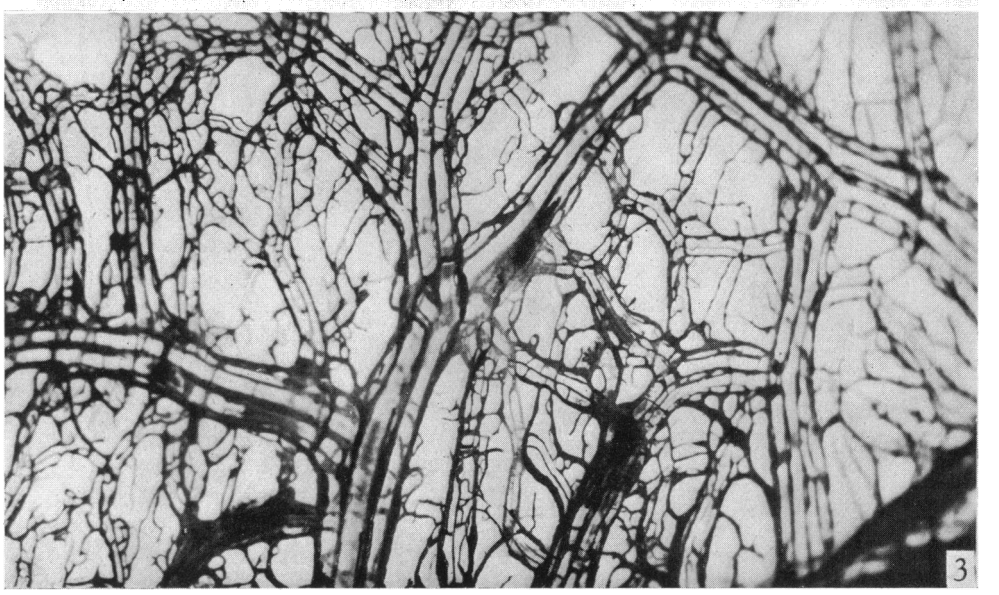
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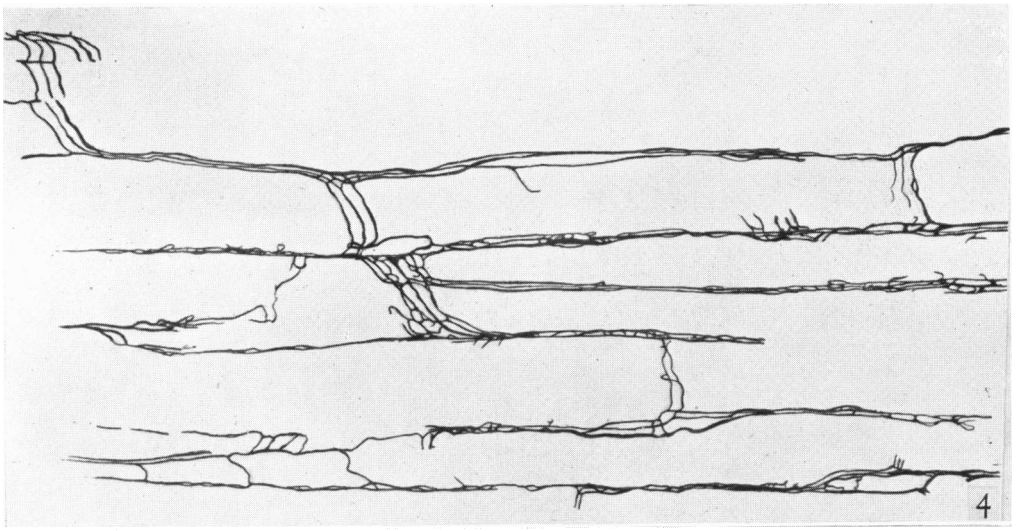
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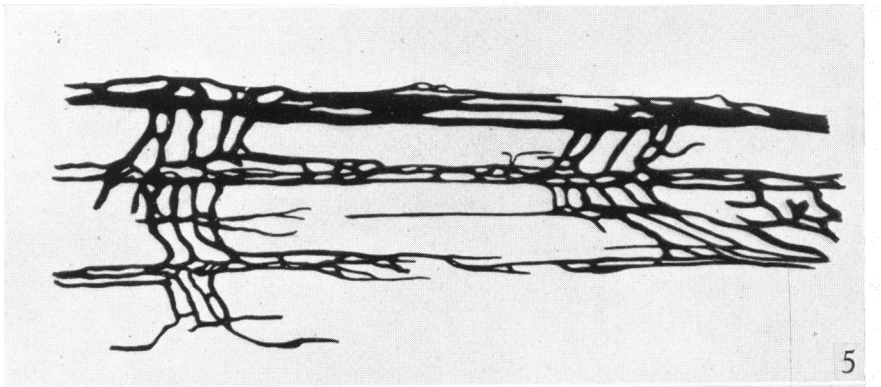
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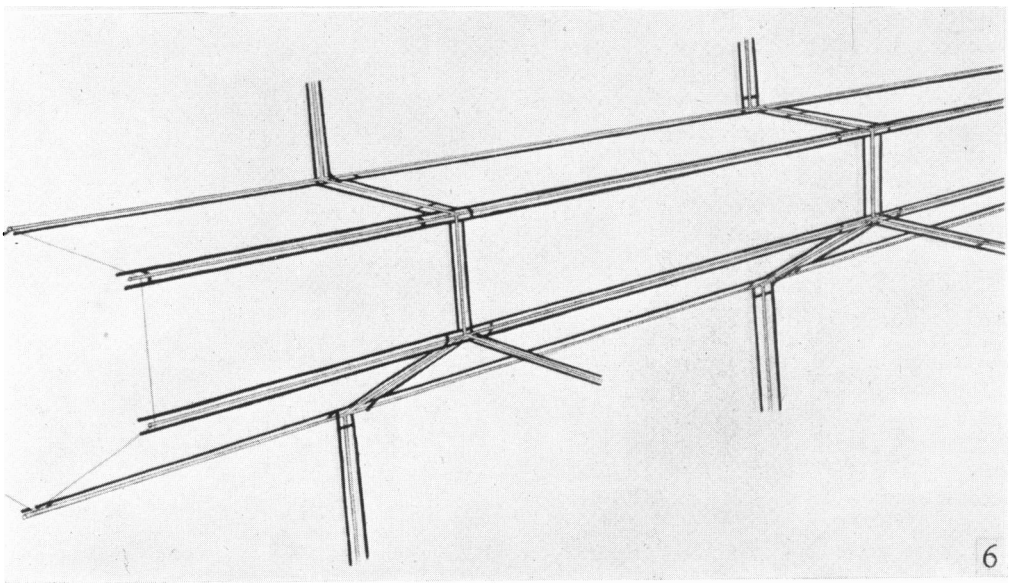
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