SOME OBSERVATIONS ON VESSELS IN THE ARTERIAL WALL.

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M.D. THESIS.

CONTENTS

Volume 1.

INTRODUCTION

This thesis deals with some aspects of the origin, distribution and development of vessels in the arterial wall. The work was carried out on foetal and post-natal material, from birth until eighty years of age. Observations were recorded with the Coslett-Nixon X-Ray Projection Microscope, which permits an examination of specimens without histological preparation, in contrast to the routine methods of previous investigators.

While the majority of the important arteries were examined, in order to determine alterations in the vascular patterns with age, particular attention was given to the aorta, coronary, and lower limb arteries, since they are the site of predilection for atherosclerosis.

The development of a blood supply to the arterial wall was studied, in order to find out when diffusion from the lumen ceased being the principal method of nourishment, and to show the differences in distribution between prenatal and postnatal vasa vasorum, especially in arteries with adaptive changes at birth.

I would like to thank Professor G.M. Wyburn for the advice and encouragement that he has given me during the course of this work.

I also wish to thank Professor D.F. Cappell, Dr. A.D.T. Govan, Dr. A.M. MacDonald, and Dr. R.I. Shaw Dunn for allowing me to visit their departments and examine specimens. Without their generous co-operation, it would have been impossible for me to have carried out the investigation reported in this thesis.

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PART 1

HISTORICAL.

PART 1

HISTORICAL

The belief, that blood vessel walls require a method, other than diffusion, for the supply of nutriment and elimination of waste products, has arisen from an accumulation of observations over the last two centuries. The vasa vasorum are partly responsible for the mechanism of nutrition, and it is to the growth of knowledge on these vessels that this historical survey is devoted, commencing with work done in the nineteenth century.

It is convenient to consider the morphological studies on the vasa vasorum in two sections:

(1) Studies between 1835-1938 .

(2) Studies between 1938-1963 .

STUDIES ON THE VASA VASORUM BETWEEN 1835-1938

This period is characterised by the use of the light microscope to interpret routine histological sections or injection preparations of the vessel wall. Rather than determine types of vascular patterns, the aim of each study was to show the specific layer in which the vasa terminated.

It is intended, therefore, to summarise the work of the principal investigators whose observations gave rise to differing opinions on the extent of intramural vascularity.

(a) Studies showing vasa vasorum in the adventitia and media:

On the basis of injection experiments (technical details not given), Risse (1843) concluded that the vasa vasorum penetrated the outer third of the media.

The majority of authors in the second half of the nineteenth century agreed with Risse's conclusion. Thus Gerlach (1848) and Kölliker (1850-1854) demonstrated capillary networks in the outer layer of the media, while histological examination of normal human arteries led Burdach (1835), Morel (1861), and Stroganow (1876) to concur in this opinion.

Gimbert (1865), from a detailed study of postmortem and surgical specimens of arteries and veins, described longitudinally arranged vasa being distributed to the adventitia, where they branched to penetrate the media at right angles and form anastomosing networks in the inner layers of the media. Observations by Köster (1875) and Schulman (1892) upon histological sections of normal human arteries in general supported Gimbert's theory, although Köster was of the opinion that occasionally the vasa might penetrate almost to the intima.

Less dogmatic in their beliefs than the Risse and Gimbert school of thought, Zahn (1890) and Grünstein (1896) studied human vessels by injection and histologica techniques and concluded that in the aorta the depth of penetration possibly varied with age, while in arteries other than the aorta the vasa were usually confined to the adventitia. Grünstein was of the opinion that better injection techniques would demonstrate more of the intramural vasculature than histological methods and that nutrient substances might also reach the vessel wall by diffusion from the lumen. Later Petroff (1923), from vital staining studies of the vessel wall, gave evidence of nutriment passing from the lumen to the intima, and vindicated Grünstein's hypothesis that the adventitia and outer half of the media obtained their nutrition from the vasa vasorum, while the remainder of the vessel wall was nourished from the lumen.

A considerable number of authors, including Thompson (1860); Raynaud (1865); Martin (1881), and Key-Åberg (1881), using routine histological techniques, commented upon the presence of vasa vasorum in the media but did not state the depth of penetration.

With the turn of the century, the emphasis in work concerning the blood vessel wall was on the role luminal blood played in the nourishment of the intima and inner media. Since the majority of these studies were pure biochemical essays and did not consider the vasa vasorum, they will not be reviewed.

In the study, 'Human Blood Vessels', Meigs (1907) stated that the vasa vasorum of the peripheral arteries were found in the outer third of the media, and Gross (1921), during an investigation of the heart's blood supply, commented upon the anastomoses between the coronary and bronchial arteries, through the adventitial vasa of the pulmonary artery.

Woodruff (1926), using India ink injection technique reported that the vasa vasorum in the aortae of the horse, dogs and lambs might extend to the internal elastic lamina. Robertson (1929), in addition to investigating the aortae of dogs and lambs reported, on the basis of injection experiments with cellulose, vasa in the outer third of the media in the normal human thoracic aorta. Comparison of the results in these human and animal studies showed that in the horse vasa penetrated to the intima, and that nutrient intimal vessels occurred in the dog, in contrast to the avascular intima and inner media in man.

(b) <u>Studies showing vasa vasorum in the adventitia.</u>

The belief that the media contained vasa vasorum in special circumstances only was shared by the minority of workers.

The principal study supporting this view was by Plotnikow (1884). From an examination of human vessels, which included aorta, limb arteries, and their corresponding veins, injected with a warm aqueous gelatin solution of Berlin blue, it was concluded that vasa vasorum were found rarely in the media of limb arteries; that there was a constant correlation between the presence of vasa in the media and intimal thickening; that the aorta and iliac arteries only contained vasa in the media on account of its exceptional thickness, and that limb veins possessed vasa penetrating to the intima.

These studies showed a similarity to the results of histological examinations in human arteries by Rokitansky (1855), Soboroff (1872) and Argaud (1903).

(c) <u>Studies showing vasa vasorum in the intima.</u>

The first major contribution to work in this field was by Lotierce (1829) (as reported by Ramsey, 1936), who examined postmortem material and concluded that intimal blood vessels occurred in the arteries of foetuses and "delicate infants", under normal conditions.

About 1870, interest was growing upon the mechanism of intimal nourishment, on account of the confliction between Letierce's work and the reports of Risso (1843), Gerlach (1848), Kölliker (1850-1854), and Gimbert (1865), showing avascularity of the intima.

Köster (1875) examined vessels affected by "arteritis", using routine histological techniques, and reported that capillary beds were also formed beneath the normal intima, with occasional intimal penetration from the lumen of larger vessels.

Durante (1871) and Ehrenreich (1880) expressed the view of the majority of authors that the intima in normal arteries was avascular, and that the method of transporting nutriment to the intima was by diffusion from the vasa vasorum.

While it is beyond the scope of this review to consider, in detail, the physiological data which led to the acceptance of intimal nourishment coming from luminal blood, the early experiments of Petroff (1923) and Anitschkow (1925), showing vital staining of vessel walls, and the absorption of bile pigments by the intima in jaundiced patients, may be mentioned.

Further morphological studies, using histological and injection techniques, by Leary (1938), Paterson

(1936) and Winternitz, Thomas and LeCompte (1938) on normal and pathological specimens of aorta and coronary arteries, showed that the intima is avascular normally, only being vascularized in "arteriosclerosis".

OBSERVATIONS ON THE VASA VASORUM BETWEEN 1938-1963.

This period is characterised by the introduction of microradiographic techniques, as an adjunct to the routine histological and injection methods used in studies of the microcirculation. These two approaches will be considered separately.

(a) Studies involving routine histological and injection techniques:

Short (1940), using Higgins Engrossing Ink, injected normal, phlebosclerotic and thrombosed femoral veins, to show that the femoral artery distributed capillaries to the media of the femoral vein in the form of "sublamellar plexuses"; that "nodal plexuses" of venous vasa were arranged alongside the arterial vasa; that the normal intima was avascular in contrast to the inner layer of the pathologically affected vessels, and that there was "vasal hypertrophy" at the edges of the attached thrombus.

In 1947, O'Neill, by selectively staining red cells with benzidene, demonstrated intramural vessels in the veins of dogs, and showed focal desquamation of the intima with increased permeability to silver nitrate, after experimental deprivation of the vasa.

Additional methods for studying capillary beds were introduced by injecting stained fat (Celestino da Costa, 1947) and the intravascular precipitation of lead chromate (Williams, 1948).

From an examination of three hundred aortae and one hundred coronary arteries, by routine histological techniques, Geiringer (1951) found that the critical thickness for secondary vascularization of the intima in the aorta was 0.5mm. and 0.35mm. for the anterior descending branch of the left coronary artery. The origin of this intimal plexus could be transmedial, luminal, or a combination, in which case an anastomoses occurred between the two sets of vessels.

Studies showing vascularization of the intima have usually been on diseased specimens. Thus Wartman (1950) confirmed the views of Horn and Finkelstein (1940) and Nelson (1941) that the normal arterial intima was avascular, before giving morbid and experimental evidence that haemorrhage in the arterial wall from dissecting aneurysm, occlusion, thrombosis, ischaemia, and rupture was the cause of secondary intimal plexuses.

Staubesand (1959), while primarily concerned with reviewing trends of thought on nutrition of the arterial wall, reported hyperaemia of the vasa after curettage of the aortic and iliac lumina in dogs, and showed cleared specimens of the horse aorta, the inner 1mm. of which was avascular. It was his contention that the innermost layer of the avascular region in the aortic wall was the "achilles heel" of the artery, being most susceptible to the effects of injury.

In an extensive investigation of the arterial wall, Woerner (1959) examined the vasa of the aorta and coronary arteries in human, dog, and rabbit specimens, using a variety of methods, including clearing with methyl salicylate, injection with potassium dichromate and lead acetate, stained fat, selective staining of red cells with benzidene, and staining of endothelial cells with alkaline phosphatase. It was found that the intima and inner third of the media were avascular in all specimens; that intimal capillaries only occurred in the presence of arteriosclerotic lesions or endothelial thickening, and that, in conformity with the views of Barcroft (1944), the mucopolysaccharides might play a significant role in facilitating the diffusion of nutriment through the inner part of the wall.

(b) Studies Involving Microradiography.

The two techniques described in this section are Contact and Projection Microradiography. These methods will be considered separately.

(i) Contact Microradiography.

Pioneered by Lamarque (1938), contact microradiography quickly became recognised as a technique for investigating radio-opaque tissues in biology. Injection of radio-opaque media enabled studies in microarteriography to be performed, Barclay (1947) being among the first workers in this field.

Schlichter (1948), using a gelatin-lead carbonate-mercuric sulfide mixture, described by Dock (1941), injected the aortae of dogs, rabbits, chickens and man, to show that the greatest vascularity was in dog aorta; that experimentally induced atherosclerosis was most easily produced in rabbits, which had the poorest aortic blood supply; that coagulation necrosis of the aortic adventitia in dogs led to cystic necrosis of the media, producing dissecting aneurysm, and that the infant aorta became less vascular with age. Earlier studies (Schlichter, 1946) demonstrated the intramural pattern of vessels in dog aorta, and emphasised the increased frequency of intimal vasa originating in the descending aorta.

Following the work of McCune (1951, 1952) on the vascularization of arterial grafts, Bellman and Gothman (1954), in a microangiographic study of aortic and femoral grafts in dogs, showed the differences between the irregular appearance and distribution of intramural vessels in the grafts and the regular pattern of the vasa vasorum in the adjacent host artery.

de Sousa and Alvares (1960), using a 50% suspension of Micropaque in water, injected the vasa of the aorta in man and dogs; reported "sinuous" and "knot" appearances in the adventitial vessels, which were interpreted as "damping mechanisms" for intramural pressure gradients, and described three patterns of cross sectional branching in the outer third of the media.

Benjamin, Bartenbach and Zeit (1960), investigating the failure of suture lines in homologous arterial transplants, examined the vasa vasorum in the human thoracic and lumbar aorta, and concluded that the vasa arose segmentally from intercostal and lumbar arteries;

that there was no cross anastomosis between vasa of opposite sides; that destruction of the vasa to the area of the aortic wall being grafted was the cause of host aneurysm, and recommended that "resection of a segment of the aorta" should not involve its immediate intercostal artery in the chest or the lumbar artery in the abdomen.

In a series of microangiographic studies, Nylander and Olerud (1960, 1961) described longitudinal adventitial vascular patterns in the abdominal aorta of the dog, which penetrated the outer media, in contrast to the transverse vessels seen in the adventitia of the inferior vena cava; reported on the abdominal intramural vessels observed when the aorta was experimentally compressed with rigid polythene tubing, and concluded that the anoxic tissues produced by the systolic compression of the wall against the tube stimulated vascular growth.

(ii) Work done involving Projection Microradiography

Studies on the blood vessel wall, using Projection Microradiography, are confined to one observation by Wyckoff (1963), in which the radiographic appearances of the human aortic wall were described, without mention of the vasa vasorum.

PART II.

THE PRINCIPLES AND METHODS OF X-RAY MICROSCOPY

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THE PRINCIPLES AND METHODS OF X-RAY MICROSCOPY

The use of x-rays for microscopy relies on the fact that x-rays have a shorter wavelength than light and, therefore, a higher resolving and greater penetrating power.

The present study was undertaken to apply this principle in elucidating the patterns and distribution of the microcirculation in the arterial wall, using the Coslett Nixon x-ray projection microscope (Model X.M.30).

Projection methods of x-ray microscopy depend on a point source of x-rays casting an enlarged image of a nearby object onto a distant fluorescent screen or photographic plate with a resolution approximately similar to the point source. The Coslett Nixon x-ray microscope operates on this principle and routinely provides a resolution of 0.1 - 0.5μ. Since the magnification depends on the ratio of the target-object to target-plate distance, both of which are variable, a primary magnification of up to 500 is obtainable depending on the nature of the object under study. In the present investigation high magnifications were not required to demonstrate the vascular patterns, but advantage was taken of the high penetrating power of the microscope to examine full thickness biological material, which was 50 mm. thick in some instances.

Operation of the Microscope.

The x-ray microscope resembles an inverted electron microscope, the general features of which are shown in text-fig. 1.

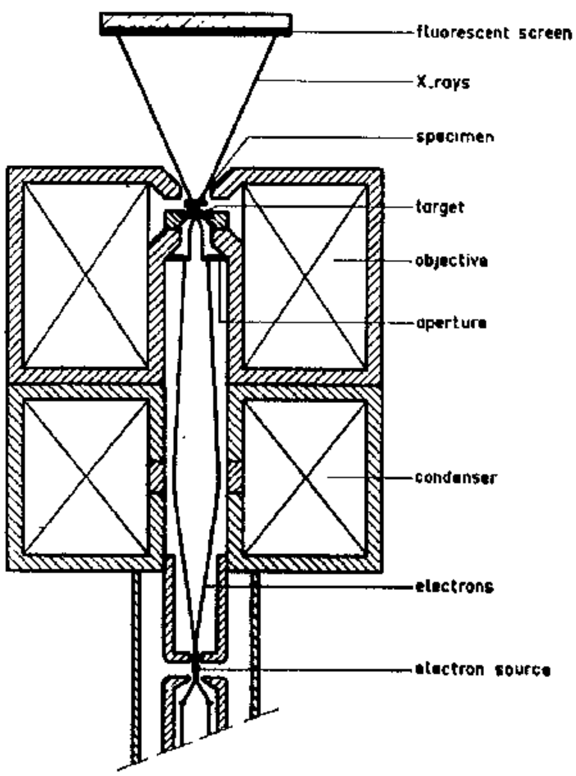
Two variable electro-magnetic lenses, termed the condenser and objective, are mounted vertically above the electron gun. A v-shaped tungsten filament (0.4μ thick) within the gun produces an electron beam, which is accelerated at a selected kilovoltage. The objective lens is fitted with a special polepiece, which produces a strong magnetic field to focus the electrons on a thin target of metal foil supported by a target assembly within the polepiece. The target produces a beam of x-rays over which a fluorescent screen or specimen holder and camera can be placed as required, and acts as a tube window producing an x-ray point source less than 1μ in diameter. The total height of the column is 80 cms.

Preliminary alignment of the microscope is carried out by lateral and axial adjustments of the two lenses, with the object of centring the electron beam upon a

Explanation of Text-Fig. 1.

Diagram illustrating the principles of the Coslett Nixon X-ray Pojection Microscope (Model X.M. 30).

X-RAY MICROSCOPY



Principle of the projection microscope.

TEXT- FIG. 1

small circular viewing screen, which is substituted for the target assembly within the pole piece of the objective lens. A greatly demagnified image of the electron source is first formed and focused on the viewing screen. This screen is then replaced by the target, which emits the x-rays from a point source, thus avoiding the difficulty of focusing x-rays. Additional focusing is carried out upon a fluorescent screen placed above the target. A fine silver mesh grid is used (1500 mesh/inch) and the sharpness of the image adjusted by altering the lens current.

The instrument has a variable kilovoltage (5-30 k.v.) and it is possible to select that voltage which gives the optimum penetration and contrast. The target is interchangeable, and copper, aluminium, tungste or silver may be chosen, depending upon the characteristi x-ray wavelength required.

A target of thin copper foil, used with an accelerating voltage of 15 k.v. and 30 microamperes tube current, provides a satisfactory combination of resolutio penetration and contrast under atmospheric conditions. Aluminium is used for thin tissue with an accelerating voltage of 7 - 10 k.v. and 30 - 50 microamperes tube current, giving the required contrast at the expense of poor penetration.

Microangiography demands a contrast medium of high radio-opacity and small particle size, that is readily miscible with blood and capable of entering the capillary bed. It was found that a colloidal suspension of barium sulphate with a constant particle size of 0.5μ or less fulfilled these conditions, and was marketed by Damancy.* Microangiograms were obtained, using this suspension, after fresh post mortem material had been injected.

Results with X-ray Microscopy.

Projection x-ray microscopy is suited to the study of the microcirculation, since all the blood vessels remain in focus throughout the full thickness arterial wall. In contrast to routine histological techniques, no preparation or sectioning of tissue is required, thus permitting the visualisation of the volume pattern of the blood vessels in undisturbed conditions. Such vascular patterns are unobtainable by light microscopy, even with the aid of clearing techniques.

Conventionally fixed material can be examined by x-ray microscopy, but it must be remembered that

* Damancy & Co., Ware, Hertfordshire, England.

histological fixatives denature protein and appreciably alter x-ray transmission. For this reason the projection micrographs were obtained from freshly injected, unfixed material, thus reproducing conditions which resembled the living arterial wall as closely as possible.

MATERIAL AND METHODS.

The arteries studied in this work and the methods used in examining the microcirculation of the arterial wall will be described, for convenience of reference, in the order the results are recorded in Parts 3, 4 and 5.

The vasa vasorum of the arteries were injected with Micropaque, which is a suspension of barium sulphate. The details and suitability of this product have been discussed above.

Particular care was taken to ensure that Micropaque was introduced at physiological pressures,* and each injection was monitored manometrically. In this way rupture of the vasa vasorum and the manufacture of arteficial channels was avoided. Occasionally, when a rupture did occur in the arterial wall, the irregular outline of the injection medium on the projection micrographs contrasted sharply with the

* 80mm. Hg. for foetuses before the 28th week: 100mm. Hg. until term, and after birth until 10 years of age. Thereafter 120mm. Hg.

regular contour of the mural vessels, and this specimen was discarded.

All the projection micrographs were recorded on Ilford Contrasty Plates.

Vessels in the Postnatal Arterial Wall.

(a) The vasa vasorum of arteries between 15 and 80 years of age.

The Aorta.

Fifty normal aortae were obtained within 8 hours of death, and examined in equally divided five year groups. Prior to injection the specimens were irrigated with saline at 37°C. to remove luminal clot.

The arterial vasa were injected: the ascending aorta retrogradely through the coronary arteries; the arch through the brachio-cephalic trunk and bronchial arteries, and the descending aorta through the intercostal, lumbar and mesenteric arteries.

Venous vasa, to the corresponding parts of the aorta, were injected through the coronary sinus, bronchial, intercostal and lumbar veins.

X-ray projection micrographs of full thickness aorti wall and 1mm. thick longitudinal and transverse sections we cut by hand and recorded, with an exposure time of 10 minutes, a copper target providing the x-radiation.

The microscope was operated at 15 k.v. and 40 microamperes.

The Coronary Arteries.

Fifty pairs of normal coronary arteries were examined within 8 hours of death, in equally divided 5 year groups, and prepared for injection as before.

The arterial side of the microcirculation was demonstrated by injection through the ascending aorta; the venous side through the coronary sinus.

X-ray projection micrographs were taken as before with an exposure time of 8 minutes.

The Pulmonary Trunk and Arteries.

Fifty normal pulmonary trunks and twenty five pairs of pulmonary arteries were examined within 8 hours of death, in equally divided 5 year groups, and prepared for injection as before.

The arterial vasa of the pulmonary trunk were shown by injection through the ascending aorta: the venous vasa through the coronary sinus. In contrast, the arterial vasa of the pulmonary arteries were demonstrated by injection through the bronchial arteries: the venous vasa through the bronchial veins.

X-ray projectioh micrographs were taken as before with an exposure time of 10 minutes.

The Arteries of Root of Neck.

Fifty normal aortic arches, with the attached proximal 3 inches of the brachio-cephalic trunk, left common carotid and subclavian arteries were obtained, prepared and examined in similar groups to the aorta.

The arterial vasa were displayed by injection through the brachio-cephalic trunk and bronchial arteries: the venous vasa through the bronchial veins.

X-ray projection micrographs were taken as before with an exposure time of 10 minutes.

The Vertebral and Internal Carotid Arteries.

Twenty pairs of normal vertebral and internal carotid arteries were examined in equally divided 5 year groups.

The vertebral and internal carotid arteries were injected in situ: the arterial vasa being demonstrated by injection through the vertebral and common carotid arteries in the root of neck: the venous vasa through the vertebral and internal jugular veins. X-ray projection micrographs were taken as before with an exposure time of 6 minutes.

The Basilar and Cerebral Arteries.

Thirty normal postmortem brains were obtained within 8 hours of death, examined in equally divided

5 year groups, and prepared for injection as before.

The arterial vasa were shown by injection through the vertebral and internal carotid arteries.

X-ray projection micrographs were taken as before with an exposure time of 4 minutes.

Upper and Lower Limb Arteries.

Thirty pairs of normal upper and lower limb arteries were obtained within 12 hours of death, examined in equally divided 5 year groups, and prepared for injection as before.

Each artery was removed in a block of tissue with the accompanying veins. The arterial vasa were demonstrated by injecting the limb arteries after occlusion of their branches: the venous vasa through the accompanying veins.

X-ray projection micrographs were taken as before with an exposure time of 5 minutes.

(b) Vasa Vasorum of Arteries between Birth and 5 Years of Age.

Twenty neonatal, and twenty normal aortae of childre were obtained within 12 hours of death. The neonatal specimens were examined in equally divided groups at weekly intervals, and the childrens' aortae at yearly intervals.

The aorta and its collateral branches, with the heart attached, were removed in a single block of tissue and irrigated with saline at 37°C. for 2 hours, before injecting the arterial and venous vasa through similar routes to the adult specimens.

Injection of the arterial vasa in the ascending aorta was accompanied by closure of the coronary sinus, to prevent retrograde filling of the venous vasa through the foramen ovale.

X-ray projection micrographs were taken with an exposure time of 5 minutes. The microscope was operated at 10k.v. and 50 microamperes, an aluminium target providing the x-radiation.

The Pulmonary Trunk and Arteries.

Twenty neonatal, and twenty childrens' pulmonary trunks and arteries were obtained, prepared and examined in similar groups to the neonatal and childrens' aortae.

The arterial and venous vasa were displayed by injecting through similar routes to adult specimens, with the foramen ovale occluded while the ascending aorta was being injected.

X-ray projection micrographs were taken under similar conditions to the aorta.

The Arteries of Root of Neck.

Twenty neonatal, and twenty childrens' aortic arches, with the attached branches were obtained, prepared and examined in similar groups to the aorta.

The arterial and venous sides of the micro-circulation were shown by injection through similar routes to adult specimens.

X-ray projection micrographs were taken under similar conditions to the aorta.

Upper and Lower Limb Arteries.

Thirty pairs of neonatal and childrens' normal limb arteries were obtained, prepared and examined in similar groups to the aorta.

The arterial and venous sides of the micro-circulation were demonstrated by injection through similar routes to adult specimens.

X-ray projection micrographs were taken under similar conditions to the aorta, with an exposure time of 4 minutes.

(c) Vasa Vasorum of Arteries between 5 and 15 Years of Ag

The Aorta.

Fifteen normal aortae of children were obtained within 12 hours of death, and examined in equally distributed three yearly groups.

The aorta and its collateral branches, with the heart attached, were removed in a single block of tissue and irrigated with warm saline at 37°C. for 2 hours, before injecting the arterial and venous vasa through similar routes to the adult specimens.

X-ray projection micrographs were taken with an exposure time of 7 minutes. The microscope was operated at 15 k.v. and 30 microamperes, a copper target providing the x-radiation.

The Pulmonary Trunk and Arteries.

Fifteen normal pulmonary trunks and arteries were obtained, prepared and examined in similar groups to the aorta.

The arterial and venous vasa were injected through similar routes to adult specimens, and x-ray projection micrographs taken with an exposure time of 6 minutes. The microscope was operated under similar conditions to the aorta.

The Arteries of Root of Neck.

Fifteen normal aortic arches were obtained, prepared and examined in similar groups to the aorta.

The arterial and venous vasa were injected through similar routes to adult specimens.

X-ray projection micrographs were taken with an exposure time of 6 minutes, the microscope being operated at 15 k.v. and 40 microamperes, a copper target providing the x-radiation.

The Coronary Arteries.

Fifteen pairs of normal coronary arteries were obtained from children between 3 and 15 years of age, the specimens being prepared similarly to the aorta, but examined in equally divided 2 year groups.

The arterial and venous vasa were injected through similar routes to adult specimens.

X-ray projection micrographs were taken with an exposure time of 4 minutes, the microscope being operated at 10 k.v. and 50 microamperes, an aluminium target providing the x-radiation.

The Upper and Lower Limb Arteries.

Fifteen pairs of normal upper and lower limb arteries were obtained, prepared and examined in similar groups to the aorta.

The arterial and venous sides of the microcirculation were demonstrated through similar routes to adult specimens.

X-ray projection micrographs were taken with an exposure time of three minutes, the microscope being operated at 15 k.v. and 30 microamperes with a copper target providing the x-radiation.

Vasa Vasorum in the Foetal Arterial Wall.

The Aorta.

Thirty foetal aortae were examined from still-births and normal foetuses in equally divided groups at fortnightly intervals from the 12th week of intrauterine life until term, within 12 hours of death.

Between the 12th and 28th week no attempt was made to differentiate between the arterial and venous vasa, the mural vessels being injected by introducing Micropaque through the umbilical vein.

After the 28th week the aorta was obtained, prepared and injected through similar routes to the neonatal and infant specimens, thus showing the arterial and venous sides of the microcirculation separately.

X-ray projection micrographs were taken with an exposure time of 2 minutes for specimens before the 28th week, and 3 minutes thereafter. The microscope was operated at 10 k.v. and 50 microamperes, an aluminium target providing the x-radiation.

The Pulmonary Trunk and Arteries.

Thirty foetal pulmonary trunks and arteries were obtained, prepared and examined in similar groups to the foetal aortae.

The foetal specimens were injected through the umbilical vein prior to the 28th week, and through similar routes to neonatal specimens thereafter.

X-ray projection micrographs were taken under similar conditions to the foetal aorta.

Vasa vasorum of arteries showing adaptive changes at birth.

The Ductus Arteriosus.

Fifteen pairs of foetal ductus arteriosus were obtained and examined in equally divided groups at fortnightly intervals from the 12th week until term, within 12 hours of death.

Ten pairs of normal specimens of neonatal ductus arteriosus; five pairs of infant specimens from the first 5 years of life; five pairs of specimens from children between 5 and 15 years, and twenty pairs of specimens from adults between 15 and 80 years of life, were examined at intervals of 1 week, 1 year, 2 years, and 5 years respectively, in equally divided groups, within 12 hours of death.

Before the 28th week the mural vessels were demonstrated in foetuses by injecting through the umbilical vein, and through the internal mammary artery, ascending and thoracic aorta in specimens after the 28th week and after birth.

X-ray projection micrographs were taken, the operative procedure being shown in Text-Fig. 2.

The Umbilical Arteries.

Umbilical arteries from 20 foetuses, stillbirths and 10 neonates were examined, the antenatal specimens being obtained in equally divided groups at 2 weekly intervals from the 12th week until term, within 12 hours of death.

Prior to the 28th week the foetuses were injected through the umbilical vein, and microradiographed similarly to foetal ductus arteriosus.

After the 28th week the foetuses, stillbirths and neonates were injected through the femoral artery, and microradiographed similarly to foetal and neonatal ductus arteriosus.

When comparing the vascular densities of specimens, the vessels were estimated against a radio-opaque mesh (200 squares /inch), which was superimposed on the specimen when the micrograph was taken. The vessels in each square were then counted, the density measurement being the number of vessels over the total number of squares on the mesh.

The intrinsic vascular arrangements were also studied histologically by Pickworth's method (sodium nitroprusside benzidene stain) and by routine preparation

Explanation of Text-Fig. 2.

Diagram illustrating the operative technique of the microscope in the investigation of the vasa vasorum of the ductus arteriosus.

TYPE of SPECIMEN	OPERATION of MICROSCOPE		TYPE of RADIATION	EXPOSURE TIME
	K.V.	MICROAMPERES		
FOETAL	10	50	Aluminium	1 minute
NEONATAL	15	40	Copper	2 minutes
INFANT	15	40	Copper	3 minutes
CHILDREN	15	40	Copper	5 minutes
ADULTS	15	40	Copper	5 minutes

TEXT-FIG. 2.

techniques with Harris's haematoxylin, Masson's and Mallory's trichrome stains.

These methods were used since the majority of the micrographs were completely translucent, and a routine histological technique was necessary to define the limits of the arterial wall, thus ensuring a correct estimation of the depth the vasa vasorum penetrated. Moreover, a basis for the critical comparison between the routine results of histological techniques and x-ray microscopy was necessary.

PART III.

VESSELS IN THE POSTNATAL ARTERIAL WALL

PART III

VESSELS IN THE POSTNATAL ARTERIAL WALL

INTRODUCTION

The vasa vasorum of arteries studied in postnatal life were, the aorta; coronary arteries; pulmonary trunk and arteries; arteries of the root of neck; basilar and cerebral arteries, and upper and lower limb arteries.

The characteristic vascular patterns in the arterial wall will be examined in three groups, establishing the adult arrangement first.

GROUP I

THE VASA VASORUM OF ARTERIES BETWEEN 15 AND 80 YEARS OF AGE.

The Aorta.

The first observation on the vasa vasorum of the aorta is attributed to Thomas Willis (Haller, 1757).

Other pertinent literature on the intramural vasculature of the aorta has been reviewed in the historical section.

(a) The Ascending Aorta.

From an examination of the micrographs it was concluded that the arterial supply to the ascending aorta originated from the coronary ostia and the terminal ventricular branches of the left coronary artery (Figs. 1 - 2).

It was found that the right and left coronary arteries distributed longitudinal coiled arteriolar channels, 100μ in diameter, to the aortic adventitia (Fig. 3). Frequent anastomoses occurred between the arterioles (Fig. 4).

From this adventitial plexus, arterioles 80μ in diameter penetrated the deep layers of the adventitia (Fig. 5), bifurcated and formed a secondary plexus of vessels, 10-20μ in diameter, in the outer two thirds of the media (Fig. 5).

It was evident from the micrographs that the adventitial arterioles and their immediate branches showed coiling, which was most marked on the convex side of the aorta (Fig. 6).

The terminal branches of the left coronary artery were distributed to the base of the aorta and attachment of the aortic valve. These arteries showed coiling, were 50μ in diameter at their origin, and formed an irregular network in the adventitia before penetrating the outer two-thirds of the media (Figs. 7-8).

From an examination of the micrographs showing the venous side of the microcirculation, it was concluded that there was a dense plexus of veins in the adventitial layer of the aorta, which commenced 1 cm. proximal to the aortic arch and drained into longitudinal venous channels, situated predominantly on the concave side of the aortic wall. Arranged approximately parallel and showing cross anastomoses, these longitudinal channels were 120-140μ in diameter and drained into tributaries of the ventricular coronary veins at the base of the aorta (Fig. 9).

The tributaries of the adventitial plexus originated in the aortic wall at the junction of the intimal and medial layers, thus appearing closer to the aortic lumen than the arteries. Coalescing in an irregular pattern, these tributaries traversed the thickness of the aortic wall to drain into the adventitial venous plexus (Fig.10).

(b) Arch of the Aorta.

The micrographs showed that the summit of the aortic arch received tightly coiled arterioles from the base of the brachio-cephalic trunk, while the sides and concave aspect of the arch of the aorta were supplied by sinuous arterioles from the bronchial arteries (Figs. 11-12).

It was found that the adventitial arterioles were 80-100μ in diameter, and penetrated the outer two-thirds of the media to form a plexus of vessels 10-20μ in diamete (Fig. 13).

The venous vasa commenced as a plexus of vessels, 20μ in diameter, in the inner third of the media, drained through the aortic wall to form an adventitial network of veins 100-140μ in diameter, situated principally on the sides and concavity of the arch, and joined the bronchial veins (Figs. 14-16).

(c) Descending Thoracic Aorta.

It was evident from the micrographs that the intercostal arteries distributed segmentally arranged adventitial arterioles, 80-100μ in diameter, which anastomosed unilaterally to form a longitudinal plexus with no cross anastomoses (Figs. 17-18).

Penetration of the outer two-thirds of the media occurred, with the formation of a secondary plexus of vessels, 10-20μ in diameter (Fig. 19).

The venous vasa originated as a plexus of vessels, 20μ in diameter, in the inner third of the media, traversed the aortic wall, formed a circumferential network of veins in the adventitia, 100-140μ in diameter, and drained into the intercostal veins (Figs. 20-21).

(d) Abdominal Aorta.

From an examination of the micrographs it was shown that adventitial arterioles, 80-100μ in diameter, arose from the lumbar and mesenteric arteries; that the distribution from the lumbar arteries was similar to the intercostals; that the mesenteric arteries supplied long sinuous arterioles to the anterior aspect and bifurcation of the aorta, extending down the common iliac arteries, and that the two sets of arterioles arborised (Figs. 22-24).

An inconstant arterial supply originated from the coeliac axis and small branches of the common iliac artery, to be distributed to the anterior aspect of the aorta and its bifurcation (Figs. 25-26).

Formation of a secondary arteriolar plexus of vessels 10-20μ in diameter, in the middle third of the media was similar to the pattern in the thoracic aorta (Fig. 27).

The origin and mural course of the venous vasa was also similar to the arrangement in the thoracic aorta, but the circumferential network of veins was denser, and drainage occurred to the lumbar veins (Figs. 28-29).

(e) Common Iliac Artery.

Longitudinally arranged, sinuous arterioles, 80 -100μ in diameter, arose from the small branches to the ureters and loose areolar tissue, to penetrate the outer third of the media and form a secondary plexus of vessels 10-20μ in diameter (Figs. 30-31).

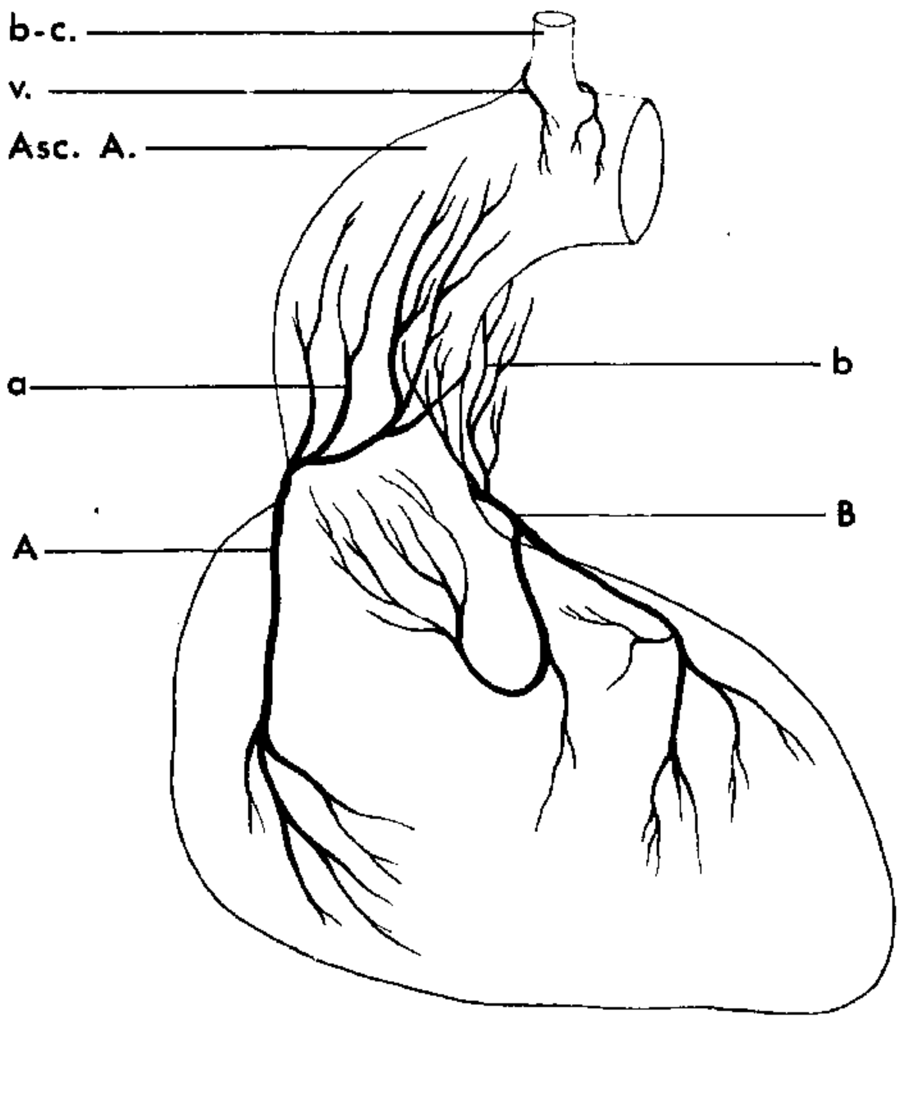
Venous vasa, arising as a network of veins 20μ in diameter in the middle third of the media, traversed the common iliac wall, formed an adventitial plexus of vessels 100μ in diameter, and drained into small retroperitoneal tributaries of the common iliac vein (Figs. 32-33).

The vasa vasorum are of importance since they supply part of the oxygen and nutrition to the aortic wal and the general features of their distribution are shown in text-figs. 3, 4 and 5.

Winternitz, Thomas and Le Compte (1938) concluded that while the aortic intima was only vascularised in "arteriosclerosis", the media contained "large sinusoids" which were venous vasa. Woerner (1959) examined serially cut sections 400μ thick, and reported "a vascular area in the inner half of the wall" in one specimen of the ascending aorta.

Explanation of Text-Fig. 3.

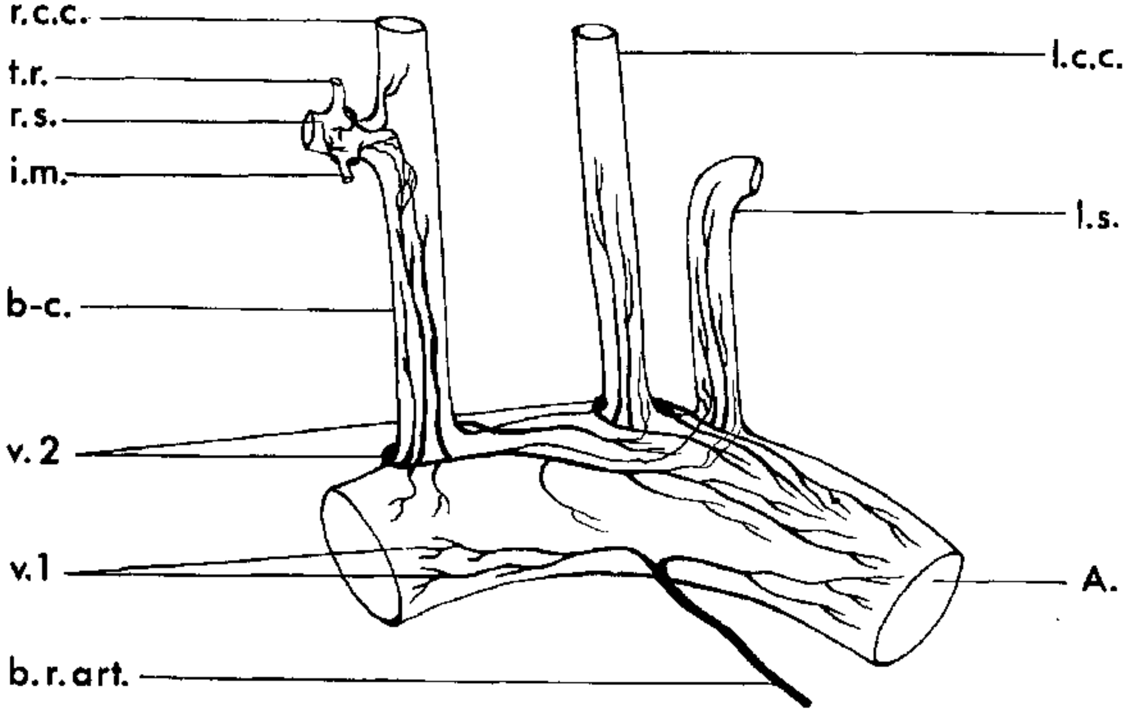
Diagram of the arterial supply to the ascending aorta (Asc.A.) and proximal part of the aortic arch, showing arterial vasa (a) arising from the right coronary (A) and the arterial vasa (b) from the left coronary artery (B). Note the arterial vasa (v) arising from the brachio-cephalic trunk (b-c) to supply the proximal aortic arch, leaving an avascular area between the vasa of the ascending aorta and arch.



TEXT-FIG. 3.

Explanation of Text-Fig. 4.

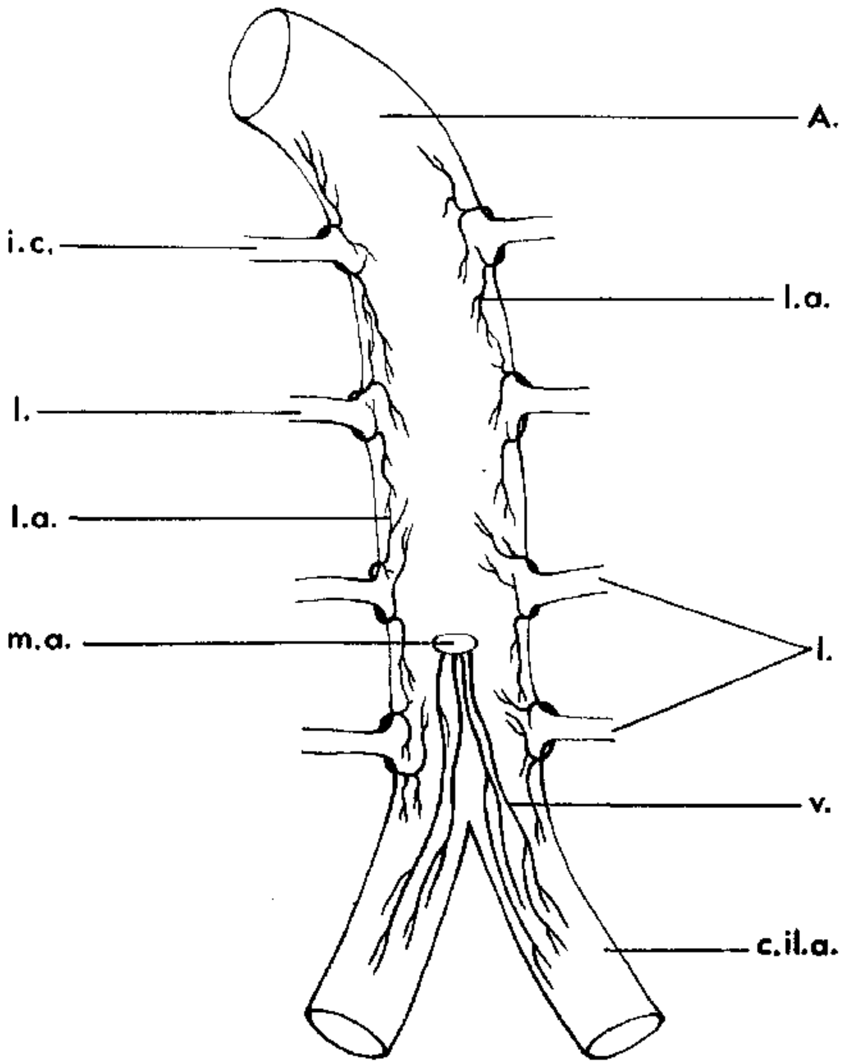
Diagram of the arterial supply to the aortic arch (A), showing arterial vasa (v1) arising from a terminal branch of the bronchial artery (b.r.art.) to supply the sides of the arch, and arterial vasa (v2) originating from the brachio-cephalic trunk (b-c) and left common carotid (l.c.c.) to supply the summit of the arch. Note the branches of the vasa on the summit of the arch supplying the brachio-cephalic trunk, left common carotid and left subclavian (l.s.), and the anastomoses with arterial vasa from the internal mammary (i.m) and thyrocervical trunk (t.r.) of the right subclavian (r.s.). Right common carotid artery (r.c.c.).



TEXT-FIG. 4.

Explanation of Text-Fig. 5.

Diagram of the arterial supply to the descending aorta (A), showing segmental arterial vasa originating from intercostal (i.c.) and lumbar arteries (l) to form longitudinal anastomotic chains (l.a.). Note the arterial vasa (v) originating from a mesenteric artery (m.a.) to supply the anterior aspect of the aorta, bifurcation and common iliac arteries (c.il.a.).



TEXT-FIG. 5.

In this series it was confirmed that the intima in the normal aorta was avascular. Two specimens, however, of the ascending aorta showed intimal stomata, from which a small arteriole, 80μ in diameter arose, pierced the intima without branching, and arborised with the arterial plexus in the media (Fig. 34).

Examination of the vascular patterns in the adventitia and media showed that the venous and arterial sides of the microcirculation could be differentiated in vessels with a diameter greater than 20μ.

It was evident from the micrographs that tortuous vessels 25-30μ in diameter lay at the junction of the media and intima. These were only found after the venous side of the microcirculation had been injected. It is suggested that they correspond to the venous vasa described by Winternitz.

It was concluded, therefore, that since small arterioles 20μ in diameter could be recognised in the middle layer of the media, the capillary-venule bed occurred in the inner third of the media (Fig. 21).

The coiling and sinuosity of the adventitial arterioles, seen in the proximal and distal aorta, were interpreted as defence mechanisms against the varying stretch effect of systole in different parts of the aorta. While there was no evidence of increased vascularity with age, the adventitial arterioles were more tightly coiled in older specimens (Fig. 25).

The arrangement of the adventitial veins on the sides and concavity of the arch of the aorta was regarded as an attempt to protect them from the full effect of the systolic contraction and allow continuous drainage.

The circumferential pattern of veins on the abdominal and thoracic aorta contrasted sharply with the longitudinal venous trunks on the ascending aorta (Figs. 9, 20, 28).

A poorly vascularized zone existed on the posterior aspect of the thoracic aorta, lying between the unilateral, longitudinal, arteriolar plexuses arising from the intercostal arteries and was regarded as a potential site for failure of suture lines in arterial grafting (Figs. 35-36). In contrast, the richer arterial supply to the wall of the common iliac artery and aorta, proximal to its bifurcation, explains the success of "saddle grafts" (Figs. 24, 26. Compare with fig. 35-36).

While a good anastomosis was observed between the arterial vasa of the thoracic, lumbar aorta and common iliac arteries, a poor anastomosis was observed with the arterial supply to the arch of the aorta. It is suggested that these poorly vascularized areas at the proximal and distal ends of the aortic arch are potential weaknesses in the aortic architecture, and may explain the occurrence of aneurysm in this site (Figs. 36a-c). In one specimen, aged 70 years, arterial vasa arose from the base of the left common carotid artery

The Coronary Arteries

Descriptions of the mural vessels in coronary arteries vary. In a study of the coronary artery wall by routine histological techniques from birth to the eighth decade of life, Gross, Epstein and Kugel (1934) concluded that vasa vasorum were not normally found in the media. From an examination of 10μ thick frozen sections of coronary arteries, Geiringer (1951) observed that the normal vasculature was confined to the adventitia, and that with increasing age the outer two thirds of the media might be penetrated.

Woerner (1959), by injecting the vessels in the wall of the anterior descending branch of the left coronary artery with lead acetate and potassium dichromate demonstrated the presence of capillaries in the adventitia and outer third of the media.

The majority of investigators (Paterson, 1936; Leary, 1938; Horn and Finkelstein, 1940; Wartman, 1950) showed that the normal intima was avascular, only acquiring a blood supply in "arteriosclerosis" (Winternitz, 1938) or after it had reached a critical thickness of 0.35mm. (Geiringer, 1951).

From an examination of the micrographs it was concluded that the arterial distribution to the coronary arteries originated from the coronary ostia and the terminal atrial and ventricular branches of the coronary arteries themselves.

It was found that the aortic adventitial arterioles, which arose from the coronary ostia, divided to distribute longitudinal, coiled arteriolar channels, 100μ in diameter to the adventitia of the proximal 1cm. of both coronary arteries and adjacent aortic wall (Figs. 37-38).

From the coronary adventitial plexus arterioles, 60-80μ in diameter, penetrated the deep layers of the adventitia, bifurcated and formed a secondary plexus of vessels, 10-20μ in diameter, in the outer third of the media, with occasional distribution to the middle third (Fig. 39).

It was evident from the micrographs that the arterial supply to the remainder of thecoronary arteries and their principal branches originated from two types of arterioles.

The first type, indirect in nature, was characterised by the fact that it originated extramurally, as a terminal atrial or ventricular branch of the coronary arteries, approached the adventitia, and divided to be distributed as longitudinal arterioles, 80-100μ in diameter (Fig. 40).

The second type, direct in nature, originated intramurally from a collateral branch of the coronary artery, while the course of the collateral branch was traversing the coronary artery wall (Fig. 41).

It was apparent that the indirect arteries supplied the outer third and occasionally the middle third of the media with longitudinally arranged arterioles 20-40μ in diameter (Fig. 42), while the direct arteries were distributed circumferentially in the outer third of the media, as arterioles 20-30μ in diameter (Fig. 43).

From an examination of the micrographs showing the venous side of the microcirculation, it was concluded that there was a dense network of veins, 80-100μ in diameter, in the adventitia of the coronary wall, which originated in the middle third of the media (Figs. 44-45).

It was found that the coronary adventitial venous plexus was a tributary of the aortic adventitial veins in the proximal 1cm. of both coronary arteries (Fig. 46), and a tributary of the atrial and ventricular veins elsewhere (Fig. 44).

The present study has demonstrated that there is an extensive vascular supply to the coronary artery wall, the general features of which are shown in text - fig. 6.

From his examination of the human coronary artery wall, Geiringer (1951) reported that the normal vasculature was confined to the adventitia, only penetrating the media with age, while Woerner (1959) stated that vessels were normally found in the adventitia and outer third of the media.

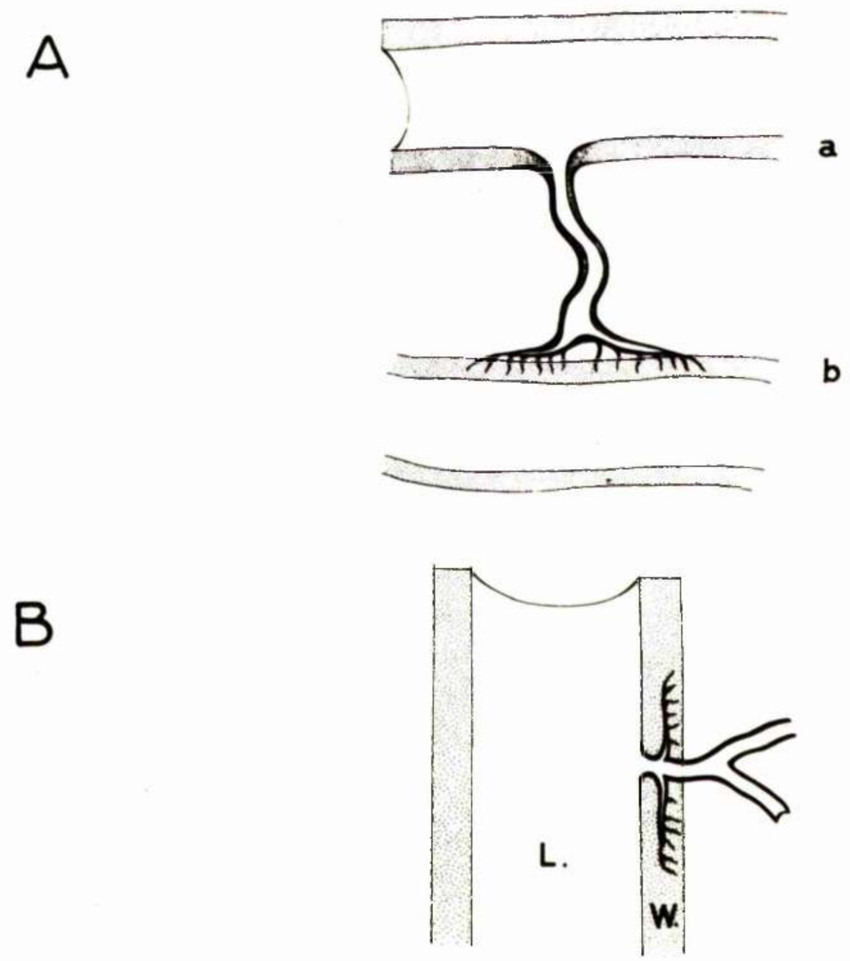
In this series, in addition to confirming that the intima and inner third of the media was avascular at all ages in the normal vessel wall, it has been shown

Explanation of Text-Fig. 6.

The arterial supply of the coronary artery wall.

Diagram A. Note collateral branch of coronary artery, (a), giving arterial vas to parent coronary artery (b).

Diagram B. Note origin of arterial vas from collateral branch as it passes from the lumen (L) through the main vessel wall (W).



TEXT - FIG. 6.

that the arterial and venous sides of the microcirculation can be differentiated in the adventitia and outer media, in vessels with a diameter greater than 20μ.

The coiling of the arterioles in the adventitia of the proximal 1cm. of the coronary artery, was interpreted as a defence mechanism against excessive stretch during systole. No anastomoses between the coronary and aortic adventitial arterioles were observed.

Particular attention was paid to the circumferential and longitudinal arrangement of the arterioles in the remainder of the coronary artery wall and principal branches.

The absence of the circular set of arterioles from the proximal 1cm. of the coronary arteries indicates a specific function.

During systole, it is suggested that the circumferential arrangement of the arterioles in the outer third of the media allows a minimal alteration in their luminal diameter, resulting in continuous mural blood flow. In contrast, the systolic effect on the longitudinal arterioles would result in an intermittent supply of blood to the coronary artery wall.

Examination of the vascular patterns in the media showed that arterioles with a diameter greater than 20μ could be identified in the outer third of the media, and that vessels could be demonstrated in the middle third of the media, 20-25μ in diameter, only after the venous side of the microcirculation had been injected.

It was concluded, therefore, that the capillary-venule bed normally occurred in the middle third of the media (Fig. 45).

With age there was evidence that the middle third of the media was penetrated by the arteriolar plexus and that the arterioles were occasionally more tightly coiled in specimens over fifty years of age (Figs.47-48).

The Pulmonary Trunk and Arteries.

Little work could be found in the literature on the vasa vasorum of the pulmonary trunk and arteries in man. Studies on the mural vessels often referred to the "pulmonary artery" without specifying the exact area being described. For this reason the main papers examining the blood vessels in the pulmonary wall will be reviewed in the authors' context.

Robertson (1929), during an injection study of the vasa vasorum with coloured cellulose in the ascending aortae of dogs and lambs, noted branches of the adventitial vessels being distributed over the "pulmonary artery" from the aortic-pulmonary groove.

By injecting the mural vessels in the human "pulmonary artery" with Higgins Engrossing Ink, Winternitz, Thomas and LeCompte (1938) concluded that the degree of vascularity lay between systemic arteries and veins, but did not illustrate their observations.

In their monographs on the lung, Miller (1950) and von Hayek (1960), stated without further amplification that the vasa vasorum to the pulmonary artery and its branches arose from the bronchial arteries.

Studies on human cadaveric and autopsy "pulmonary arteries", using routine histological and injection techniques, led Tobin (1960) to conclude that the mural vessels were confined to the outer third of the media and that the vasa on the pulmonary veins formed a richer plexus than on the arterial wall.

Sobin, Frasher and Tremer (1962), by injecting rabbits in vivo with silicone rubber, examined the vasa in the "pulmonary artery and its branches"; showed the spiral nature of the adventitial arterioles, and demonstrated venous vasa, parallel to the arterioles, as tributaries of the cardiac veins.

Anastomoses between the coronary and bronchial arteries, through the vasa of the pulmonary trunk have been postulated by Haller (1757), Cruveilhier (1842), and Gross (1921), but illustrations are not shown.

(a) The Pulmonary Trunk.

From an examination of the micrographs it was concluded that the arterial supply to the walls of the pulmonary trunk, bifurcation and proximal 1cm. of the pulmonary arteries, originated from the coronary ostia and the terminal ventricular branches of the right coronary artery.

It was found that the coronary ostia distributed arterioles, 100μ in diameter, to the aortic-pulmonary groove: the right anteriorly; the left posteriorly (Fig. 49). Branches from the arterioles in the aortic-pulmonary groove formed two patterns in the adventitia of the pulmonary trunk.

The first pattern, consisting of longitudinal, coiled arterioles, 60-80μ in diameter, lay along the convex border of the pulmonary trunk, and terminated on the dorsal aspect of the bifurcation in an irregular network of vessels (Fig. 50).

The second pattern was composed of short, coiled arterioles, 60-80μ in diameter, forming asymetrical networks and appeared on the anterior and posterior wall of the pulmonary trunk, terminating at the pulmonary bifurcation (Figs. 51-52).

It was evident from the micrographs that the arteriolar plexus on the pulmonary bifurcation distributed parallel, coiled arterioles, 40-50μ in diameter, to the proximal 1cm. of the pulmonary arteries (Fig. 53).

From the adventitial arterial plexus on the pulmonary trunk, bifurcation and proximal 1cm. of the pulmonary arteries, sinuous arterioles penetrated the deep layers of the adventitia, to form a secondary network of vessels, 10-20μ in diameter, in the outer third of the media (Fig. 54).

Terminal ventricular branches of the right coronary artery were distributed to the base of the pulmonary trunk and the attachment of the pulmonary valve. These arterioles showed coiling, were 50μ in diameter at their origin, and formed an irregular network in the adventitia before penetrating the outer third of the media (Figs. 55-56).

Examination of the micrographs demonstrating the venous vasa of the pulmonary trunk, bifurcation and proximal 1cm. of the pulmonary arteries, showed veins, 25-30μ in diameter, originating in the middle third of the media, traversing the pulmonary wall, and draining into longitudinally arranged adventitial vessels, 100-140μ in diameter, which were tributaries of the ventricular coronary veins (Figs. 57-58).

Anastomoses between the adventitial veins of the aorta and pulmonary trunk were observed across the aortic-pulmonary groove (Fig. 59).

(b) The Pulmonary Arteries.

From an examination of the micrographs it was concluded that the arterial distribution to the pulmonary arteries originated from the terminal branches of the bronchial arteries.

It was found that the adventitial arteriolar plexus was formed by arteries, 100-120μ in diameter, which approached the wall of the pulmonary artery obliquely, to divide and distribute longitudinal, coiled arterioles, 60-80μ in diameter, to the outer layers of the adventitia (Figs. 60-61).

The arterial vasa in the adventitia of lobar and segmental branches of the pulmonary artery showed a characteristic sinuosity, which diminished and and finally disappeared, leaving parallel, straight, adventitial arterioles, 40-50μ in diameter in the walls of branches less than 1cm. in diameter (Figs. 62-63).

It was clear from the micrographs that, while arterioles, 40-50μ in diameter, penetrated the deep layers of the adventitia, to bifurcate and form a secondary plexus of vessels 10-20μ in diameter, in the outer third of the media in the extrahilar part of the pulmonary arteries, the arterial network was confined to the adventitia in the remainder of the pulmonary arterial tree (Figs. 64-65).

The venous vasa, arising in the deep adventitial layers of the intrahilar branches of the pulmonary artery, as vessels 25-30μ in diameter, and at the junction of the outer and middle thirds of the media elsewhere, traversed the pulmonary wall to form a dense network of adventitial veins, 60-100μ in diameter, and become tributaries of the bronchial veins (Figs. 66-69).

This study has shown the extensive network of mural vessels in the pulmonary trunk, arteries and their branches the general features of which are shown in text-fig. 7.

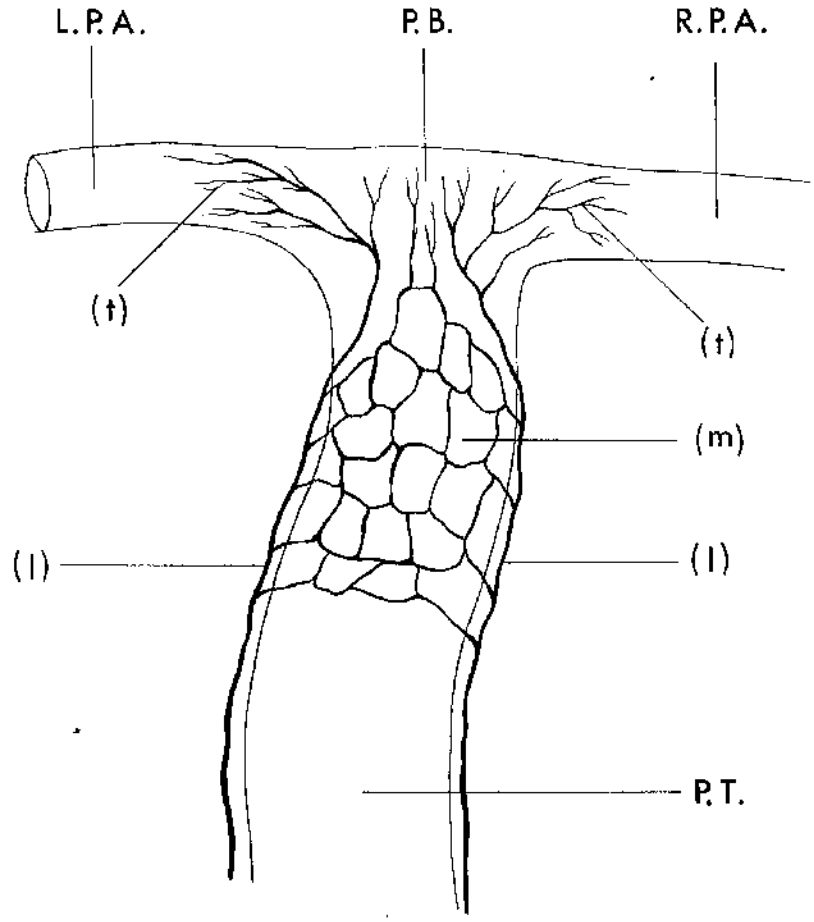
Examination of the vascular patterns in the adventitia and media showed that the arterial and venous sides of the microcirculation could be differentiated in vessels with a diameter greater than 20μ.

In comparison to the ascending aorta, it was found that the distribution of pulmonary adventitial arterioles was richer (Figs. 2, 50).

The coiling and sinuosity of the adventitial arterioles in the pulmonary trunk, arteries and their segmental branches, was interpreted as a defence

Explanation of Text-Fig. 7.

Diagram of the arterial supply to the pulmonary trunk (P.T.), pulmonary bifurcation (P.B.), and right and left pulmonary arteries (R.P.A.;L.P.A.), showing the longitudinal arterial vasa (1) on the margins of the pulmonary trunk, and the mosaics (m) on the anterior surface. Note the termination of the arterial vasa (t) on the pulmonary bifurcation and proximal parts of the pulmonary arteries.



TEXT - FIG. 7.

mechanism against vasal stretch during systole.

Particular attention was paid to the two distinct arterial patterns in the adventitia of the pulmonary trunk. It is suggested that the longitudinal, tightly coiled arterioles, found on the convex side of the pulmonary trunk, are being exposed to the maximal stretch of the unsupported pulmonary wall, while the mosaic arteriolar pattern on the anterior and posterior walls of the pulmonary trunk is an adaptation to maintain circulation under less severe conditions of vasal stretch.

From studies on the blood supply to the heart, Gross (1921) concluded that an anastomoses existed between the coronary and bronchial arteries through the vasa of the pulmonary trunk. The terminal distribution of the arterial vasa to the pulmonary trunk has been shown to occur 1cm. lateral to the pulmonary bifurcation. In this series it was confirmed that a rich anastomoses existed between the coronary and bronchial arteries through the vasa on the proximal 1cm. of the pulmonary artery (Fig. 70).

Since recognisable arterioles, 20μ in diameter, could be identified in the outer third of the media in the pulmonary trunk, pulmonary arteries, and superficially in the adventitia of arteries within the lung, and since vessels, 25-30μ in diameter, could be demonstrated in the middle third of the media in the pulmonary trunk and at the junction of the outer and middle third of the media and deep adventitial layers in corresponding parts of the pulmonary tree, after injection of the venous side of the microcirculation, it was concluded that the capillary-venule bed in the pulmonary trunk occurred in the middle third of the media: in the outer third of the media of the pulmonary artery, and in the deep layers of the adventitia in its intra-hilar branches (Figs. 58,64, 65).

With age, while there was no evidence of increased vascularity in any part of the arterial tree or additional anastomoses with the ascending aortic vasa through the arterioles in the aortic-pulmonary groove, an increased coiling and tortuosity of the adventitial arterioles was noted on the pulmonary trunk and proximal part of the pulmonary artery (Fig. 70).

Attempts to demonstrate where the arterial wall was completely dependent upon luminal blood for nutriment showed that vasa vasorum could not be demonstrated in arteries with a diameter less than 2mm., the longitudinal arteriolar plexus becoming progressively poorer up to this point (Fig. 63).

In this study it was confirmed that the intima was avascular.

The Arteries of Root of Neck

Lowenberg and Schumacker (1948), by staining red cells with benzidene, demonstrated the differences in vascular patterns between arterial and venous vasa in canine carotid aorta and coronary vessels, and concluded that this method would be suitable for investigation of the role of the vasa in arterial repair and venous transplantation.

It was evident from the micrographs that the proximal arterial supply to the root of neck arteries originated from the arteriolar plexus on the summit of the aortic arch, and anastomosed distally, in the case of the brachio-cephalic trunk and left subclavian, with arterial vasa arising from the thyrocervical trunk and internal mammary arteries (Figs. 71-72).

Parallel, longitudinally arranged, coiled adventitial arterioles, 80-100μ in diameter, surrounded the brachio-cephalic trunk, left common carotid and subclavian arteries, branches penetrating the outer third of the media to form a secondary plexus of vessels 10-20μ in diameter (Figs. 71, 73).

From an examination of the micrographs it was clear that the venous vasa originated in the middle third of the media, traversed the walls of the root of neck arteries, to drain into longitudinally arranged veins, 80-100μ in diameter, which were tributaries of the aortic arch venous plexus (Figs. 74-75).

The present study has shown that there is an extensive vascular supply to the root of neck arteries, the general features of which are shown in text-fig. 4.

While the arteriolar plexus on the brachio-cephalic trunk had the richest and most markedly coiled distribution of the three root of neck arteries, the arterial supply to the left subclavian was poorest. The coiling of the adventitial arterioles was regarded as a defence mechanism against the stretching effect of systole.

The arterial supply to the bifurcation of the brachio-cephalic trunk from the thyrocervical trunk and internal mammary artery of the right subclavian anastomosed freely with the proximal arteriolar channels from the aortic summit (Fig. 72).

A similar anastomoses occurred on the left subclavian artery at the level of the thoracic inlet.

The longitudinal venous plexus, richest on the brachio-cephalic trunk and poorest on the left subclavian, was similar in distribution to the adventitial veins in the ascending aorta.

Since recognisable arterioles, 20μ in diameter could be recognised in the outer third of the media, and vessels 25-30μ could be demonstrated in the middle third of the media, only after the injection of the venous side of the microcirculation, it was concluded that the capillary-venule bed occurred in the middle third of the media (Fig. 74).

A similar distribution of vasa vasorum can be demonstrated in the common iliac arteries, revealing a greater portion of avascular arterial wall than in the parent aorta, where the capillary-venule bed has been shown to lie in the inner third of the media.

The Vertebral and Internal Carotid Arteries

No references could be found in the literature on the patterns and distribution of the vasa vasorum in human vertebral and internal carotid arteries.

It was found that the extracranial arterial supply to the vertebral artery originated from spinal arteries in the foramina transversaria, while the internal carotid received an arteriolar plexus from the terminal branches of the ascending pharyngeal, occipital and posterior auricular arteries.

Longitudinally arranged adventitial arterioles, occasionally coiled and 40-80μ in diameter, surrounded both arteries to penetrate the outer third of the media in the proximal third of their extracranial courses only (Figs. 76-80).

Examination of the micrographs showed that the intracranial arterial supply to both arteries was formed by an extension of the extracranial adventitial plexus into the skull, to anastomose with arterioles from the posterior inferior cerebellar and inferior hypophyseal arteries respectively (Figs. 81-82).

The intracranial adventitial plexus of vessels, 30-60μ in diameter, were longitudinally arranged, uncoiled and entirely confined to the adventitia (Figs. 83-84).

It was evident from the micrographs that the venous vasa commenced at the base of skull, as a longitudinally arranged plexus of vessels, 50-100μ in diameter, which became richer and drained the outer third of the media on the wall of the proximal portion of the vertebral and internal carotid arteries (Figs. 85-90).

The aim of this study was to compare the intramural vessels on the intra and extracranial parts of the vertebral and internal carotid arteries.

The adventitial arterioles on the wall of the proximal part of both arteries showed occasional coiling, and this was interpreted as a defence mechanism against the stretch effect of systole. Intracranially, in contrast, there was no coiling, and although an anastomoses existed with the extracranial plexus, the distribution of the arterioles was less dense.

While the adventitial arterioles on the intracranial part of the vertebral artery could be traced onto the basilar artery, the arterial supply ceased on the internal carotid artery at the origin of the anterior and middle cerebral arteries (Fig. 91).

It would appear that the intra and extracranial venous vasa drain separately. Injection of the vertebral and internal jugular veins showed vessels starting at the base of the skull. Attempts to demonstrate the intracranial veins on the arterial wall failed on account of a well defined drainage route.

As indicated by the x-ray microscope there is no specialised arrangement of the vasa at the carotid sinus.

Since recognisable arterioles, 20μ in diameter could be demonstrated in the outer third of the media in the proximal part of the vertebral and internal carotid arteries, and since venous vasa, with a diameter greater than 20μ, could be seen in these layers also, it was concluded that the capillary-venule bed lay in the outer third of the media in the proximal parts of the arteries, and in the deep layers of the adventitia elsewhere (Figs. 78, 80, 83, 84).

Age changes revealed an increased vascularity of the vertebral artery only, and an increased tortuosity of the arterioles on both arteries in older specimens (Figs. 92-93).

The Basilar and Cerebral Arteries

With the exception of Gimbert (1865), who concluded that the distribution of the vasa vasorum to the basilar artery was less dense than to the walls of other arteries, there have been no significant observations upon the distribution of mural vessels in the basilar artery.

It was found that the arterial supply to the basilar artery was indirect in nature, being characterised by the origin of arterioles, 60-80μ in diameter from terminal branches of the basilar artery, which looped back to the parent vessel, to be distributed in the adventitia (Fig. 94).

Forming a sparse adventitial plexus, longitudinally arranged, the arterioles showed no evidence of coiling or penetrating the inner layers of the wall (Fig. 95).

From an examination of the micrographs it was clear that there were no vasa vasorum in the walls of the cerebral arteries.

Observations on the internal carotid artery, proximal to the origin of the anterior and middle cerebral arteries, revealed a small number of arterioles, 40-60μ in diameter, in the adventitia alone. (Fig. 91).

The arterial walls of the circle of Willis were shown to be avascular, except in four cases, where terminal branches from the adventitial arterioles on the basilar artery could be followed onto the adventitial layer of the posterior communicating artery (Fig. 96).

Routine histological examination of the walls of the basilar and cerebral arteries shows that the media is poorly developed, the adventitia being the principal layer (Bloom and Fawcett, 1962).

Distal to the union of the vertebral arteries, the arteriolar plexus on the basilar artery progressively diminishes, and disappears on the posterior communicating artery. It was concluded, therefore, that the source of nutriment was principally luminal, and completely so in the cerebral arteries, where no vasa could be demonstrated.

The lack of a well defined route for the venous drainage of the basilar artery, prevented a completed picture of the microcirculation being demonstrated. In one specimen the internal jugular vein was injected with the brain in situ, and a small plexus of vessels was found on the basilar artery, but the technique had to be abandoned on account of subcutaneous staining of the face by the injection medium.

Examination of the age changes in the distribution of the arterial vasa to the basilar artery, revealed an increase in vascularity of the adventitia, and slight tortuosity of the arterioles in one specimen, aged 70 years (Fig. 97). There was no evidence of vascularization of the media in older specimens.

Upper and Lower Limb Arteries

Descriptions of the distribution of the vasa vasorum in limb arteries in man vary. The main papers describing the mural vessels are found in nineteenth century literature, recent works being few in number.

From an examination of upper and lower limb arteries obtained surgically and at necropsy, Gimbert (1865) concluded that the vasa vasorum of a limb artery arose from its collateral branches or neighbouring arteries, to penetrate the wall and be distributed to the adventitia and occasionally the media. This view was supported by Letierce (1829)*, Schulman (1892), and Sewell (1913), upon microscopic preparations of normal arteries.

Injection studies upon human common iliac and femoral arteries, using an aqueous solution of Berlin blue, led Plotnikow (1884) to state that the vasa vasorum of limb arteries were confined to the adventitia, only penetrating the media if intimal thickening

*As cited by Ramsey (1936).

occurred. This belief was shared by Rokitansky (1855), Soboroff (1872), Argaud (1903), and Lange (1924), using routine histological techniques to study normal and diseased arteries.

With vital staining techniques, Petroff (1923) showed that the intima and inner third of the media of arteries derived nutriment from the lumen of vessels, the remainder of the wall being supplied by the vasa vasorum. This opinion was supported by Antischkow (1925), who demonstrated the postmortem absorption of bile pigment by the intima; in vivo absorption of bile pigment in jaundiced patients, and the absorption of cholesterol by rabbits under experimental conditions.

The views of these authors have been reviewed against the background of their contemporary opinion in the historical section.

(a) Upper Limb Arteries.

From an examination of the micrographs it was concluded that the arterial supply of the subclavian, axillary, brachial, radial and ulnar arteries was indirect in nature, the adventitial arterioles arising extramurally from the terminal arborisations of collateral branches of the parent artery.

It was found that arteries, 120-150μ in diameter, approached the adventitia obliquely, to divide and distribute longitudinal coiled arterioles, 80-100μ in diameter, to the wall of the subclavian, axillary and brachial arteries (Figs. 98-100).

The arterial vasa in the adventitia of the radial and ulnar arteries showed a characteristic sinuosity, which diminished and finally disappeared, leaving parallel, straight arterioles in the adventitia, 30-50μ in diameter (Figs. 101-102).

It was clear from the micrographs that, while arterioles 40-50μ in diameter, penetrated the deep layers of the adventitia, to bifurcate and form a secondary plexus of vessels, 10-20μ in diameter, in the outer third of the media of the subclavian and axillary arteries, the arterial network was confined to the adventitia in the remainder of the limb arteries (Figs. 103-104).

The venous vasa, arising in the deep layers of the adventitia in the radial, ulnar and brachial arteries, as vessels 25-30μ in diameter, and at the junction of the outer and middle third of the media in the subclavian and axillary arteries, traversed the arterial wall to form a dense network of adventitial veins, 60-100μ in diameter, and become tributaries of adjacent muscular and accompanying veins (Figs. 105-108).

(b) Lower Limb Arteries.

From an examination of the micrographs it was concluded that the arterial supply to the femoral, popliteal and tibial arteries was indirect in nature, the adventitial arterioles arising extramurally from the terminal arborisations of collateral branches of the parent artery.

It was found that arteries, 100-120μ in diameter, approached the adventitia obliquely to divide and distribute longitudinal coiled arterioles, 80-100μ in diameter, to the wall of the femoral and popliteal arteries (Figs. 112-113).

The arterial vasa in the adventitia of the arteria profunda, medial and lateral circumflex femoral and tibial arteries showed a characteristic sinuosity, which diminished and finally disappeared, leaving parallel, straight adventitial arterioles, 30-50μ in diameter (Figs. 114-117).

It was clear from the micrographs that, while arterioles, 40-50μ in diameter, penetrated the deep layers of the adventitia, to bifurcate and form a secondary plexus of vessels, 10-20μ in diameter, in the outer third of the media of the femoral artery, the arterial network was confined to the adventitia in the remainder of the limb arteries and their principal branches (Figs. 118-119).

The venous vasa, arising in the deep layers of the adventitia in the arteria profunda, medial and lateral circumflex femoral and tibial arteries, as vessels 25-30μ in diameter, and at the junction of the outer and middle third of the media in the femoral artery, traversed the arterial wall to form a dense adventitial network of veins, 60-100μ in diameter, and become tributaries of adjacent muscular and accompanying veins (Figs. 120-124).

The aim of this study was to demonstrate the mural vessels in the principal arteries of the upper and lower limbs.

Examination of the vascular patterns in the adventitia and media showed that the arterial and venous sides of the microcirculation could be differentiate in vessels with a diameter greater than 20μ.

In the principal arteries of the upper and lower limbs, the longitudinal, adventitial arterioles in the arterial wall anastomosed proximally and distally, so that a profuse plexus of vessels was formed around the length of the arterial tree (Figs. 109, 125).

The characteristic coiling of the adventitial arterioles was interpreted as a defence mechanism against vasal stretch during systole.

Attempts to demonstrate where the arterial tree was completely dependent upon luminal blood for nutriment showed that the vasa vasorum could not be observed in arteries with a diameter less than 2mm., the longitudinal arteriolar plexus becoming progressively poorer up to this point (Figs. 110, 126).

Particular attention was paid to the capillary-venule bed. It was evident from the micrographs that vessels 25-30μ in diameter, lay at the junction of the outer and middle thirds of the media in the subclavian, axillary, and femoral arteries, and in the deep layers of the adventitia in the remainder of the arterial tree. These vessels were only found after the venous side of the microcirculation had been injected. Since an arteriolar plexus could be demonstrated in the outer third of the media in the subclavian, axillary and femoral arteries, and in the adventitia of the remainder of the distal principal limb arteries, it was concluded that the capillary-venule bed lay at the junction of the outer and middle third of the media in the subclavian, axillary, and femoral arteries, and in the deep layers of the adventitia elsewhere (Figs. 107, 108, 123, 124).

With age, increased coiling and vascularity was observed in the arterial wall over forty, especially in the proximal arteries of the limb, but there was no evidence of further mural penetration (Figs. 111, 127).

In all specimens examined, it was confirmed that the intima was avascular.

GROUP II.

THE VASA VASORUM OF ARTERIES BETWEEN BIRTH AND 5 YEARS OF AGE

Little work could be found in the literature on the vasa vasorum of arteries in the early years of life.

In a comparative review of the aortic blood supply in dogs, chickens, rabbits and man, Schlichter (1948) concluded that the greatest vascularity was in infant aortae.

The aim of this study was to establish alterations in the vascular patterns in the arterial wall during the neonatal period (first month of life), and at yearly intervals thereafter.

The Aorta

From an examination of the micrographs it was concluded that the arterial supply to the neonatal and infant aortae originated similarly to the adult, but varied in distribution.

(a) The Ascending Aorta.

In the neonatal aortae, it was found that an irregular network of arterioles, 40-60μ in diameter, densest around the base of the aorta, was formed in the adventitia (Fig. 128).

In the infant aortae, the irregular adventitial network was less dense at the end of the first year, being replaced by longitudinal, sinuous arterioles, 60μ in diameter, in the second year (Fig. 129).

It was clear from the micrographs that by the fifth year the longitudinal arteriolar pattern had increased in density, the vessels showing slight coiling and terminating proximal to the aortic arch (Fig. 130).

From the adventitial arteriolar plexus, the arterial vasa penetrated the outer third of the media to form a secondary network of vessels, 10-20μ in diameter, in the fourth year (Fig. 131).

Examination of the micrographs showed that the venous vasa formed an irregular plexus, densest in neonatal aortae, consisting of vessels 50-70μ in diameter, which was confined to the adventitia until the fourth year, when it drained the outer third of the media (Figs. 132-134).

(b) Arch of the Aorta

In the neonatal aortae, it was found that an irregular network of arterioles 40-50μ in diameter, densest on the summit of the aorta, existed in the adventitia (Fig. 135).

In the infant aortae, the irregular adventitial network was less dense at the end of the first year, being replaced by sinuous arterioles on the summit of the aorta, but remaining plexiform elsewhere (Fig. 136).

It was apparent from the micrographs that by the fifth year the sinuosity of the arterioles on the summit of the aortic arch had increased, while a longitudinally arranged pattern of arterioles had replaced the irregular plexus on the sides and concavity of the arch (Figs. 137-138).

From the adventitial arteriolar plexus, the arterial vasa penetrated the outer third of the media to form a secondary network of vessels, 10-20μ in diameter, in the fourth year (Fig. 139).

Examination of the micrographs showed that the venous vasa formed an irregular plexus, densest in neonatal aortae, which was confined to the adventitia until the fourth year, when it drained the outer third of the media, to form a network of vessels, 50-70μ in diameter (Figs. 140-142).

(c) Descending Aorta.

In the neonatal aortae it was found that a spiral network of arterioles, 40-60μ in diameter, encircled the descending thoracic and abdominal aorta (Fig. 143).

In the infant aortae, the spiral network was replaced by an irregular plexus of arterioles, 50-70μ in diameter, situated predominantly on the lateral aspects of the aorta in the second year, and by the fourth year the longitudinal arrangement of arterioles, seen in adult aortae, was forming, leaving a narrow avascular area on the dorsal aspect of the descending aorta (Figs. 144-145).

From the adventitial arteriolar plexus, the arterial vasa penetrated the outer third of the media to form a secondary network of vessels, 10-20μ in diameter, in the fourth year (Fig. 146).

Examination of the micrographs showed that the venous vasa formed an irregular plexus, densest in neonatal aortae, which was confined to the adventitia until the fourth year, when it drained the outer third of the media to form a network of veins, 80-100μ in diameter (Figs. 147-149).

(d) Common Iliac Artery.

In the neonatal arteries it was found that an irregular network of arterioles, 40-60μ in diameter, was formed in the adventitia (fig. 150).

In the infant arteries, the irregular adventitial network was less dense at the end of the first year, being replaced by longitudinal, sinuous arterioles in the fourth year (Figs. 151-152).

From the adventitial arteriolar plexus, arterial vasa penetrated the superficial layers of the outer third of the media in the fourth year, to form a secondary network of vessels, 10-20μ in diameter (Fig. 153)

Examination of the micrographs showed that the venous vasa formed an irregular plexus, densest in neonatal aortae, which was confined to the adventitia until the fourth year, when it drained the superficial layers of the outer third of the media to form a network of veins, 60-80μ in diameter (Figs. 154-156).

It was clear from the micrographs that the vascular patterns displayed by the mural vessels in the aorta altered considerably in the first five years of life, and that these changes occurred at the same time in different parts of the aorta.

The first year of life was characterised by an irregular network of arterial vasa on the ascending aorta and arch, with a well defined spiral arrangement of vessels on the descending aorta, both patterns being reduced in vascular density towards the end of the year. This arrangement of vessels was similar to the pattern seen in the aortic wall in the later months of intrauterine life (vide infra). The reduction in vascularity was interpreted as the first stage in the alteration of the vasal architecture to the adult form.

The second year was characterised by the appearance of longitudinally arranged, sinuous arterioles on the ascending aorta and the summit of the aortic arch, including a replacement of the spiral network on the descending aorta by an irregular plexus of arterioles, situated principally on the lateral aspect of the aorta. These changes were found to occur constantly in specimens between the ages of 12-18 months, and were regarded as the templates for the formation of adult patterns.

Between the end of the second and fourth years, the appearance of the arterial vasa in the adventitia resembled the adult picture more closely on account of the increased sinuosity of the arterioles on the ascending aorta and the summit of the aortic arch. The lateral longitudinal plexus of arterial vasa was clearly demonstrable by the end of the fourth year on the descending aorta, with a definite area of diminished vascularity on the dorsal aspect.

Penetration of the superficial layers of the media by small arterioles occurred in the fourth year, and this was interpreted as a nutritional necessity accompanying the increase in size and thickness of the aortic wall at this time (Bloom and Fawcett, 1962).

In the fifth year it was clear from the micrographs that coiling of the arterial vasa was occurring on the ascending aorta. This was regarded as a defence mechanism against vasal stretch, accompanying the increase in systolic pressure, which occurs at this time.

The sequence of changes in the arterial pattern of the common iliac artery closely resembled the aorta, an irregular network of vessels being replaced by longitudinally arranged arterioles, which became sinuous in the fourth year and supplied the superficial layers of the media.

The venous vasa of the complete aorta and common iliac artery showed little alteration in vascular pattern in the first five years of life. The venous plexus was densest in neonates, diminished at the end of the first year, and accompanied the penetration of the arterial vasa in the fourth year by draining the superficial layers of the media.

In contrast to the poor anastomoses occurring between the mural vessels at the proximal and distal ends of the adult aortic arch, in the neonatal and infant arch a good anastomosis was observed and this was maintained to the limit of this age group (Fig.135).

Pulmonary Trunk and Arteries.

Little work could be found in the literature on the vasa vasorum of the pulmonary trunk and arteries in the early years of life. Winternitz, Thomas and Le Compte (1938) state, without further amplification or illustration, that the vasa vasorum of the "pulmonary artery" communicate with the vasa of the ductus arteriosus.

From an examination of the micrographs it was concluded that the arterial supply to the neonatal and infant pulmonary trunks and arteries originated similarly to the adult, but varied in distribution.

(a) Pulmonary Trunk.

In the neonatal pulmonary trunk it was found that an irregular plexus of arterioles 40-60μ in diameter, was formed in the adventitia of the pulmonary wall, being densest around the base and terminating on the pulmonary bifurcation in a sparse network (Fig. 157).

In the infant pulmonary trunks, the irregular arteriolar plexus was less dense at the base of the pulmonary trunk by the end of the first year, being replaced by longitudinal, sinuous arterioles, 60μ in diameter, in the second year (Figs. 158-159).

It was clear from the micrographs that there was an increase in the density of the longitudinal arteriolar pattern by the fifth year, with evidence of coiling of the arterial vasa at the base of the pulmonary trunk (Fig. 160).

From the adventitial arteriolar plexus the arterial vasa penetrated the superficial layers of the outer third of the media in the fourth year, to form a secondary network of vessels 10-20μ in diameter (Fig. 161).

Examination of the venous vasa showed that an irregular plexus, densest in neonatal specimens, was formed in the adventitia, until the fourth year, when small tributaries drained the outer third of the media to form longitudinally arranged adventitial veins, 50-70μ in diameter, which were tributaries of the ventricular coronary veins (Figs. 162-164).

(b) Pulmonary Arteries.

In the neonatal pulmonary arteries it was found that an irregular network of arterioles, 40-50μ in diameter, was formed in the adventitia of the extrahilar parts of the pulmonary artery, the intrahilar parts remaining avascular (Fig. 165).

In the infant pulmonary arteries, longitudinally arranged sinuous arterioles, 60-80μ in diameter, replaced the irregular adventitial network on the extrahilar part of the pulmonary arterial wall, and extended onto the proximal parts of the intrahilar pulmonary wall, as straight arterioles 30-50μ in diameter, in the second year (Figs. 166-167).

It was clear from the micrographs that by the fifth year the longitudinal arteriolar pattern on the extrahilar part of the pulmonary arterial wall had increased in density, and that the intrahilar part of the pulmonary artery had a longitudinally arranged plexus of arterioles in the adventitia, which terminated in branches 2 mm. in diameter (Figs. 168-169).

From the adventitial arteriolar plexus arterial vasa penetrated the superficial layers of the outer third of the media on the proximal parts of the extrahilar portion of the pulmonary artery in the fourth year, being confined to the adventitia elsewhere (Figs. 170-171).

Examination of the micrographs showed that the venous vasa formed an irregular plexus, densest in neonatal specimens, which was confined to the adventitia until the fourth year, when it drained the outer third of the media on the proximal parts of the extrahilar pulmonary arteries, to form a network of veins 80-100μ in diameter. Venous vasa appeared on the intrahilar parts of the pulmonary wall in the second year, and remained adventitial (Figs. 172-177).

It was clear from the micrographs that the vascular patterns displayed by the mural vessels in the pulmonary trunk and arteries altered in the first five years of life.

The first year of life was characterised by an irregular network of arterial vasa on the pulmonary trunk and extrahilar part of the pulmonary arteries, both patterns being reduced in vascular density towards the end of the first year. This pattern was similar to the arrangement of vessels on the pulmonary trunk in the later months of intrauterine life, but differed from the foetal pulmonary arteries which were almost avascular (Lauke, 1965a) (vide infra). The immediate postnatal development of arterial vasa on the extrahilar pulmonary arteries was regarded as a nutritional necessity fulfilling the increased metabolic demands of a vessel wall taking the systolic force of the altered circulation. The reduction in vasculature towards the end of the first year was interpreted as the first stage in the alteration of the vasal architecture to the adult form.

The second year was characterised by the appearance of longitudinally arranged sinuous arterioles on the pulmonary trunk and extrahilar pulmonary arteries, with an extension onto the proximal parts of the intrahilar pulmonary arteries. These changes occurred constantly in specimens between the ages of 18-24 months, and were regarded as the templates for the formation of adult patterns.

Between the second and fifth years, the appearance of the arterial vasa on the pulmonary arteries resembled the adult picture more closely, and the intrahilar pulmonary arterial wall received an ingrowth of vessels, which was confined to the adventitia. The longitudinal arterioles on the pulmonary trunk resembled the adult pattern, and showed coiling in the vessels at the base, but there was no evidence of the formation of the mosaic patterns seen on the anterior and posterior surfaces in later life.

Penetration of the superficial layers of the outer third of the media occurred in the fourth year in the pulmonary trunk and the proximal parts of the pulmonary arteries. This was similar to the development of an intramural pattern in the ascending aorta, (Clarke, 1965 d) (and was interpreted as before.)

The rapid vascularization of the distal part of the extrahilar pulmonary arteries in the neonatal period contrasted sharply with the foetal picture, in which a few vessels spread onto the pulmonary arteries from the pulmonary bifurcation. This was interpreted as a nutritional requirement for the pulmonary arterial wall meeting the adapted circulation.

The venous vasa of the pulmonary trunk and arteries were found to vary little after the second year. Prior to this time the intrahilar pulmonary arteries were avascular, but with the ingrowth of arterioles to the adventitia an accompanying plexus of veins appeared. The veins in the walls of the pulmonary trunk and arteries, were tributaries of the ventricular coronary veins and bronchial veins respectively.

The Arteries of the Root of Neck.

No reference could be found in the literature on the development of vascular patterns in the walls of arteries of the root of neck in the first five years of life.

From an examination of the micrographs it was concluded that the arterial supply to the neonatal and infant root of neck arteries originated similarly to the adult, but varied in distribution.

In the neonatal arteries, an irregular adventitial network of arterioles, 30-50μ in diameter, surrounded the brachio-cephalic trunk, left common carotid, and subclavian arteries(Fig. I78).

In the infant arteries, the irregular adventitial network was less dense at the end of the first year, being replaced by longitudinal, sinuous arterioles, 50-60μ in diameter, at the end of the second year (Fig. 179).

It was apparent from the micrographs that by the fifth year the sinuosity of the arterioles had increased (Fi,. I80).

From the adventitial arteriolar plexus, the arterial vasa penetrated the outer third of the media superficially to form a secondary plexus of vessels, 10-20μ in diameter, in the fourth year (Fig. 181).

Examination of the micrographs showed that the venous vasa formed an irregular plexus, densest in neonatal arteries, which was confined to the adventitia until the fourth year, when it drained the outer third of the media to form a network of vessels, 50-70μ in diameter, which were tributaries of the venous plexus on the aortic arch (Figs. 182-184).

It was clear from the micrographs that the vascular patterns displayed by the mural vessels in the root of neck arteries altered in the first five years of life.

The first year of life was characterised by an irregular network of arterial vasa on the brachio-cephalic trunk, left common carotid and subclavian arteries, which was densest in the neonatal period, being reduced at the end of the first year. The reduction in vascularity was interpreted as the first stage in the alteration of the vasal architecture to the adult form.

The second year was characterised by the appearance of longitudinally arranged sinuous arterioles, which replaced the previous arterial network and resembled the adult arrangement.

By the fifth year there was evidence of increased sinuosity and this was interpreted as being a precursor to the coiling of the adventitial arterioles in the adult.

Penetration of the outer third of the media by arterioles occurred in the fourth year, thus resembling the pattern of development in the aorta, pulmonary trunk and common iliac arteries.

Anastomoses between the arterial vasa on the proximal limb arteries and respective root of neck arteries was observed, thereby forming the precursor of the adult arrangement (Fig. 178).

The venous vasa of the arteries of root of neck showed a dense plexiform pattern, which was reduced at the end of the first year and replaced by longitudinal venous channels in the second year. Receiving tributaries from the outer third of the media in the fourth year, these channels became tributaries of the bronchial veins through the venous plexus on the aortic arch.

Upper and Lower Limb Arteries

No reference could be found in the literature on the development of vascular patterns in the walls of limb vessels in the first five years of life.

From an examination of micrographs it was concluded that the arterial supply to the neonatal and infant limb arteries originated similarly to the adult, but varied in distribution.

(a) Upper Limb.

In the neonatal limb arteries, it was found that an irregular network of arterioles, 30-50μ in diameter, surrounded the principal arteries of the limb, forming a continuous longitudinal plexus (Fig. 185).

In the infant limb arteries, it was found that the irregular network was similar in appearance and density until the fourth year, when longitudinal, sinuous arterioles, 40-80μ in diameter, replaced the adventitial plexus and ensheathed the axillary, brachial, radial and ulnar arteries (Figs. 186-187).

Examination of the micrographs showed that the venous vasa formed an irregular plexus, which was confined to the adventitia and consisted of vessels 50-80μ in diameter (Fig. 188).

(b) Lower Limb.

The formation and distribution of the arterial vasa was similar in the lower limb, an irregular network of arterioles, 40-60μ in diameter, being replaced in the fourth year by longitudinal, sinuous arterioles, 60–80μ in diameter which ensheathed the femoral, popliteal, and tibial arteries (Figs. 189–191).

The venous vasa formed an irregular plexus of veins, 60–100μ in diameter, which was confined to the adventitia (Fig. 192).

It was clear from the micrographs that the arterial patterns in the mural vessels altered in the first five years of life.

In both limbs the first year of life was characterised by an irregular network of arterial vasa, which was distributed to the adventitia of the principal arteries of the limbs. There was no evidence of an alteration in the vascular density during this period.

Between the end of the first year and third year the neonatal pattern was maintained, until the fourth year, when the arterial adventitial network was replaced by longitudinal, sinuous arterioles, which closely resembled the adult picture without arteriolar coiling.

There was no evidence from the micrographs which suggested that penetration of the media occurred in this age group.

The venous vasa of the limb arteries showed little alteration in vascular pattern in the first year of life, and apart from a slight reduction in the vascular density in the following years, the irregular plexus of veins was found to be confined to the adventitia.

GROUP III

THE VASA VASORUM OF ARTERIES BETWEEN 5 AND 15 YEARS OF AGE

No references could be found in the literature to work done on the vasa vasorum of arteries in this age group.

The aim of this study was to establish alterations in the patterns and distribution of the vasa vasorum as the arterial wall aged.

The Aorta

From an examination of the micrographs it was concluded that the arterial supply to the aortae of this age group originated similarly to the adult, but varied in distribution.

It was clear that no changes occurred in the vascular patterns, distribution, or depth of penetration of the arterial vasa between the fifth and tenth year.

(a) The Ascending Aorta.

In the aortae of children between the tenth and twelfth year the picture altered. The longitudinal adventitial arterioles showed increased sinuosity and coiling, until, between the thirteenth and fifteenth year, the adult appearance could be demonstrated (Fig. 193).

From the adventitial arteriolar plexus, the arterial vasa began to penetrate the middle third of the media in the tenth year, vascularization of this layer being completed by the fifteenth year (Fig. 194).

Examination of the micrographs showed that the adventitial veins retained their irregular plexiform appearance until the twelfth year, when well defined longitudinal channels were formed, which received tributaries from an ever increasing portion of the media, as the arterial vasa penetrated this layer, until the adult pattern was attained (Figs. 195-196).

(b) The Arch of the Aorta.

In the aortae of children between the tenth and twelfth year the picture altered. The adventitial arterioles upon the summit of the aortic arch showed increased sinuosity and coiling, until from the thirteenth year the adult form could be demonstrated, while the arterial vasa on the sides of the aortic arch became more sinuous (Figs. 197-198).

From the adventitial arteriolar plexus, the arterial vasa began to penetrate the middle third of the media in the tenth year, the adult appearance being attained in the fifteenth year (Fig. 199).

Examination of the micrographs showed that the venous vasa retained the irregular pattern seen in infant aortic arches, tributaries draining into the adventitial plexus from the inner third of the media in the fifteenth year (Figs. 200-201).

(c) Descending Thoracic Aorta.

In the aortae of children between the tenth and twelfth year the picture altered. The longitudinally arranged adventitial plexus of arterioles was reduced in density, and replaced by well defined sinuous arterioles, which showed a segmental anastomoses, and formed a longitudinal chain of arterial vasa on the lateral aspect of the aorta. By the fifteenth year the avascular strip on the dorsal aspect of the descending thoracic aorta had widened to the adult appearance (Figs. 202-203).

Examination of the micrographs showed that the irregular circumferential pattern of venous vasa, seen in infant aortae, was retained, tributaries draining into the adventitial plexus from the inner third of the media in the fifteenth year (Figs. 204-205).

(d) Abdominal Aorta.

In the aortae of children between the tenth and twelfth year the picture altered. The longitudinally arranged adventitial plexus of arterioles was reduced in density, and replaced by well defined sinuous arterioles, which showed a segmental anastomoses, and formed a longitudinal chain of arterial vasa on the lateral aspect of the aorta. In addition, the arterioles from the mesenteric arteries became more prominent in the twelfth year, and attained an adult appearance in the fifteenth year (Figs. 206-207).

From the adventitial arteriolar plexus, the arterial vasa began to penetrate the middle third of the media in the tenth year, the adult appearance being shown in the fifteenth year (Fig. 208).

Examination of the micrographs showed that the adventitial venous plexus developed similarly to the thoracic aorta, but was denser, thus fulfilling the adult conditions (Fig. 209).

(e) Common Iliac Artery.

In the iliac arteries little alteration in the vascular pattern occurred. The longitudinal adventitial arterioles showed increased sinuosity in the tenth year, adult appearances being demonstrated in the fifteenth year (Fig. 210).

Penetration of the remainder of the outer third of the media occurred in the tenth year, and the adult arteriolar pattern was demonstrated by the fifteenth year (Fig. 211).

Examination of the micrographs showed that the pattern of the adventitial venous network retained the irregular arrangement seen in infant arteries, tributaries draining into the adventitial veins from the middle third of the media in the fifteenth year (Figs. 212-213).

It was clear from the micrographs that the vascular patterns displayed by the mural vessels in the aorta altered between the fifth and fifteenth year, and that these changes occurred at the same time in different parts of the aorta.

Between the fifth and tenth years the vascular patterns described for infant aorta were retained.

The tenth and twelfth years of life were characterised by an increased sinuosity and coiling of the adventitial arterioles on the ascending aorta and the summit of the aortic arch, while the longitudinal chain of arterial vasa on the lateral aspect of the descending thoracic aorta and abdominal aorta was formed. In addition the arterial vasa arising from the mesenteric arteries became prominent on the anterior surface of the abdominal aorta, and the avascular strip on the dorsal aspect of the thoracic aorta became prominent (Fig. 203).

Penetration of the middle third of the media commenced in the tenth year and was completed in the fifteenth year.

Between the thirteenth and fifteenth years the arterial patterns, which were emerging in the adventitial arterioles from the tenth year, were completed and the adult picture was simulated.

The venous vasa of the entire aorta showed little change between the fifth and tenth years.

The twelfth year was characterised by the appearance of longitudinal venous channels in the adventitia of the ascending aorta, but elsewhere the irregular plexiform pattern was retained, draining into circumferential veins in the descending aorta.

As the arterial vasa penetrated the middle third of the media from the tenth year, venous tributaries drained an ever increasing portion of the media, until by the fifteenth year venous vasa could be demonstrated in the inner third of the media.

The latent period between the fifth and tenth years in the development of the vascular patterns is in agreement with the observed growth lag in the arterial wall at this time (Bloom and Fawcett, 1962). In the tenth year the growth of the aorta commences again (Bloom and Fawcett, 1962) and this is in accordance with the development of an increased intramural pattern of vessels.

In contrast to the good anastomoses occurring between the mural vessels at the proximal and distal ends of the young aortic arch, the anastomoses in the aortae of children were observed to diminish in the tenth year, until the adult pattern was attained in the fifteenth year (Fig. 193: compare Fig. 135).

The sequence of changes in the vasa of the common iliac artery was limited to an increased sinuosity of the adventitial arterioles and the vascularization of all the outer third of the media from the tenth year, with venous tributaries draining the middle third of the media by the limit of this age group.

The Pulmonary Trunk and Arteries

No references could be found in the literature to work done on the vasa vasorum of arteries in this age group.

The aim of this study was to establish alterations in vascular patterns and distribution of the vasa vasorum as the arterial wall aged.

From an examination of the micrographs it was concluded that the arterial supply to the pulmonary trunk and arteries originated similarly to the adult, but varied in distribution.

It was clear that no changes occurred in the vascular patterns, distribution, or depth of penetration of the arterial vasa between the fifth and tenth year.

(a) Pulmonary Trunk.

In the pulmonary trunks of children between the tenth and twelfth year the picture altered. The longitudinal adventitial arterioles showed increased sinuosity and coiling at the margins and base of the pulmonary trunk, until between the thirteenth and fifteenth year, the adult appearance was demonstrated (Figs. 214-215).

It was clear from the micrographs that the mosaic patterns, seen on the anterior and posterior surfaces of adult specimens, began to form in the tenth year by replacing the longitudinal arterioles of the infant specimens (Fig. 216).

From the adventitial arteriolar plexus, the arterial vasa began to penetrate the remainder of the outer third of the media in the tenth year, vascularization of this layer being completed by the fifteenth year (Fig. 217).

Examination of the micrographs showed that there was an increase in the longitudinal venous channels in the adventitia in the twelfth year, tributaries draining into adventitial veins from the middle third of the media by the fifteenth year(Figs. 218-219).

(b) Pulmonary Arteries.

In the pulmonary arteries of children between the tenth and twelfth year the picture altered. The longitudinal adventitial arterioles on the extrahilar part of the pulmonary arteries showed coiling, while the arterioles in the adventitia of the intrahilar arteries became more sinuous, until the adult appearance was formed in the fifteenth year(Figs. 220-221).

From the adventitial arteriolar plexus, the arterial vasa began to penetrate the outer third of the media on the distal part of the extrahilar pulmonary arteries in the tenth year, vascularization of this layer being complete by the fifteenth year. The arterial vasa were confined to the adventitia of the intrahilar pulmonary arteries, an increase in the density of the vascular pattern being the only change observed (Fig. 222-223a).

Examination of the micrographs showed that the venous vasa retained the irregular pattern seen in infant pulmonary arteries, tributaries draining into the adventitial plexus from the junction of the outer and middle third of the media in the extrahilar arteries, but being confined to the deep adventitial layers in the intrahilar arteries (Fig. 224-226a).

It was clear from the micrographs that the vascular patterns of the mural vessels in the pulmonary trunk and arteries altered between the fifth and fifteenth year. Between the fifth and tenth years the vascular patterns described for infant specimens were retained.

The tenth to twelfth years of life were characterised by increased coiling of the adventitial arterioles at the base and margins of the pulmonary trunk and on the extrahilar part of the pulmonary arteries. In addition the adventitial arterioles on the intrahilar arteries showed increased sinuosity. The mosaic patterns on the anterior and posterior surfaces of the pulmonary trunks were formed at this time, and appeared to emerge from a cross anastomotic network between the existing longitudinal arterioles in the adventitia.

Between the thirteenth and fifteenth years the arterial patterns which were forming from the tenth year were completed and the adult picture was simulated.

Penetration of the outer third of the media in the distal part of the extrahilar arteries commenced in the tenth year and was completed in the fifteenth year, but the arterial vasa remained in the adventitia of the intrahilar pulmonary arteries.

The venous vasa showed little change between the fifth and tenth years. The twelfth year was characterised by an increase in the longitudinal venous channels in the adventitia of the pulmonary trunk, and cross anastomoses with the adventitial veins on the ascending aorta appeared (Fig. I95).

The latent period between the fifth and tenth years in the development of the vascular patterns is similar to the aorta (Clarke 1965a). In the tenth year the mural vessels alter their characteristics, as do the aortic vasa, and this would appear to provide for the growth of the pulmonary trunk and ascending aorta at this time.

Dubreuil, Lacoste and Raymond(I936) state that the adult type of respiratory unit does not develop until some years after birth. This observation is in accord with the evidence produced in this study, that the mural vessels in the pulmonary arteries and their branches do not present adult features until the fifteenth year.

The Arteries of the Root of Neck

No reference could be found in the literature to work done on the vasa vasorum of arteries in this age group.

From an examination of the micrographs it was concluded that the arterial supply to the arteries of the root of neck originated similarly to the adult, but varied in distribution.

It was clear that no changes occurred in the vascular patterns or depth of penetration of the arterial vasa between the fifth and tenth year.

In the arteries of children between the tenth and twelfth year the picture altered. The longitudinal adventitial arterioles showed coiling, until by the fifteenth year the adult appearance was demonstrated (Fig. 227).

From the adventitial arteriolar plexus, arterial vasa began to penetrate the remainder of the outer third of the media in the tenth year, vascularization of this layer being completed in the fifteenth year (Fig. 228).

Examination of the micrographs showed that the adventitial veins retained their irregular plexiform appearance until the twelfth year, when longitudinal channels were formed, which received tributaries from an ever increasing portion of the media as the arterial vasa penetrated this layer, until the adult pattern was attained (Figs. 229-230).

It was clear from the micrographs that the vascular patterns of the mural vessels in the root of neck arteries altered between the fifth and fifteenth years. Between the fifth and tenth years the vascular patterns described for infant arteries were retained.

The tenth year of life was characterised by coiling of the adventitial arterioles and penetration of all the outer third of the media by the arterial vasa.

Between the thirteenth and fifteenth years the arterial patterns, which were forming in the tenth year, were completed.

The venous vasa showed little change between the fifth and tenth years. The twelfth year was characterised by the appearance of longitudinal venous channels in the adventitia, tributaries draining the middle third of the media.

The latent period between the fifth and tenth years in the development of the vascular patterns is similar to the aorta. The coiling of the adventitial arterioles was interpreted as a defence mechanism against vasal stretch from the increasing systolic pressure. The vascularization of the arterial wall occurs at the same time as the arterial vasa penetrate the aortic wall, and this would appear to provide for the growth of the arterial wall at this time (Bloom and Fawcett, 1962).

The Coronary Arteries

No references could be found in the literature to the development of vascular patterns in the walls of the coronary arteries.

In this study observations were confined to specimens examined between the third and fifteenth years of life at two year intervals. It was found that specimens from hearts in the first three years of life were too small to investigate by the present technique.

From an examination of the micrographs it was concluded that the arterial supply to the infant and childrens' coronary arteries originated similarly to the adult, but varied in distribution.

In the infant coronary arteries, between the third and fifth years, it was found that an irregular network of arterioles, 60-80μ in diameter, was formed in the adventitia (Fig. 231).

It was clear from the micrographs that in the tenth year the picture altered. The adventitial network of arterioles was replaced by longitudinal sinuous arterioles, which became coiled on the proximal 1cm. of the coronary artery in the twelfth year (Figs. 232-233).

It was evident from the micrographs that the longitudinal and circumferential arterioles, seen in the outer third of the media in the adult, appeared in the tenth year, vascularization of this layer being completed in the fifteenth year (Figs. 234-235).

Examination of the micrographs showed that in the infant coronary arteries, between the third and fifth years, there was an irregular plexus of adventitial veins, 50-70μ in diameter (Fig. 236).

It was found that the adventitial veins retained their irregular plexiform appearance and received tributaries from an ever increasing portion of the media from the tenth year, until the adult picture was demonstrated in the fifteenth year (Figs. 237-238).

It was apparent from the micrographs that the vascular patterns displayed by the mural vessels in the coronary arteries altered considerably between the third and fifteenth years.

The fifth year was characterised by an irregular network of arterial vasa which was confined to the adventitia. This pattern was retained until the tenth year, when longitudinal sinuous arterioles formed with coiling quickly appearing on the proximal 1cm. of the coronary artery in the twelfth year.

Penetration of the outer third of the media commenced in the tenth year and was completed in the fifteenth.

The pattern of the venous vasa in the adventitia of the coronary arteries showed little change in this age group, the only change being the appearance of tributaries draining the media from the tenth year.

The latent period in the development of the vascular patterns between the fifth and tenth years is similar to the picture seen in the aorta, pulmonary vessels, and limb arteries (vide infra). Similarly the sinuosity, coiling and penetration of the media by adventitial arterioles follows the chronological sequence seen in the other arteries examined.

<u>The Upper and Lower Limb Arteries</u>

No references could be found in the literature to the development of vascular patterns in the walls of limb vessels in this age group.

From an examination of the micrographs it was concluded that the arterial supply to the principal limb arteries originated similarly to the adult, but varied in distribution.

In the limb arteries of children no changes occurred in the vascular patterns or depth of penetration between the fifth and tenth years.

(a) Upper Limb.

In the limb arteries of children between the tenth and twelfth year the picture altered. The longitudinal adventitial arterioles of the subclavian, axillary and brachial arteries showed coiling, while the adventitial arterial plexus on the radial and ulnar arteries showed increased sinuosity (Figs. 239-241).

From the adventitial arterial network, the arterial vasa began to penetrate the outer third of the media of the subclavian and axillary arteries in the tenth year, vascularization of this layer being completed in the thirteenth year (Fig. 242).

Examination of the micrographs showed that the longitudinal adventitial venous channels of the subclavian and axillary arteries received tributaries from the outer third of the media in the tenth year (Fig. 243).

(b) Lower Limb.

In the lower limb arteries of children between the tenth and twelfth year the picture altered. The longitudinal adventitial arterioles of the femoral and popliteal arteries showed coiling, while the adventitial arterial network on the circumflex femoral and tibial arteries showed increased sinuosity (Figs. 244-246).

From the adventitial arteriolar plexus, the arterial vasa began to penetrate the outer third of the media of the femoral artery in the tenth year, vascularization of this layer being completed in the thirteenth year (Fig. 247).

Examination of the micrographs showed that the longitudinal adventitial venous channels of the femoral artery received tributaries from the outer third of the media in the tenth year (Fig. 248).

It was clear from the micrographs that the vascular patterns of the mural vessels in the principal limb arteries altered between the fifth and fifteenth years.

Between the fifth and tenth years the vascular patterns described for infant specimens were retained.

The tenth year of life was characterised by increased coiling of the adventitial arterioles on the proximal limb arteries, and sinuosity of the arterioles on the distal arteries.

Penetration of the outer third of the media occurred in the proximal arteries from the tenth year, but like adult specimens, the arterial plexus was confined to the adventitia of the distal arteries and their principal branches.

The latent period between the fifth and tenth years in the development of the vascular patterns is similar to the aorta. The coiling and increased sinuosity of the adventitial arterioles was interpreted as a defence mechanism against vasal stretch from the increasing systolic pressure. The vascularization of the proximal arterial wall occurs at the same time as the arterial vasa penetrate the aortic wall, and this would appear to provide for the arterial growth in the developing limbs.

The venous vasa showed little alteration in their arrangement, apart from receiving tributaries from the media as the arterial vasa penetrated the proximal limb arteries. Like adult specimens, the venous vasa were confined to the adventitia of the distal limb arteries.

PART IV.

DEVELOPMENT OF VESSELS IN THE ARTERIAL WALL

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INTRODUCTION

The majority of studies on the embryology of the cardiovascular system do not include a description of the vasa vasorum.

Winternitz, Thomas and Le Compte (1938), state that "by the time the aorta is formed as a single tube of endothelium, lying in an area of loose and indifferent mesenchyme, it has already, in the region of the future renal branches, many connections with the adjacent capillary network". This observation is supported by illustrations showing a para-aortic plexus of vessels in 10mm. and 24mm. rabbit and pig embryos. In addition, it was concluded that the capillary "sprouts" surrounding the aorta formed before the mesenchymal coat had condensed, so that their growth was not interfered with.

The aim of this work was to establish when the human arterial wall was vascularized, and to determine any changes which occurred in the pattern or distribution of the vasa vasorum. In this study the foetal aorta and pulmonary trunk were examined.

<u>The Aorta</u>

(a) Aortae examined between the 12th - 28th week.

It was clear from the micrographs that in the 12th week of intrauterine life a sparse network of periaortic vessels, 10-15μ in diameter, surrounded the abdominal aorta at the origin of the renal arteries, leaving the remainder of the aorta avascular (Fig. 249).

In the foetal aortae examined between the 12th - 16th week it was found that the periaortic network had spread to the thoracic aorta and abdominal aorta as far as the aortic bifurcation (Figs. 250-251). Examination of the ascending aorta and arch, at this time, showed that vessels, 15-20μ in diameter, could be demonstrated around the base of the ascending aorta and the summit of the aortic arch (Fig. 252-253).

Between the 16th - 28th week it was found that the periaortic network of vasa surrounding the thoracic and abdominal aorta had increased in density, with evidence of a spiral pattern of vessels, 30-40μ in diameter, appearing on the abdominal aorta from the 20th week (Figs. 254-255). The vessels around the base of the ascending aorta began to ascend towards the aortico-pulmonary groove and surround the proximal part of the ascending aorta with an irregular plexus of vessels

20-30μ in diameter (Fig. 256). Little change could be observed in the vascular arrangement on the aortic arch in this period.

(b) Aortae examined between the 28th week and term.

In the foetal aortae examined between the 28th week and term the arterial and venous vasa could be demonstrated separately and it was evident from the micrographs that the arterial supply to the foetal aortae originated similarly to the adult, but varied in distribution.

(i) Ascending Aorta.

In the 28th week it was found that an irregular plexus of adventitial arterioles, 30-40μ in diameter, surrounded the base and proximal half of the aorta, arterial vasa extending onto the distal half in the 32nd week (Figs. 257-258).

It was evident from the micrographs that the neonatal pattern of adventitial arterioles was attained in the 34th week (Fig. 259).

Examination of the micrographs showed that the venous vasa formed an irregular plexus of vessels, 40-50μ in diameter, in the 28th week, and that the neonatal appearance could be demonstrated in the 34th (Figs. 260-261).

(ii) Arch of the Aorta.

In the 28th week it was found that an irregular plexus of arterioles, 30-40μ in diameter, was distributed to the adventitia on the summit of the aortic arch (Fig. 262). Between the 28th - 32nd week the micrographs showed that this plexus increased in density and extended onto the sides of the arch, until in the 34th week the neonatal arrangement was demonstrated (Figs. 263-265).

It was clear from the micrographs that the venous vasa formed an irregular network of vessels, 40-50μ in diameter, on the summit of the aortic arch in the 28th week, and that by the 32nd, tributaries were draining the sides of the arch, giving a similar appearance to the neonatal picture in the 34th week (Figs. 266-267).

(iii) Descending Aorta.

In the 28th week it was found that a spiral network of arterioles, 40-50μ in diameter surrounded the abdominal aorta, and that by the 32nd week this network had extended onto the thoracic aorta, replacing the irregular plexus of vessels observed before the 28th week (Fig. 268). This picture was retained until birth.

Examination of the micrographs showed that the venous vasa formed an irregular plexus of vessels, 50-60μ in diameter, in the 28th week, and that this pattern was retained until term, the plexus becoming more dense on the abdominal aorta from the 32nd week (Figs. 269-270).

It was clear from the micrographs that the vascular patterns displayed by the mural vessels in the aorta altered in intrauterine life.

The twelfth week of intrauterine life was characterised by the development of vasa vasorum on the wall of the abdominal aorta, adjacent to the origin of the renal arteries and took the form of a periaortic plexus of vessels, which spread to envelop the remainder of the descending aorta in an adventitial plexus by the sixteenth week.

In an analysis of the factors influencing the appearance and development of capillary beds, Clark (1918) reported that "increased metabolism causes increase in blood pressure in the capillary area, to which the endothelium is thought to respond by sending out sprouts"; that the formation, enlargement, maintenance and atrophy of capillaries is partly dependent on the amount of blood flow, and confirmed Thomas's second histomechanical law that, increase in the length of a vessel is governed by the tension exerted on the vessel wall in a longitudinal direction by the tissues and organs outside that vessel.

From a series of direct studies on the regional blood flow in foetal lambs, Reynolds (1961), concluded that 73% of the cardiac output passed to the descending aorta, 13-18% being distributed to the abdominal viscera and hindquarters.

During this study it was observed that the vasa vasorum, which first appeared on the abdominal aorta, had extensive communications with vessels on the dorsal wall of the foetus, in the region of the developing viscera, and in two early specimens (which were not included in this series) the dorsal wall plexus approached the side of the abdominal aorta, which was avascular.

In view of these observations and the findings of Clark and Reynolds, it is suggested that the stimulus for the growth of the capillary bed on the dorsal wall of the foetus is the metabolic activity of the developing viscera, and that the vasal plexus on the abdominal aorta, in the 12th week, is an extension of the dorsal capillary network.

The extension of the vasal plexus on the abdominal aorta to envelop the remainder of the descending aorta by the sixteenth week was interpreted as a haemodynamic response illustrating Thomas's second histomechanical law, as the aorta lengthened.

According to Bloom and Fawcett (1962) the aorta acquires its outer coats in the fourth month of intrauterine life, but this was not accompanied by an alteration in the vasal architecture, until the twentieth week, when a spiral pattern of vessels surrounded the abdominal aorta, and extended on to the thoracic aorta by the thirty second week.

The poor development of the vasa vasorum was most marked on the wall of the ascending aorta and arch, where mural vessels were not prominent until the twenty eighth week.

It would appear that the neonatal pattern of vasa vasorum is attained first in the descending aorta in the thirty second week, and this is followed by the ascending aorta and arch in the thirty fourth week.

It is of interest to note that the development of the vasa vasorum is not prominent in all parts of the aorta until the twenty eighth week, when the foetus is recognised as viable.

Unfortunately no cases of congenital coarctation of the aorta could be studied.

The Pulmonary Trunk and Arteries

The only reference to the vasa vasorum of the foetal pulmonary trunk is by Winternitz (1938), who states that the ductus arteriosus receives vasa from the pulmonary trunk, but does not amplify his description.

(a) Pulmonary trunks examined between the 12th-28th week.

It was clear from the micrographs that in the 16th week of intrauterine life a fine network of vessels, 10-30μ in diameter, surrounded the base of the pulmonary trunk, which was avascular until this time (Fig. 271).

Between the 16th-28th week an irregular plexus of vessels began to spread over the anterior and posterior surfaces of the pulmonary trunk from the aortic-pulmonary groove, forming an anastomotic network with the vessels on the ascending aorta (Fig. 272).

(b) Pulmonary Trunks examined between 28th week and term.

In the 28th week it was found that an irregular plexus of adventitial arterioles, 30-40μ in diameter, surrounded the base and proximal half of the pulmonary trunk, arterial vasa extending on to the distal half and bifurcation in the 32nd week (Figs. 273-274).

Examination of the micrographs showed that the neonatal pattern of adventitial arterioles was attained in the 34th week (Fig. 275).

It was apparent from the micrographs that the venous vasa formed an irregular plexus of vessels, 40-50μ in diameter, in the 28th week and that the neonatal appearance could be demonstrated in the 34th week (Figs. 276-277).

(c) The Pulmonary Arteries.

It was evident from the micrographs that the extrahilar portion of the pulmonary artery wall was avascular, until the 32nd week, when the pulmonary bifurcation had been vascularized and a few vessels extended onto the proximal part of the pulmonary arteries (Fig. 274).

It was clear from the micrographs that the vascular patterns of the vasa vasorum altered in intrauterine life.

The chronological appearance of the pulmonary vasa was similar to the ascending aorta, a fine plexus of vessels around the base of the pulmonary trunk developing into a well defined network by the twenty eighth week, and assuming the neonatal characteristics in the thirty fourth week.

From the thirty second week an arteriolar network extended from the pulmonary bifurcation onto the proximal part of the pulmonary arteries and ductus arteriosus, whose mural vessels are described below, in the thirty fourth week.

PART V.

VESSELS IN THE WALLS OF THE ARTERIES SHOWING ADAPTIVE CHANGES AT BIRTH.

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VESSELS IN THE WALLS OF THE ARTERIES SHOWING ADAPTIVE CHANGES AT BIRTH.

INTRODUCTION

Little attention has been given to the vasa vasorum of vessels showing adaptive changes at brith in man.

In this study foetal and postnatal specimens of ductus arteriosus and umbilical arteries were examined.

Ductus Arteriosus.

The numerous descriptive and experimental studies conducted on the ductus arteriosus have been concerned principally with the mechanism and time of closure, and the resultant adaptive changes which occur in the neonatal circulation (Barcroft, 1947; Dawes, 1955; Sciacca, 1960). Little reference could be found in the literature to the vasa vasorum of the ductus arteriosus.

The main work is by Winternitz, Thomas and LeCompte, (1938), who injected the vasa vasorum of the pulmonary trunk in foetuses and neonates; demonstrated branches from the plexus in the adventitia of the pulmonary bifurcation extending onto the ductus arteriosus, and concluded that the intramural vessels increased in density after birth.

From an examination of the micrographs it was evident that the vasa vasorum of the foetal and neonatal ductus arteriosus originated from the plexus of vessels in the adventitia of the pulmonary bifurcation and proximal part of the left pulmonary artery, thoracic aorta, and the terminal branches of the internal mammary arteries.

(a) Foetal Ductus Arteriosus.

It was clear from the micrographs that the wall of the foetal ductus arteriosus was avascular until the 28th week of intrauterine life.

Between the 28th week andterm vasa vasorum were found to be distributed to the adventitial layer in the wall of the ductus arteriosus.

(i) Vasa from the Internal Mammary Arteries.

It was evident from the micrographs that an irregular plexus of arterioles, 10-40μ in diameter, originating from the internal mammary arteries, was distributed to the entire length of the ductus from the 28th week (Fig. 278).

(ii) Vasa from the thoracic aorta and pulmonary artery.

Examination of the micrographs showed that the adventitial arteriolar plexus on the wall of the ductus arteriosus was supplemented by an ingrowth of arterioles, 40-50μ in diameter, from the thoracic aorta and pulmonary artery in the 34th week (Figs. 279-280), which arborised with the existing arteriolar plexus from the terminal branches of the internal mammary arteries (Fig. 279).

(b) Neonatal Ductus Arteriosus.

It was clear from the micrographs that the adventitial arteriolar plexus varied in distribution during this period.

First Week:

In the first seventy two hours of life there was no evidence from the micrographs of alteration in the intramural pattern or distribution. Thereafter, the picture altered.

It was apparent from the micrographs that the irregular pattern of the adventitial arteriolar plexus had increased in density, and that a secondary network of arterioles, 30-50μ in diameter, penetrated the outer half of the media towards the end of the first week (Figs. 281-282).

Second Week:

The micrographs showed that the irregular pattern of adventitial arterioles was retained, appearing as a plexus of vessels, 80-100μ in diameter (Fig. 283).

From the adventitial arteriolar plexus, arterial vasa, 40-80μ in diameter, penetrated the media and intima, the wall of the ductus arteriosus being completely vascularized towards the end of the second week (Fig. 284).

Third Week:

In the third week, examination of the micrographs showed that the lumen of the ductus arteriosus was being progressively filled with vascular tissue containing arterioles 40-60μ in diameter (Fig. 285). These vessels originated from the terminal branches of the mural arterioles, thus forming a dense arteriolar network in the lumen and wall of the ductus arteriosus (Fig. 286).

Fourth Week:

It was clear from the micrographs that the density of the arteriolar plexus in the wall and lumen of the ductus arteriosus began to diminish in the second half of the fourth week, although all the layers remained vascularized (Fig. 287).

(c) Infant Ductus Arteriosus.

Examination of the micrographs showed that a progressive ischaemia, which was most marked in the first six months, occurred in the intima and media of the ductus arteriosus (Fig. 288). By the end of the first year the ductus arteriosus consisted of a cord of tissue with a network of arterioles, 60-80μ in diameter, which were confined to the adventitia and arborised with the arterial vasa of the thoracic aorta and pulmonary artery (Fig. 289).

Between the second and fifth years of life the micrographs demonstrated a sparse arteriolar network, 80-100μ in diameter, arranged longitudinally, and confined to the adventitia (Fig. 290). Arborisation with the arterial vasa of the thoracic aorta had been severed, and in two specimens the aortic half of the ductus was avascular (Fig. 291).

(d) Ductus Arteriosus in Children.

Between the fifth and fifteenth years the micrographs showed that the arteriolar plexus was confined to the adventitia of the pulmonary half of the ductus until the tenth year (Fig. 292). Thereafter, the micrographs demonstrated a reduction in the density of the adventitial arteriolar plexus (Fig. 293).

(e) Ductus Arteriosus in Adults.

Examination of the ductus arteriosus between the fifteenth and eightieth years showed that vasa vasorum could be demonstrated in three specimens. The picture, in each case, consisted of two or three arterioles, 80-100μ in diameter, which were confined to the adventitia of the pulmonary half of the ductus arteriosus (Fig. 294).

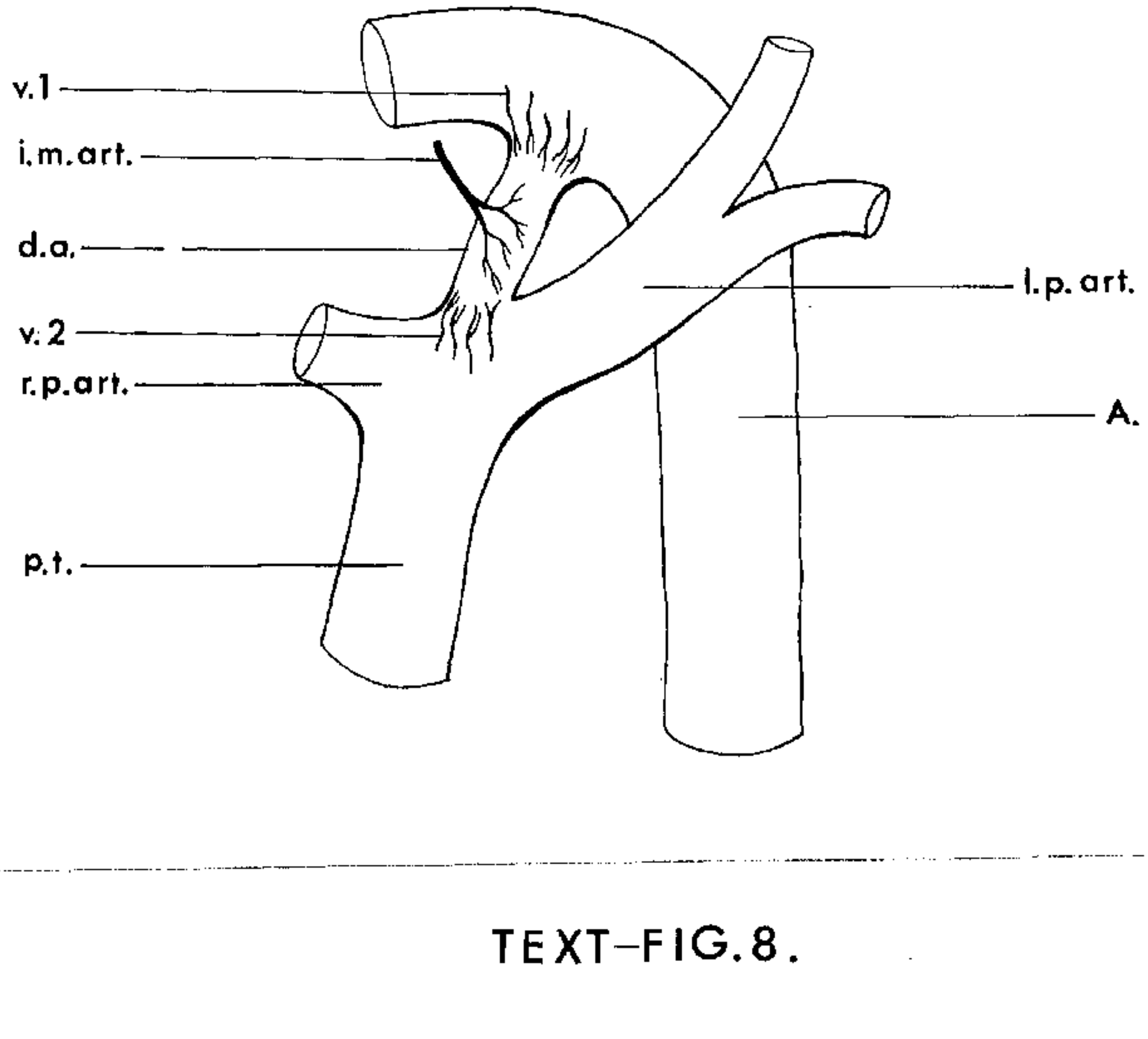
It was clear from the micrographs that there was an extensive vascular supply to the wall of the ductus arteriosus, the general features of which are shown in text-fig. 8.

Winternitz, Thomas and LeCompte (1938) stated that the ductus in newborn infants showed no vascularity in the inner media or intima, and that in one case a 'small twig of vessels' was found in the media. Later they noted that the media and intima were vascularized in infants aged two and four months.

As indicated by the x-ray microscope, the foetal ductus is vascularized by terminal branches of the internal mammary arteries in the twenty eighth week of intrauterine life, a supplementary distribution coming from the arterial vasa of the thoracic aorta and pulmonary artery. The neonatal pattern is attained in the thirty fourth week, so that the foetal vessels have developed in a period of six weeks. This is in

Explanation of Text-Fig. 8.

Diagram of the arterial supply to the ductus arteriosus (d.a.), showing arterial vasa originating from terminal branches of the internal mammary artery (i.m.art.), thoracic aorta (v1) and left pulmonary artery (v2). Aorta (A): pulmonary trunk (p.t.): right pulmonary artery (r.p.art.): left pulmonary artery (l.p.art.).



TEXT–FIG.8.

contrast to the slower development of the vasa in the aorta and pulmonary trunk.

In this study no alteration in the pattern or distribution of the vasa could be demonstrated in the first seventy two hours of life. Thereafter, the outer half of the media was penetrated in the remainder of the first week, complete vascularization of the wall occurring in the second week. This increased vascularity in the wall of the ductus confirms Winternitz's observation on postnatal specimens but at an earlier age.

The third week was the time of maximum vascularity, on account of the infiltration and partial occlusion of the lumen by tissue containing a dense arteriolar plexus. This phase lasted about ten days and towards the end of the fourth week the vessels in the lumen and inner half of the media and intima began to atrophy. It would appear that the vessels in the lumen are outgrowths from the vasa in the wall of the ductus, since complete continuity could be demonstrated between the arterioles in the two areas.

The remainder of the first year was characterised by a progressive ischaemia, which affected the intima and the media first, so that by the end of the first year the vasa were confined to the adventitia.

The definite pattern of growth and atrophy of the intramural vessels in the first year indicates a specific function. It is suggested that the vascularization of the wall of the ductus in the second week is a necessary prelude to the ingrowth of vessels required to supply the tissue which infiltrates and obliterates the lumen of the ductus, and so completes the functional adaptation in the circulation, occurring in the fourth week (personal communication - MacDonald). The subsequent atrophy of the vessels in the wall of the ductus was interpreted as a physiological ischaemia, which took place after competent closure of the ductus.

The observation by Winternitz that the vasa of the ductus, thoracic aorta and pulmonary artery anastomose was not confirmed. As indicated by the x-ray microscope the arborisation between the vasa in the wall of the ductus and aorta was severed between the second and fifth years, resulting in a progressive withdrawal of the adventitial vessels towards the pulmonary end of the ductus, the aortic half of the ductus being avascular in the fifth year. By the fifteenth year only a meagre arteriolar plexus could be demonstrated on the pulmonary half of the ductus.

From a study of the adult ductus, Winternitz comments that, by introducing a micropipette filled with dye into the lumen, 'channels' could be demonstrated, which communicated with 'small blood vessels in the surrounding adventitial tissue'. In this work three adult specimens showed vasa in the adventitia of the pulmonary half of the ductus, which communicated with the arterial plexus in the adventitia of the pulmonary artery.

Attempts to demonstrate the venous vasa in postnatal specimens through the routine venous routes in the thorax met with repeated failure. It is suggested that the veins in the wall of the ductus arteriosus are tributaries of the veins in the mediastinum, and that failure to inject the venous vasa was due to a lack of a common venous pathway.

The Umbilical Arteries

During a study of the subendothelial cushions in human foetal umbilical arteries, Monie (1945) noted the presence of adventitial vessels in the intra-abdominal umbilical arteries of 167mm. embryos, and concluded that the mural vessels originated from the anterior abdominal wall and a vascular plexus around the bladder of 235mm. specimens.

It was clear from the micrographs that the intra-abdominal parts of the umbilical arteries were avascular until the 20th week, and that the extra-abdominal parts were devoid of vasa at all ages.

In the 20th week it was found that an irregular plexus of vessels, 20-30μ in diameter, surrounded the iliac arteries, and distributed a fine network of vasa to the adventitia of the proximal 0.5 cm. of the umbilical arteries, leaving the remainder of the vessels avascular (Fig. 295).

Between the 20th-28th weeks the periadventitial network of vasa had increased in density and extended to surround the proximal 1cm. of the umbilical arteries (Fig. 296).

Examination of the micrographs showed that between the 28th week and term, a plexus of arterial vasa, 20-40μ in diameter, was distributed to the umbilical arteries from the epigastric arteries in the anterior abdominal wall (Fig. 297).

It was evident from the micrographs that the neonatal pattern of vasa was attained in the 34th week, mural vessels, 40-50μ in diameter, being distributed to the adventitial layer of the proximal and distal ends of the umbilical arteries, with an intermediate avascular portion (Figs. 298-299).

In the neonatal umbilical arteries the picture altered. In the first forty eight hours there was no change in the vasa vasorum. Thereafter, it was clear from the micrographs that the arterial vasa to the umbilical arteries from the internal iliac and epigastric arteries atrophied, until by the tenth day only the proximal 1cm. of the umbilical arterial wall was vascularized (Figs. 300-302).

The present study has shown that the pattern and distribution of the vasa vasorum in the umbilical arteries altered in intrauterine and postnatal life.

Although Monie's observation that the intra-abdominal part of the umbilical arteries receive vasa was confirmed, no evidence was found suggesting that vasa originated from the vascular plexus around the bladder.

In this study it was demonstrated that the vasa vasorum to the proximal 0.5-1cm. of the intra-abdominal part of the umbilical arteries originated as branches of the mural plexus on the internal iliac artery in the twentieth week, the distribution being completed in the twenty-eighth week. In addition vasa were distributed to the distal end of the umbilical arteries from the twenty-eighth week and the neonatal picture was demonstrated by the thirty-fourth week.

An avascular area of varying length was found between the vascularized extremities of the arterial wall.

In neonatal life the rapidity with which the vasa vasorum receded from the distal end of the umbilical artery was marked, the wall being avascular by the tenth day. In contrast, although the density of the mural plexus was reduced on the proximal part of the vessel, a small portion of the wall retained vasa vasorum. It is suggested that this is the part proximal to the point of obliteration, becoming the origin of the superior vesical artery.

The rapid disappearance of the vasa vasorum from the wall of the distal part of the umbilical artery was interpreted as an effect of the muscular contraction which occurs in the immediate postnatal life.

In this work the vasa vasorum were found to be confined to the adventitial layer of the arterial wall.

Attempts to demonstrate the venous vasa failed. It is possible that the venous vasa of the proximal and distal ends of the umbilical arteries are tributaries of the plexus of veins on the posterior and anterior abdominal walls respectively, and that lack of a common venous pathway prevents injection.

PART VI.

HISTOLOGICAL OBSERVATIONS ON VESSELS IN THE ARTERIAL WALL.

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All the arteries examined radiologically were investigated by routine histological techniques and by Pickworth's method to provide controls and a critical comparison of the various methods and their results.

The arteries will be considered in the same order as the results were recorded in Parts III, IV and V.

Postnatal Arteries.

Histological examination of these arteries showed the routine appearances of the vasa vasorum in the adventitia. Confined to the adventitia at birth, the mural vessels could be seen penetrating the media at the same chronological intervals described previously, but it was not possible to demonstrate vasa in the inner third of the media in the aorta (Figs. 303 - 306).

Foetal Arteries.

Results with the foetal arteries confirmed the radiological observations that vasa vasorum were confined to the adventitia during intrauterine life, vascularization of the wall being demonstrated at corresponding times (Figs. 307 - 308).

Arteries showing Adaptive Changes at Birth.

The presence of mural vessels was confirmed in the adventitia of the wall of the ductus arteriosus from the 28th week. In postnatal life, however, it was not possible to demonstrate vasa in the inner media during the neonatal period, while in the infant and childrens' specimens mural vessels could be defined with less frequency than by radiological techniques. In adult specimens occasional vasa could be seen in the adventitia, confirming the radiological observations (Figs. 309 - 311).

The presence and distribution of the vasa vasorum in the umbilical arteries was confirmed by histological methods (Figs. 312 - 313).

In this study, routine histological techniques, using Mallory and Masson stains, were combined with a method for staining the red cells in the vasa vasorum (Pickworth's method) in order to compare these results with the radiological observations.

While the presence, depth of penetration and time of appearance of the vasa vasorum could be indicated by these methods, no precise conception of the origin and pattern of distribution could be obtained, and it was impossible to differentiate the arterial and venous vasa.

In comparison, the radiological technique afforded an opportunity of examining the pattern and distribution of the mural vessels, giving visual evidence of their origin and actual morphological appearance in the arterial wall without histological preparation, and its inevitable distortion of normal tissue. As indicated by the x-ray microscope a fuller picture of the vasa vasorum is obtained and more of the vascularization of the arterial wall is observed, although the possibility of false channels being injected can not be ruled out. The impression, in this work, was that when a false channel was opened up, an unmistakable irregular outline was recorded on the micrograph, and such specimens were ignored (Fig. 3I4).

PART VII.

CONCLUSIONS.

PART VII.

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The technical difficulties encountered in demonstrating the patterns of the vasa vasorum constitute a limiting factor in studying the vessels in the arterial wall.

X-ray microscopy presents a method which circumvents some of these problems. Its advantage is that unfixed material can be examined in full thickness preparations with the visualisation of small arterioles an capillaries. In this study the particulate diameter of Micropaque, which was 0.5μ or less, allowed the mural vessels to be filled, and at the same time provided an injection medium which was sufficiently radio-opaque to provide contrast. Under the pressures utilised, the injection entered the vasa vasorum freely and did not extravasate into the arterial wall.

On the other hand the technique depends upon an injection method with all the hazards of incomplete filling of the vessels, and an avascular area can be regarded as one which has not accepted the injection medium. Some might regard observations on areas reported avascular as invalid, only recognising a description of what has actually been injected. In this work, the criterion for accepting an area as avascular in foetal arteries and adult aorta was the repeated failure to introduce the injection medium into the arterial wall under conditions which filled capillary beds elsewhere in the same specimen.

In contrast to injection methods, techniques which require the staining of red cells (Pickworth, 1934) depend upon the uniform filling of the capillaries with red blood corpuscles at the time of death. Demonstration of alkaline phosphatase in the endothelial cells of blood vessels (Scharrer, 1950) requires histological preparation and does not allow the full pattern of the vasa vasorum to be appreciated, in contrast to the routine x-ray micrograph.

The Adult Arterial Wall:

In the arterial wall of adults (injected with Micropaque within eight to twelve hours of death) the results showed that the origin, distribution and characteristic appearance of the arterial and venous vasa could be visualised in full thickness specimens, and 1mm. thick sections.

As indicated by the x-ray microscope the adventitial arterioles were frequently coiled or tortuous as they lay in the arterial wall, and this was

interpreted as a defence mechanism against the stretch effect of systole. It was found that this characteristic of adventitial arterioles was most noticeable in the aorta, coronary, root of neck arteries, proximal limb arteries and the pulmonary trunk.
In the more distal arteries, such as the radial, tibial or basilar arteries, the coiling was replaced by a sinuosity, which diminished and finally disappeared, leaving straight arterioles. Finally, vessels with a diameter less than 2mm. did not possess vasa vasorum.

Particular attention was paid to the depth the vasa vasorum penetrated the different arterial walls, and an evaluation of the layer in which the capillary-venule bed lay was made. Examination of the micrographs showed that in the aorta the capillary-venule bed lay in the inner third of the media, and that as the more peripheral arteries were reached it became more superficial in the arterial wall, until in the distal limb arteries only the adventitia was vascularized.

Certain special features emerged in the pattern and distribution of the arterial vasa. In the coronary arteries a longitudinal and circularly arranged set of arterioles lay in the outer third of the media, while in the adventitia of the aorta well defined avascular areas were demonstrated at the proximal and distal ends of the aortic arch and on the posterior aspect of the thoracic aorta. It was suggested that the two sets of arterioles in the wall of the coronary arteries had a specific function providing a continuous blood supply to the vessel during the varying pressure effects of the cardiac cycle, the circular set being less compressed during systole. The avascular areas in the aortic arch wall were regarded as potential weaknesses in the arterial architecture and correlated with the occurrence of aortic aneurysm in these sites. The poorly vascularized posterior aspect of the aorta was interpreted as the reason for the difficulties encountered in proximal aortic grafting, in comparison to the good results of "saddle grafts" at the well vascularized aortic bifurcation.

With age the most significant changes in the adventitial arterioles were increased coiling, and an increased vascularity in the wall of certain arteries.

The venous vasa were found to consist of irregular plexuses, although well defined longitudinal channels were formed on the ascending aorta and pulmonary trunk with circumferential veins draining the adventitia of the descending aorta.

The predominance of the longitudinal venous channels on the concave aspect of the ascending aorta and concavity of the aortic arch was interpreted as a defence mechanism protecting the veins against occlusive effects of systole, thus permitting continuous drainage.

Neonatal, Infant and Childrens' Arterial Wall:

The characteristic feature of the arterial wall in this age group was the dense irregular plexus of arterioles which existed at birth, apart from the descending aorta in which a spiral pattern of arterioles occurred.

As indicated by the x-ray microscope, the development of the vasa vasorum followed a definite chronological pattern in the arterial wall.

By the end of the first year the arterial wall was less vascular and the templates of adult patterns replaced the neonatal and infant plexuses in the second year.

By the fifth year the adventitial arterioles showed increased sinuosity or coiling in the aorta, pulmonary trunk, root of neck arteries, common iliac and limb arterie Moreover, the outer third of the media began to be vascularized in the fourth year in all these vessels except the limb arteries.

Little alteration in the picture occurred until the tenth year when the remainder of the media, in the arteries already discussed, was vascularized. About this time the coronary and proximal arterial wall in the limbs was penetrated, and between the thirteenth and fifteenth year this process was completed in all the arteries examined.

The fifteenth year also saw the complete development of the adult patterns in the adventitial arterioles.

The Foetal Arterial Wall:

The aorta and pulmonary trunk were examined in this age group, and the micrographs showed that a chronological sequence affected the development of vasa vasorum in different parts of the arterial wall.

As indicated by the x-ray microscope the aorta was avascular until the twelfth week and the pulmonary trunk until the sixteenth week of intrauterine life.

Thereafter, the characteristic mural pattern was an irregular plexus of vessels, which first appeared on the abdominal aorta in the region of the renal arteries. Spreading proximally and distally, this plexus ensheathed the length of the descending aorta by the sixteenth week, with separate plexuses appearing at the base of the ascending aorta and summit of the aortic arch.

By the twenty eighth week it was possible to differentiate between the arterial and venous vasa, the veins retaining an irregular plexiform appearance until term.

From the twentieth week a spiral pattern of arterial vasa could be demonstrated on the abdominal aorta, which spread later to the thoracic aorta. An irregular plexus of arterioles was retained in the remainder of the aorta.

The neonatal pattern of vasa was achieved by the thirty second week on the descending aorta and the thirty fourth week on the ascending aorta and arch.

Throughout intrauterine life the vasa vasorum were confined to the adventitia.

The pulmonary trunk possessed an irregular plexus of vessels around the base from the sixteenth week, and this gradually extended to surround the entire length of the vessel, the neonatal appearance being developed by the thirty fourth week.

Arteries showing adaptive changes at birth:

The ductus arteriosus and umbilical arteries were examined in this group.

Until the twenty eighth week the ductus was avascular. Thereafter an adventitial plexus of vessels was distributed from the internal mammary arteries, ascending and thoracic aorta, the neonatal appearance being demonstrated by the thirty fourth week.

The speed with which the foetal vessels developed in the wall of the ductus arteriosus contrasted sharply with the slower development in the aorta and pulmonary trunk.

After birth, the ductus arteriosus was progressively vascularized in all its layers, the process being completed in the third week of postnatal life. The tissue occluding the lumen was also vascularized.

From the fourth week a progressive ischaemia affected the inner layers of the wall until by the end of the first year only the adventitia was vascularized again.

The rapid vascularization of the ductus became maximal in the third week of postnatal life coinciding with the time of functional closure. It was suggested that the ingrowth of vasa vasorum to all the layers of the ductus was a prelude to the vascularization of the tissue occluding the lumen, thus allowing the circulatory route to be adapted.

As indicated by the x-ray microscope the aortic half of the ductus arteriosus became avascular from the fifth year, and from the tenth year the vessels in the pulmonary half diminished.

Examination of adult specimens showed that only three were vascularized, the vasa being confined to the pulmonary half of the vessels in all cases.

The umbilical arteries were also avascular until the twentieth week, when vasa were distributed to the proximal and distal ends of the intra-abdominal parts from the iliac and epigastric arteries respectively. The extra-abdominal parts of the umbilical arteries remained avascular.

By the thirty fourth week the neonatal pattern of vasa had developed, showing an adventitial plexus of vessels at the proximal and distal ends of the intra-abdominal parts of the arteries, with an intermediate zone which was avascular.

Forty eight hours after birth there was a rapid ischaemia in the distal part of the umbilical arteries, but the proximal part of the vessels retained vasa vasorum, and it was suggested that this portion became the origin of the superior vesical artery.

The rapid ischaemia on the adventitia of the distal part of the artery was interpreted as an effect of the strong contraction of muscle occurring at this time in the umbilical cord.

In closing, therefore, it can be said that vascular studies may be undertaken with injection techniques or by staining the red cells. Staining methods are particularly suitable for investigating adaptive changes in vascular patterns under varying conditions, giving a true picture of the actual physiological state of the circulation at that time. Injection methods, in contrast, present the vascular pattern at its maximum capacity, and are suited for purely anatomical investigations. For this reason, along with the technical advances of x-ray microscopy, the vasa vasorum of the foetal and postnatal arterial wall were investigated by this method, and it is suggested that it is a technique which has application in the study of "Blood Supplies" at the level of small arterioles and capillaries.

SUMMARY

This thesis is entitled "Some observations on Vessels in the Arterial Wall" and is concerned with a study of the vasa vasorum in the aorta; coronary arteries; pulmonary trunk and arteries; arteries of the root of neck; basilar and cerebral arteries; limb arteries, ductus arteriosus and umbilical arteries.

Postnatal specimens were examined from birth to eighty years of age, to compare the characteristic pattern and distribution of the vasa vasorum in the arterial wall and the changes which occur with age.

Foetal specimens were examined to determine when the arterial wall ceased being dependent completely upon luminal blood for nourishment, and to compare the prenatal patterns and distribution of the intramural vessels with the postnatal microcirculation.

The umbilical arteries and ductus arteriosus were chosen as examples of arteries showing adaptive changes at birth, and the effect of this on the vasa vasorum was considered.

Both foetal and postnatal arteries were injected at physiological pressures with a radio-opaque medium (Micropaque) and examined with the Coslett Nixon x-ray projection microscope. This instrument produces

a point source of x-rays from a metal target, which penetrates the full thickness arterial wall, and allows examination of the specimen without routine histological preparation, in contrast to previous investigations.

In each artery the aim of the examination was to differentiate between the arterial and venous sides of the microcirculation; examine the characteristic patterns of the arterial and venous vasa; determine the depth the intramural vessels penetrated, and investigate the effect of age on the development of vasal architecture.

In intrauterine life it was found that vasa vasorum first appeared on the abdominal aorta, and that the neonatal pattern had developed in the remainder of the aortic wall and pulmonary trunk by the thirty fourth week, all the vasa being confined to the adventitial layer.

Postnatal development of the vasa vasorum was characterised by the template of adult appearances being formed in the adventitia in the second year, and penetration of the media from the fourth year, with vascularization of the arterial wall being completed by the fifteenth year.

Arteries showing adaptive changes at birth were vascularized in the later weeks of pregnancy; showed the neonatal pattern by the thirty fourth week, and were characterised by a rapid ischaemia after birth.

From these findings the importance of the vasa vasorum in relation to the haemodynamics of the circulation as it affected the arterial wall; the formation of aortic aneurysm and aortic grafting, and the extent the arterial wall was vascularized by vasa vasorum was discussed.

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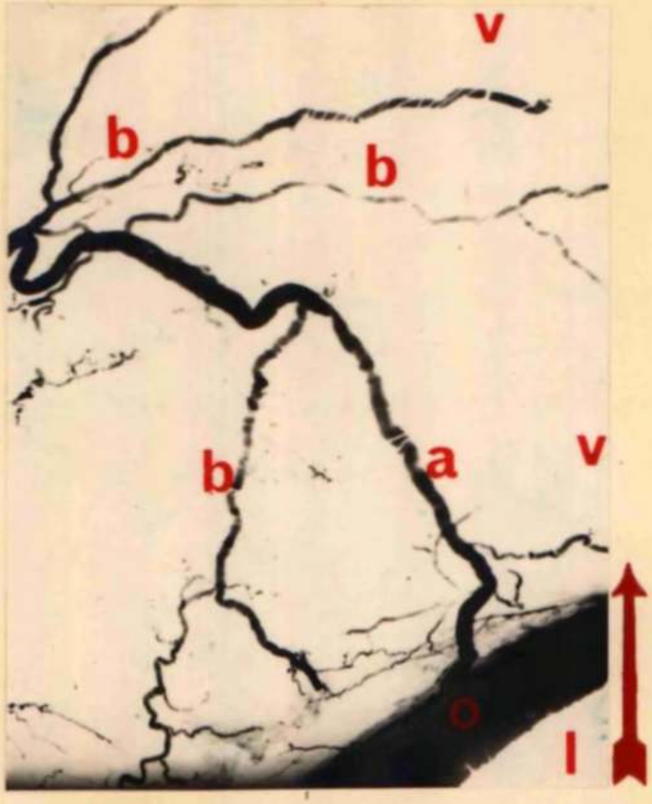
APPENDIX

Portions of this thesis have been submitted and accepted for publication in the following journals.

1. An X-Ray Microscopic Study of the Vasa Vasorum in the Normal Human Ascending Aorta. Br. Heart J. In Press.
2. An X-Ray Microscopic Study of the Vasa Vasorum of the Normal Human Aortic Arch. Thorax. In Press.
3. An X-Ray Microscopic Study of the Vasa Vasorum of the Norman Human Thoracic Aorta. Z. Anat. und Entwickl - Gesch. In Press.
4. An X-Ray Microscopic Study of the Vasa Vasorum of the Normal Human Coronary Arteries. J. Anat. Lond. In Press.
5. An X-Ray Microscopic Study of the Vasa Vasorum of the Normal Human Pulmonary Trunk. Acta. Anat. In Press.
6. An X-Ray Microscopic Study of the Vasa Vasorum of the Normal Human Intrahilar Pulmonary Arteries. Thorax. In Press.
7. An X-Ray Microscopic Study of the Vasa Vasorum of the Normal Human Upper Limb Arteries. Acta Anat. In Press.
8. An X-Ray Microscopic Study of the Vasa Vasorum of the Normal Human Lower Limb Arteries. Anat. Anzeig. In Press.

9. An X-Ray Microscopic Study of the Vasa Vasorum of the Normal Human Root of Neck Arteries. J. Neurol. Sci. In Press.

10. An X-Ray Microscopic Study of the Vasa Vasorum of the Human Ductus Arteriosus. J. Anat. Lond. Submitted for publication.



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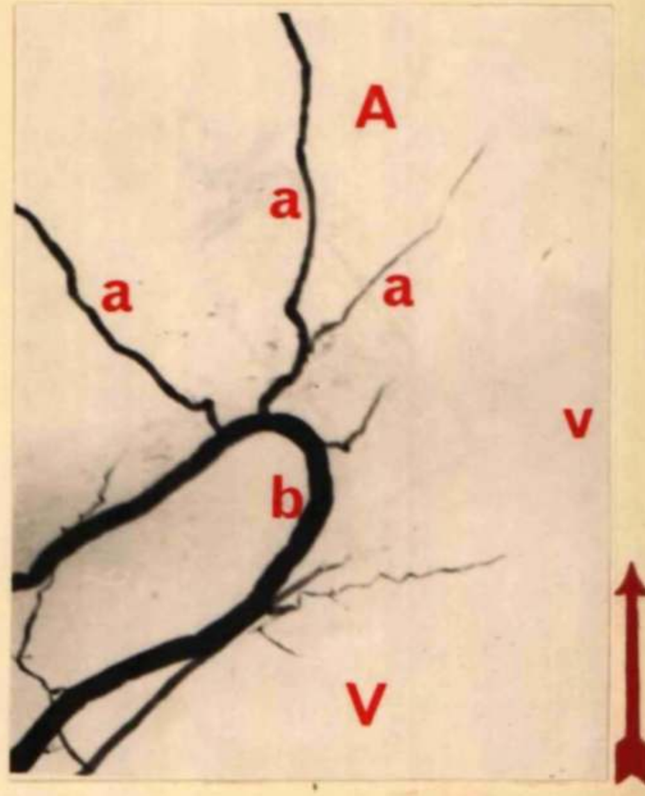

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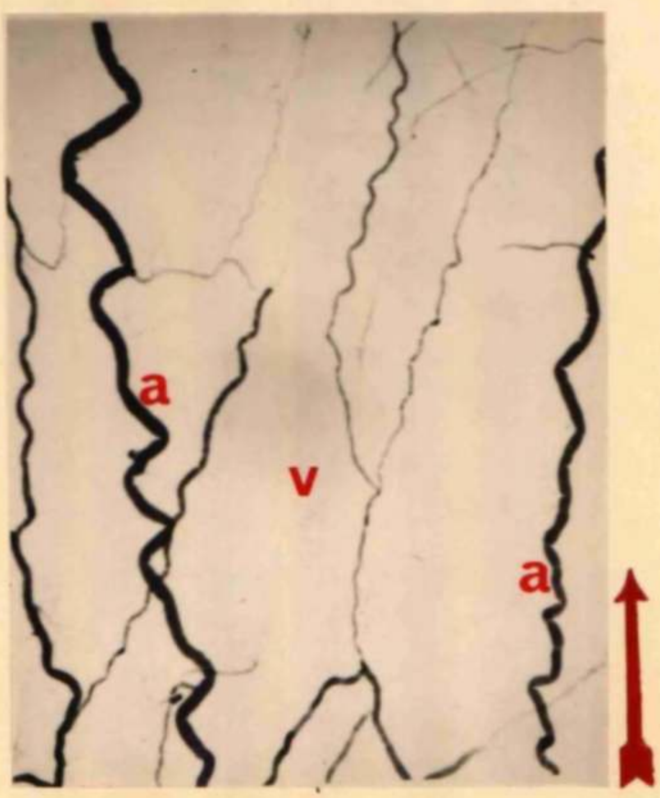

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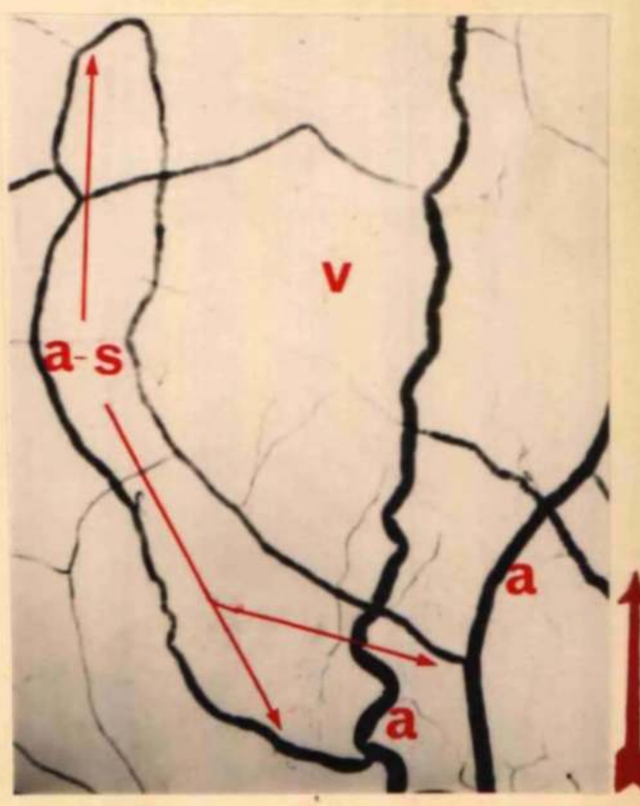

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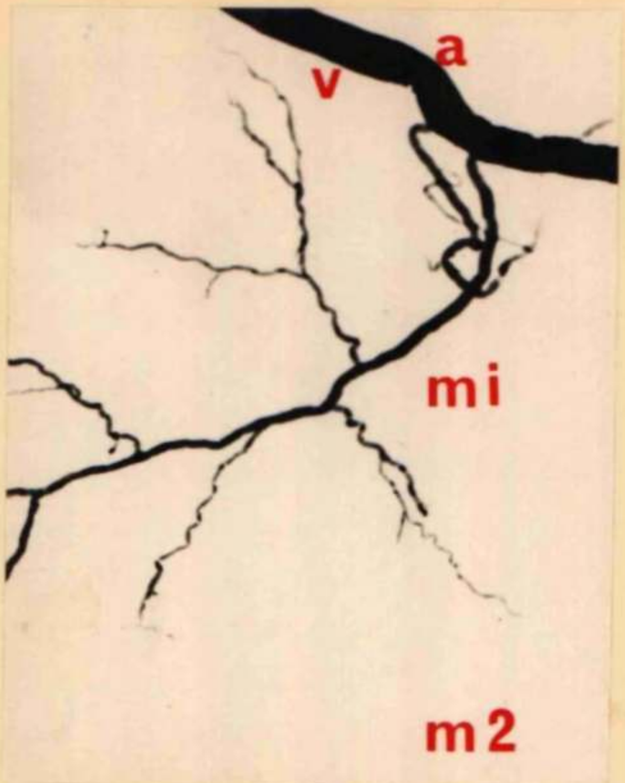

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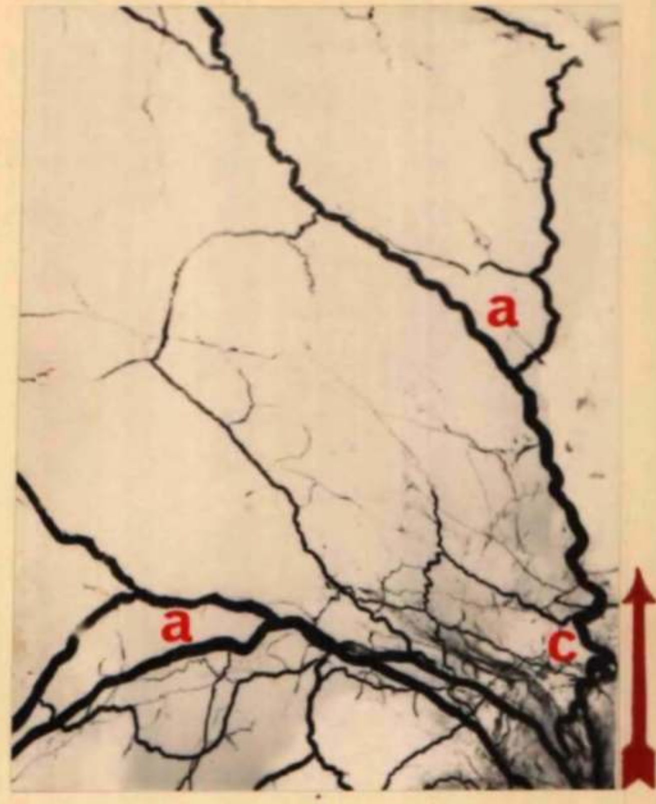

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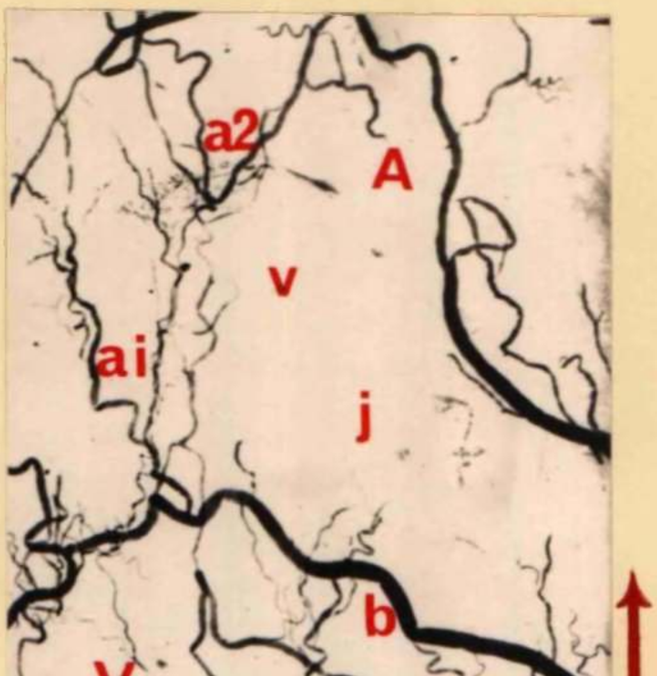

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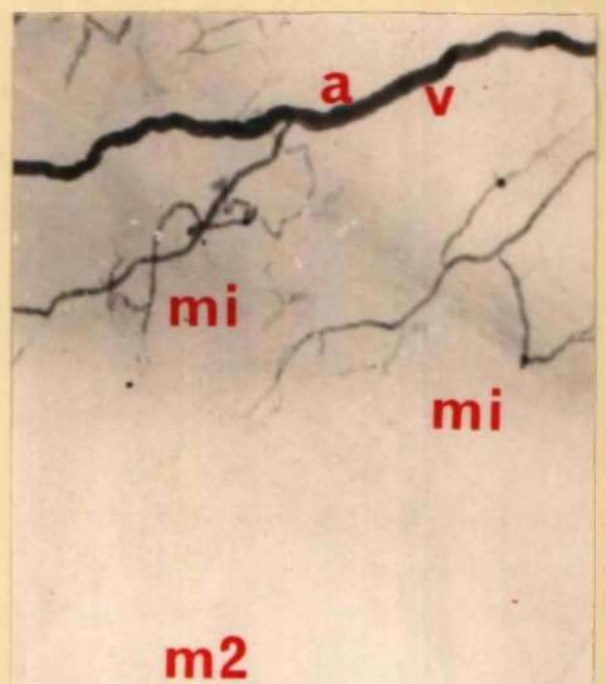

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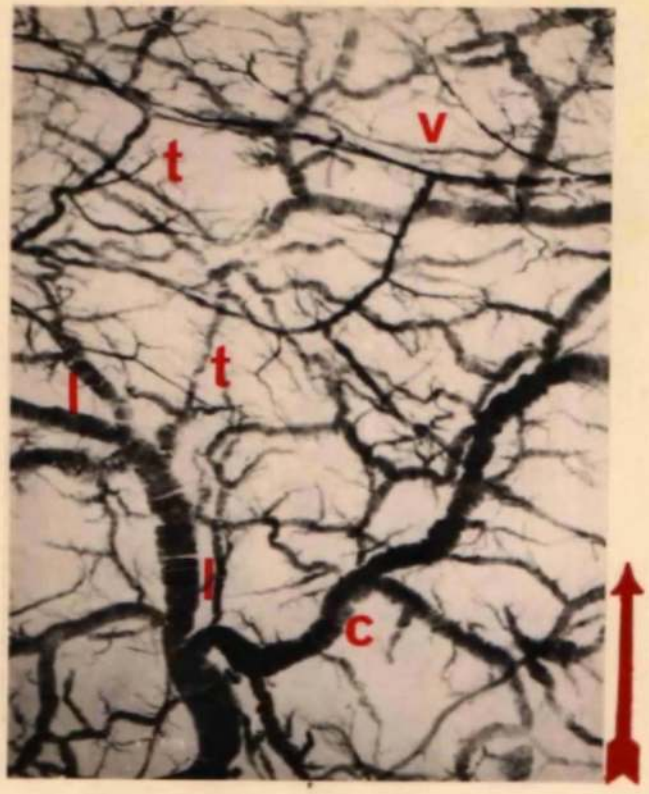

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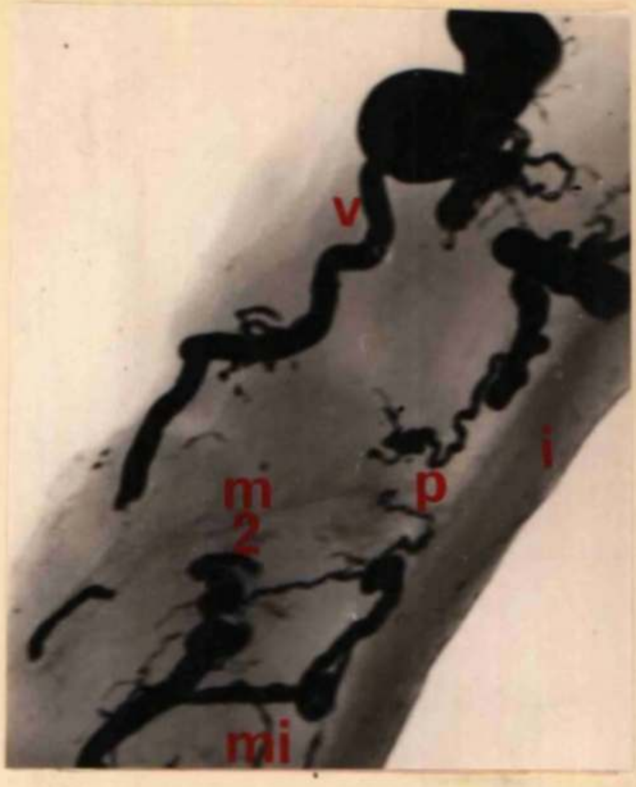

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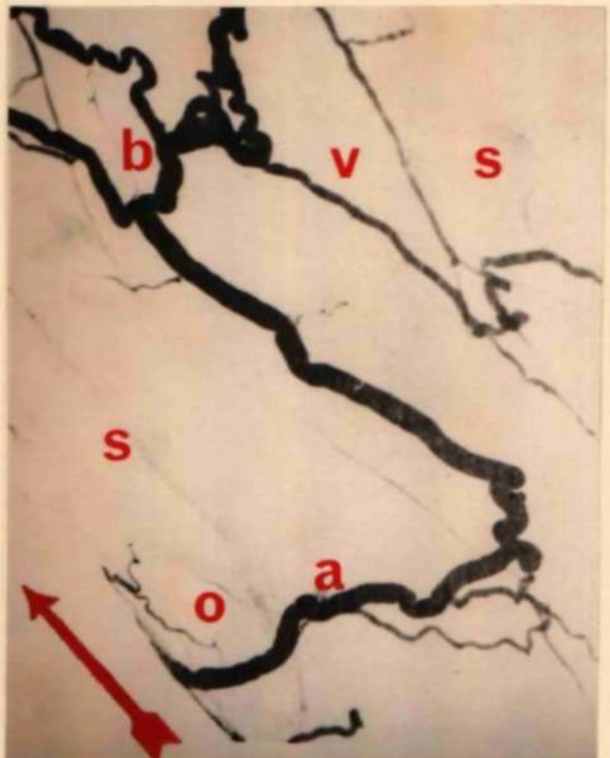

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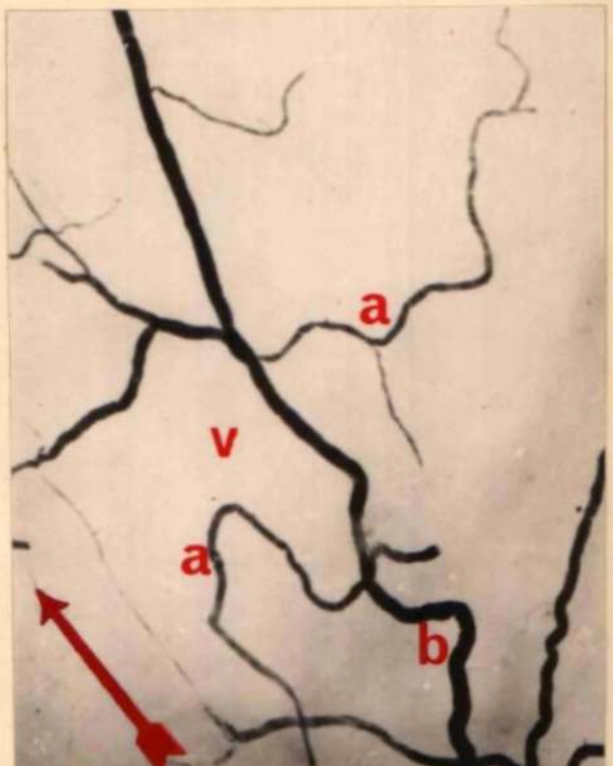

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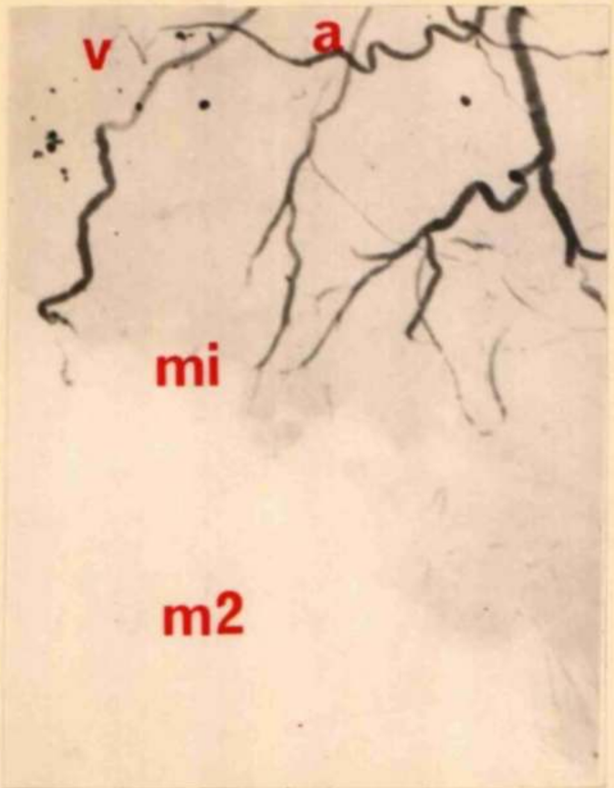

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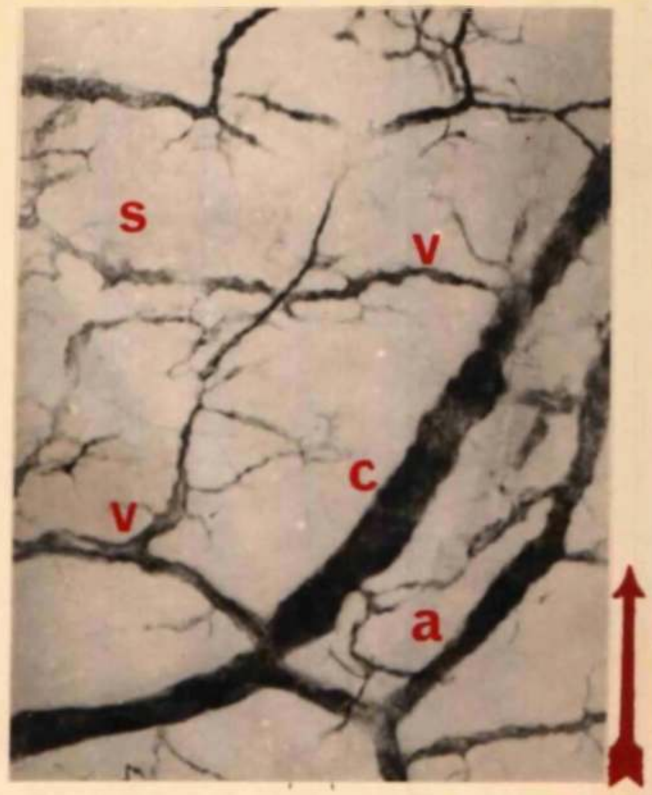

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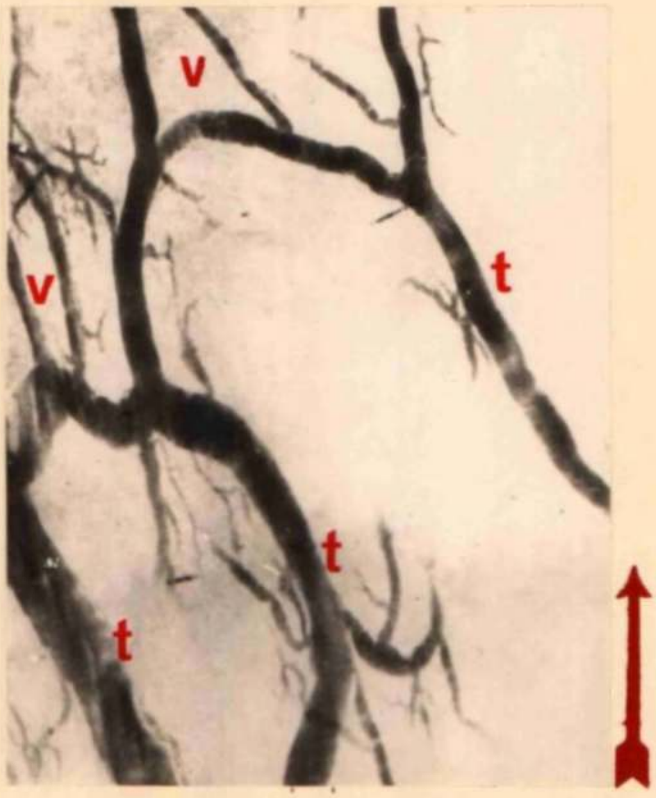

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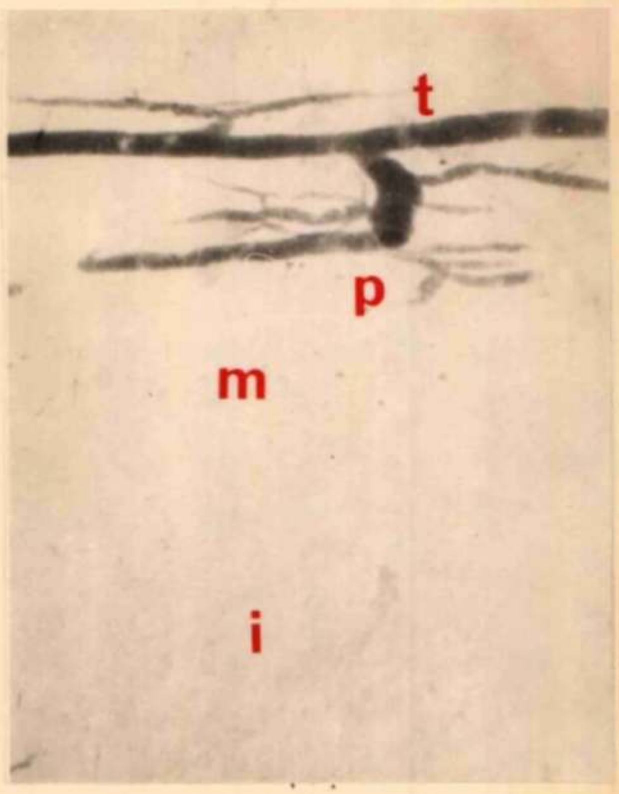

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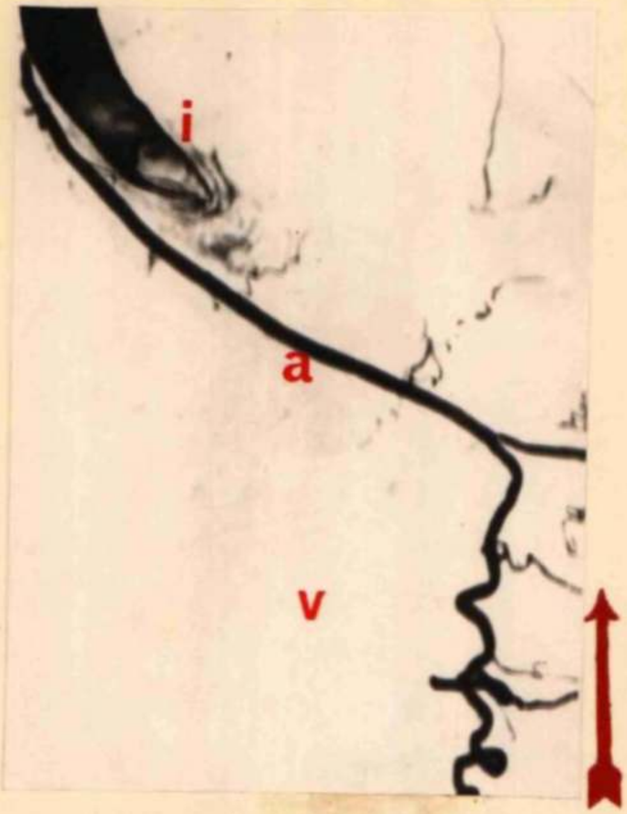

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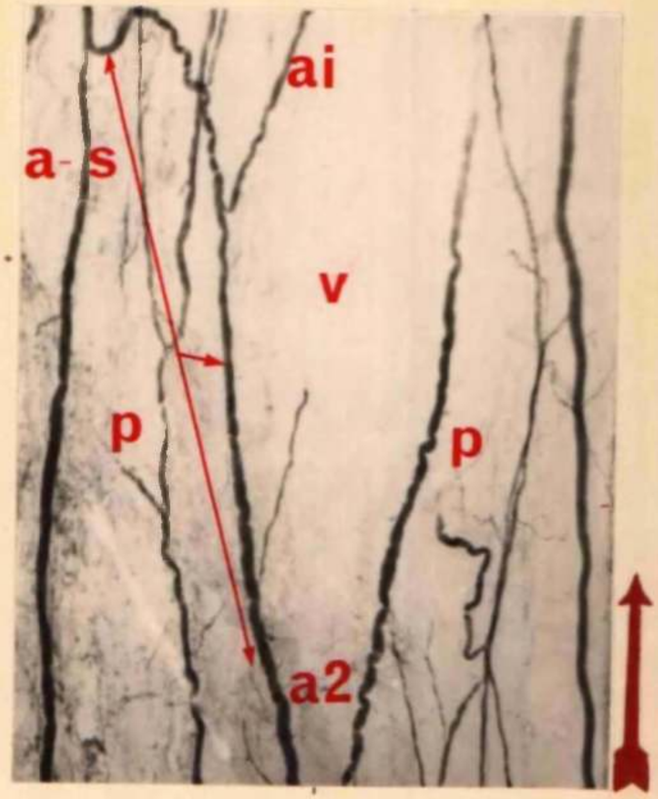

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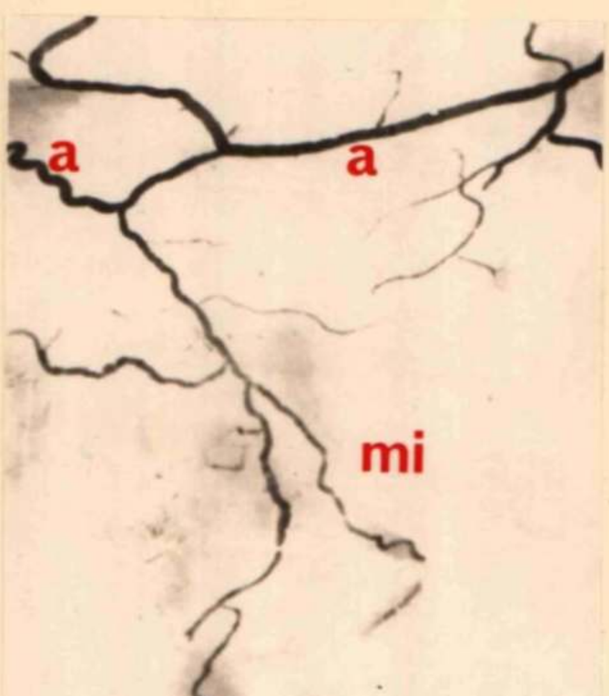

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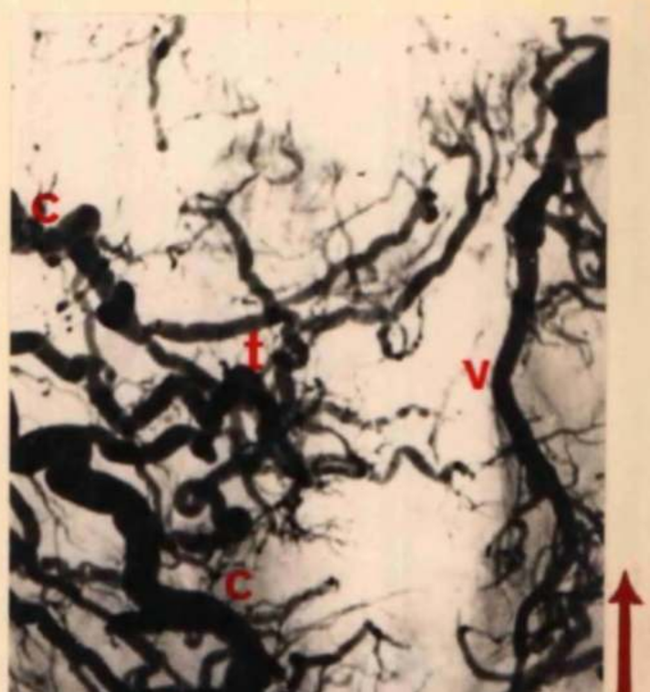

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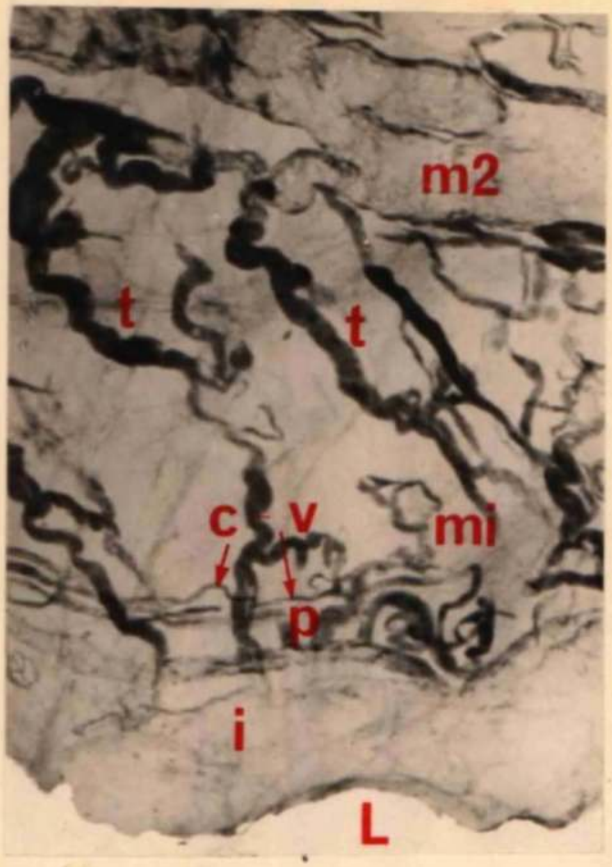

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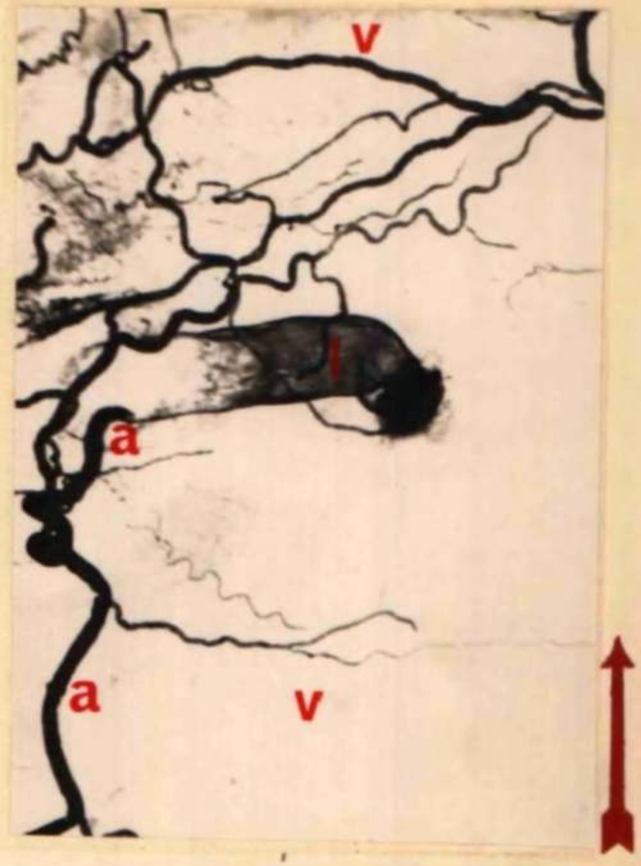

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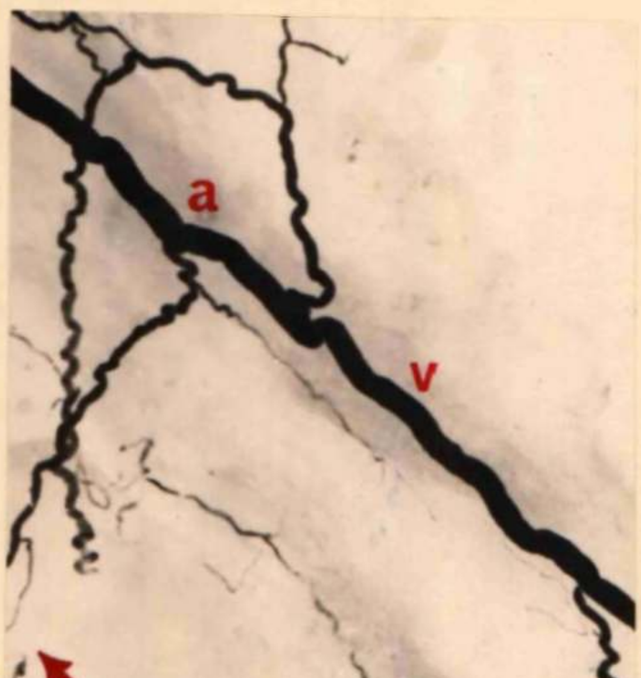

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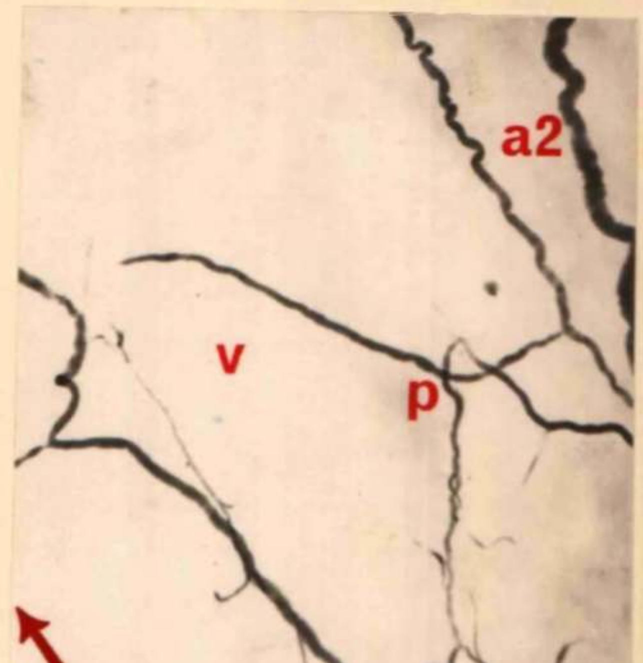

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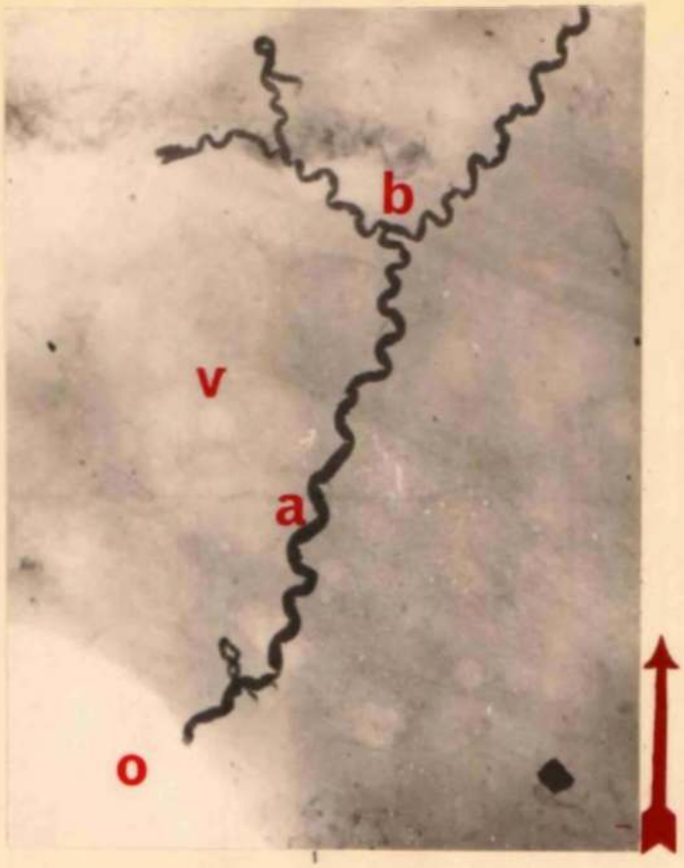

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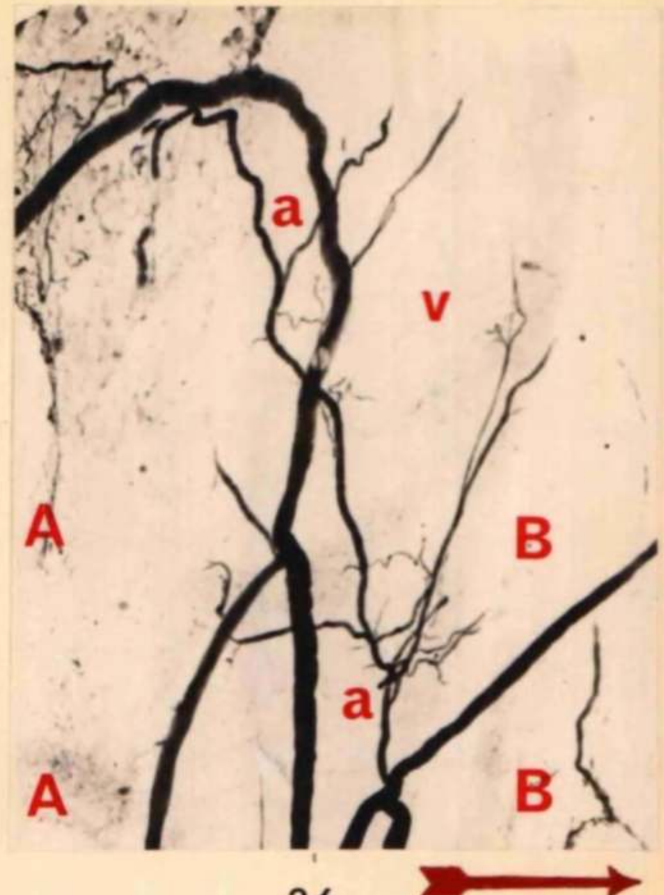

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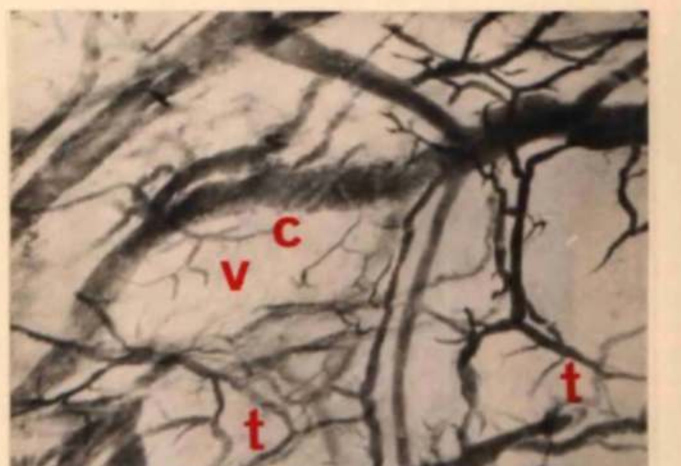

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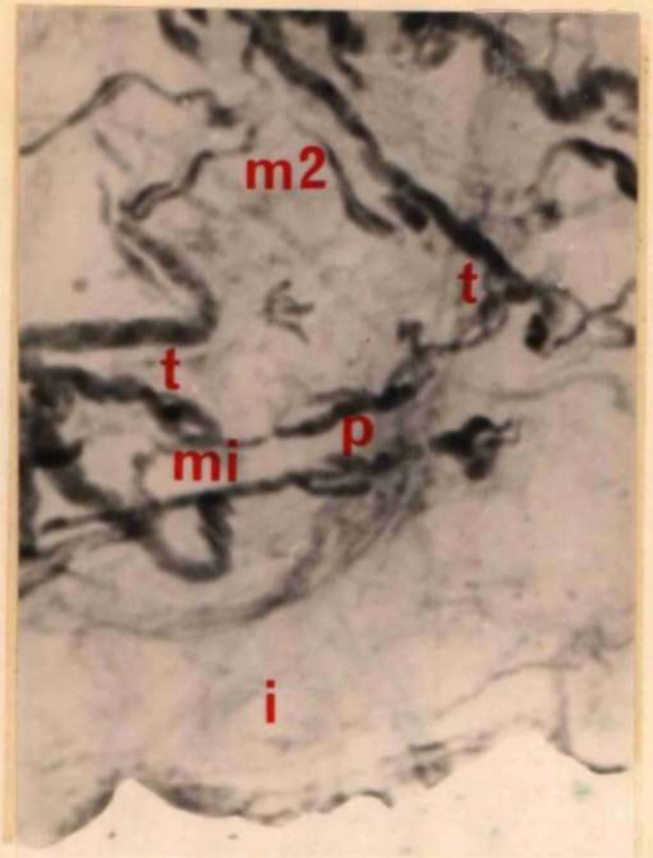

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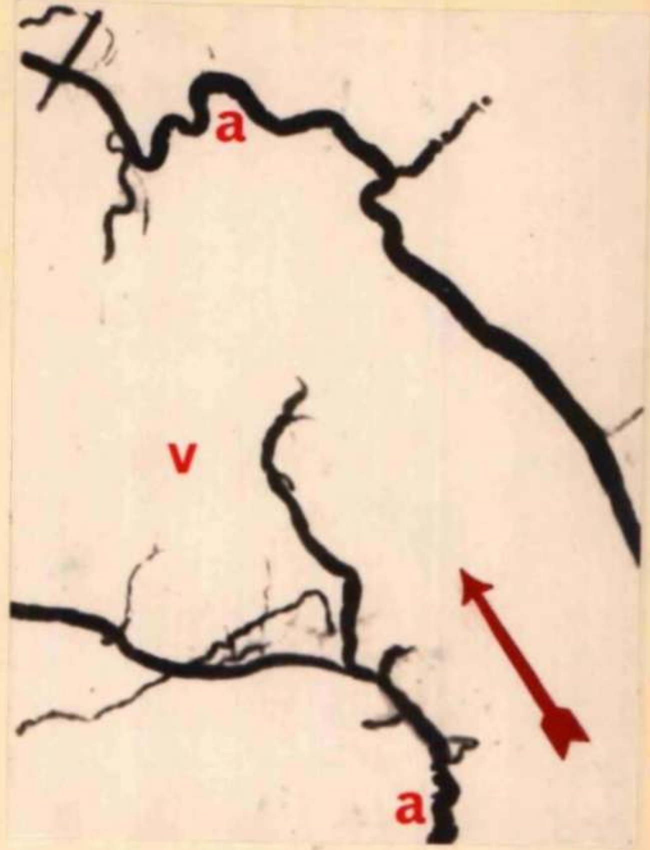

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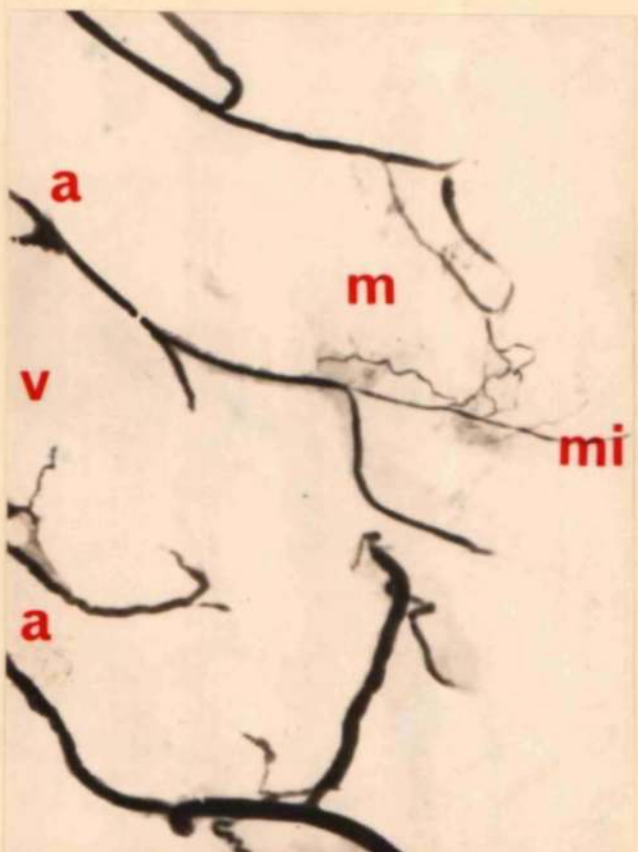

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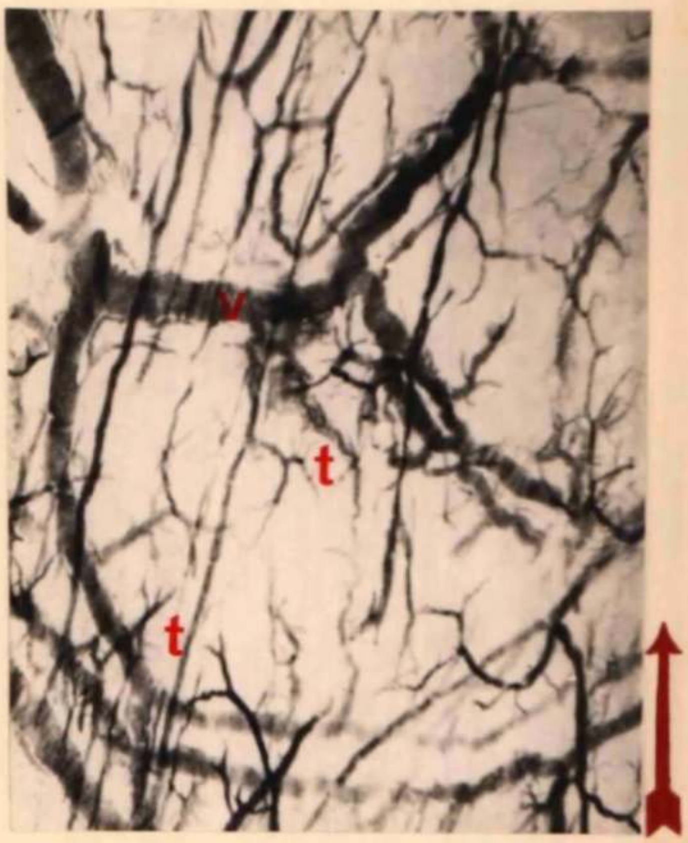

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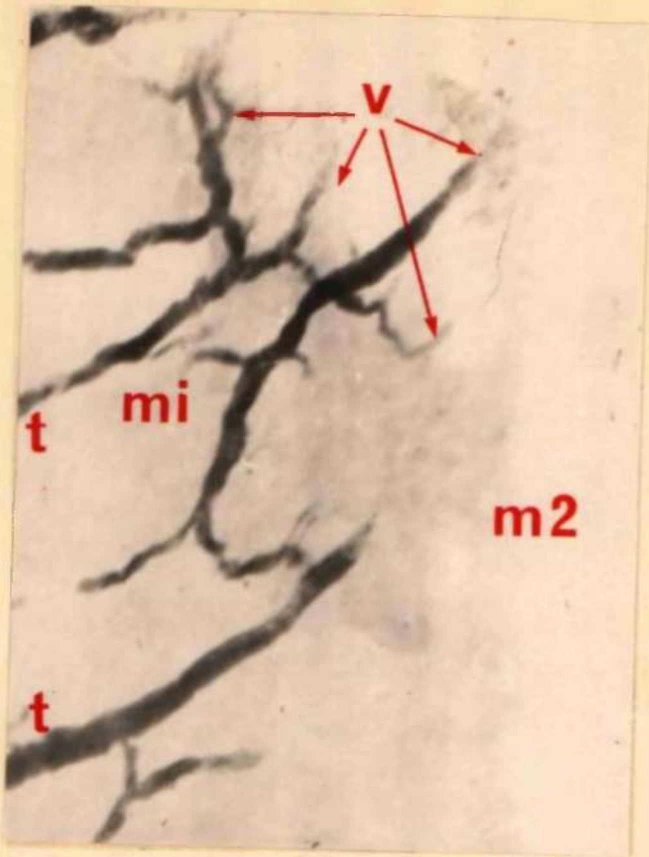

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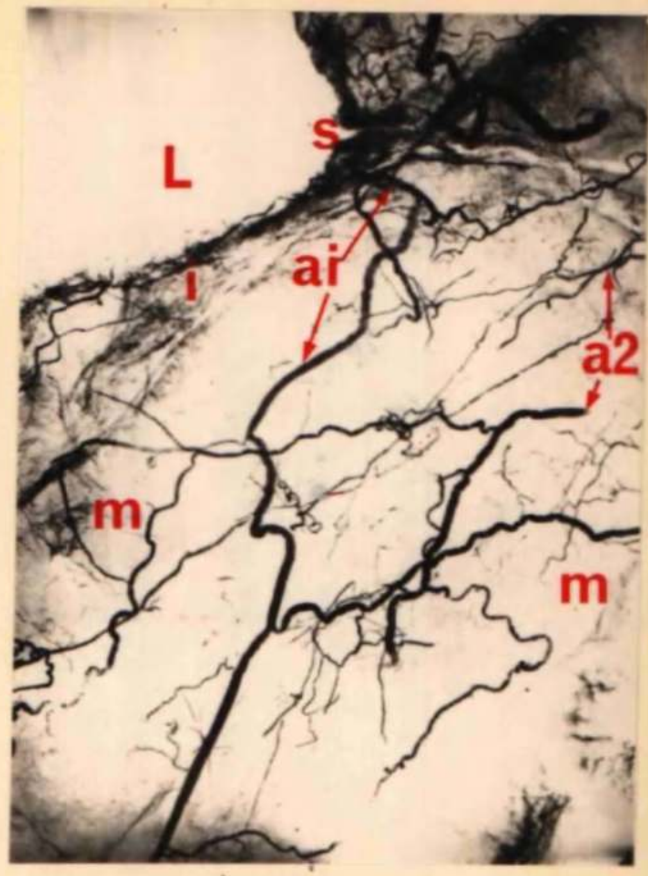

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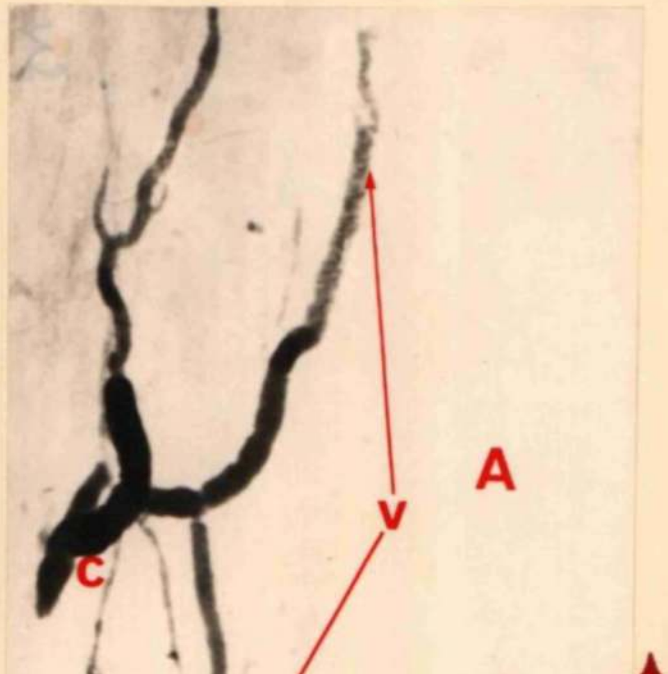

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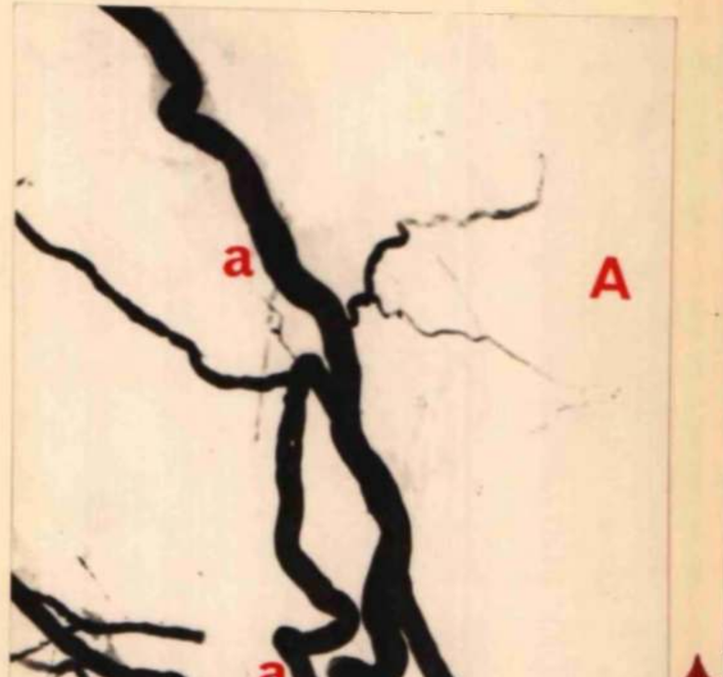

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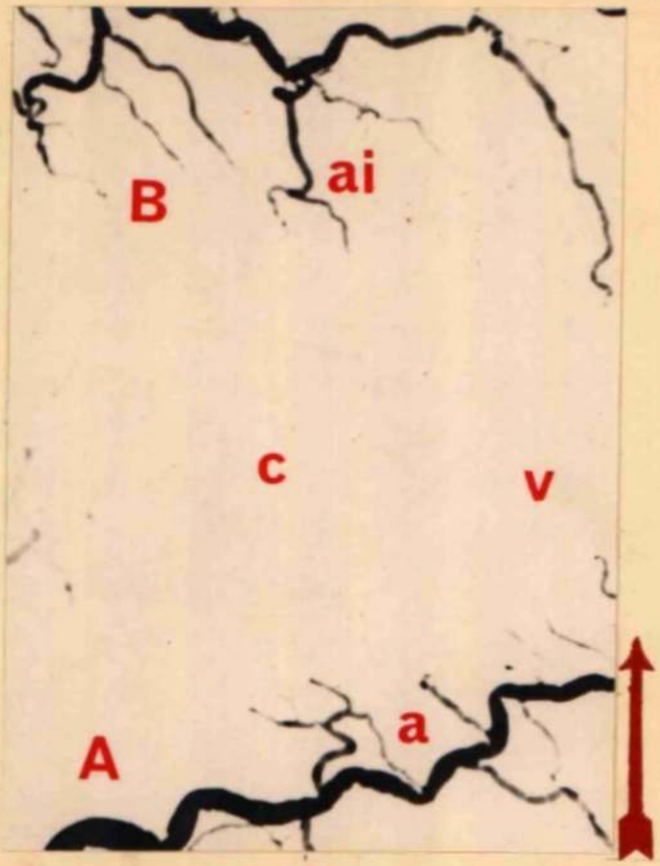

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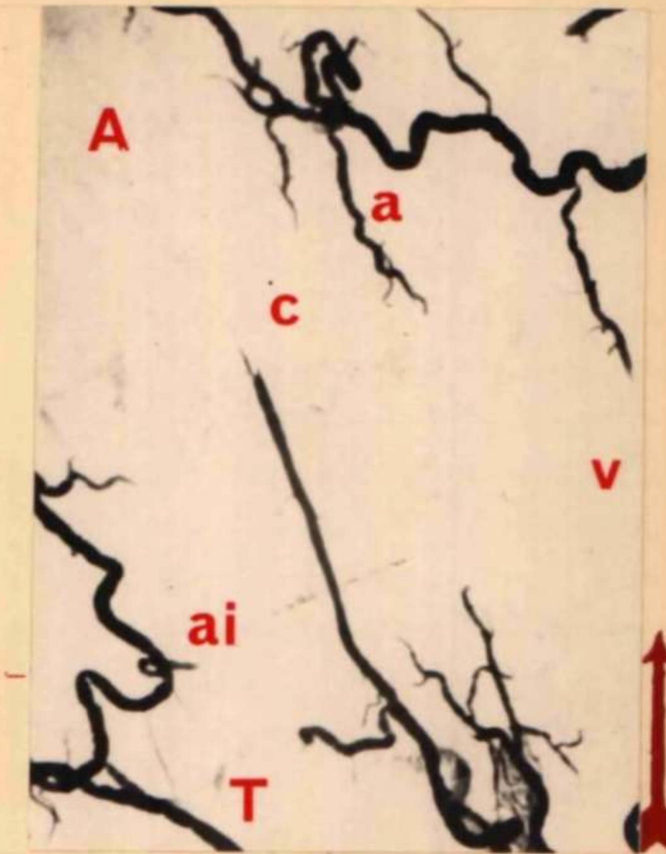

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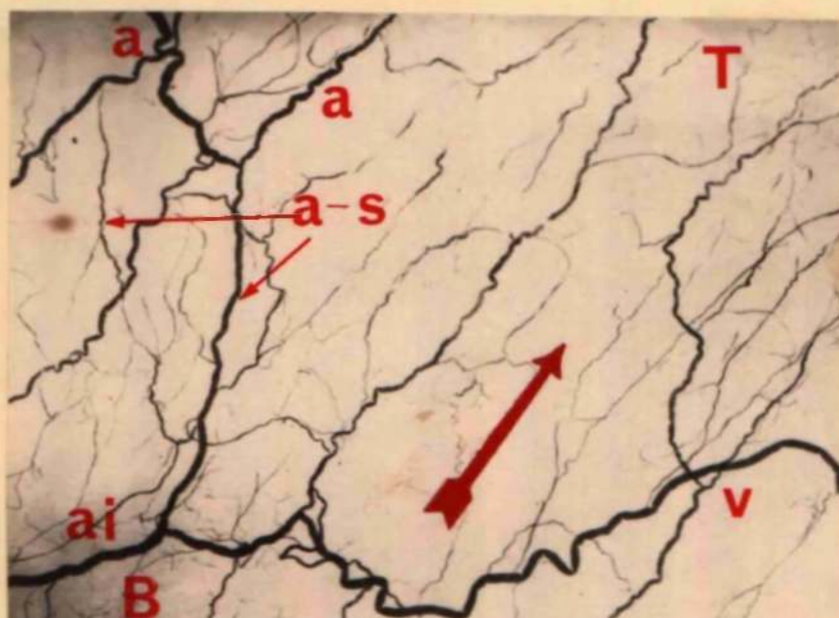

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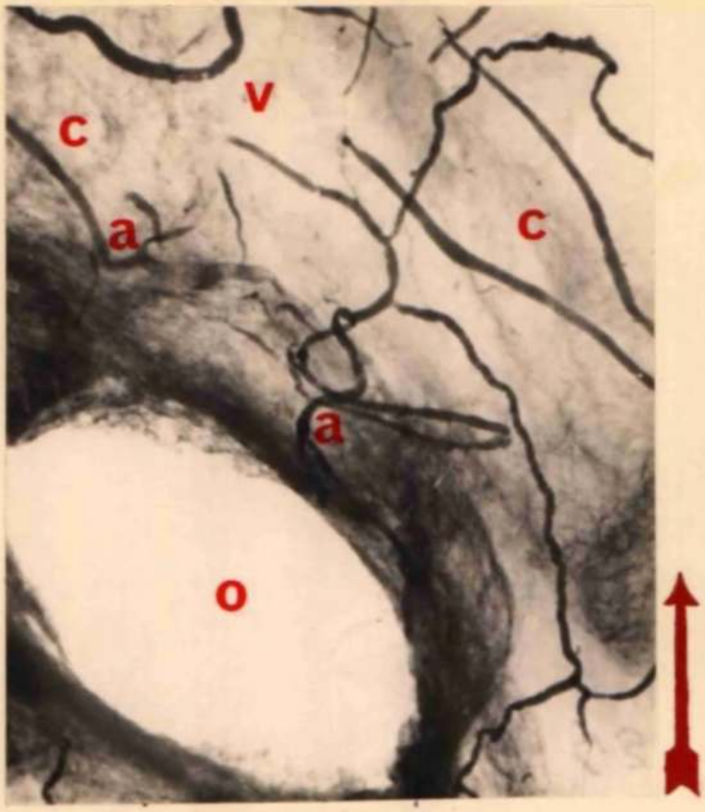

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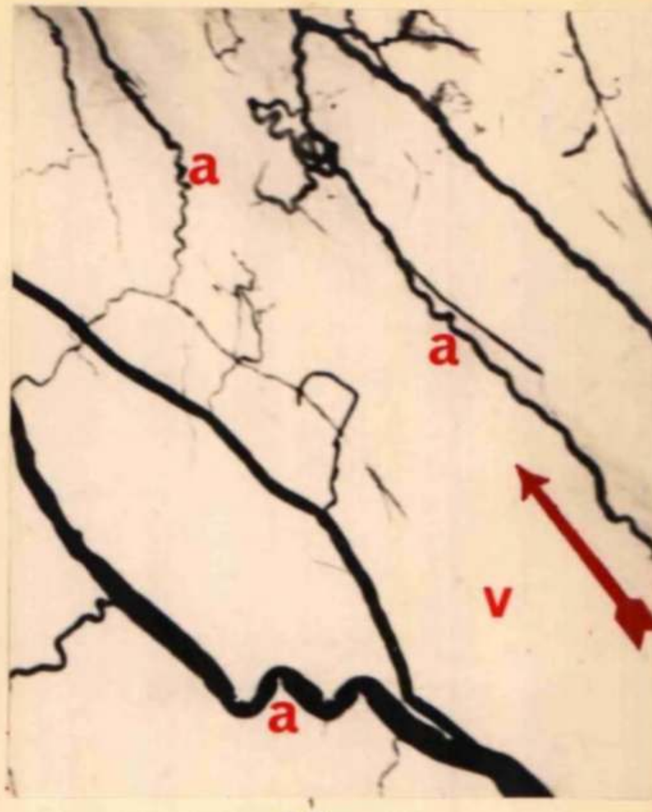

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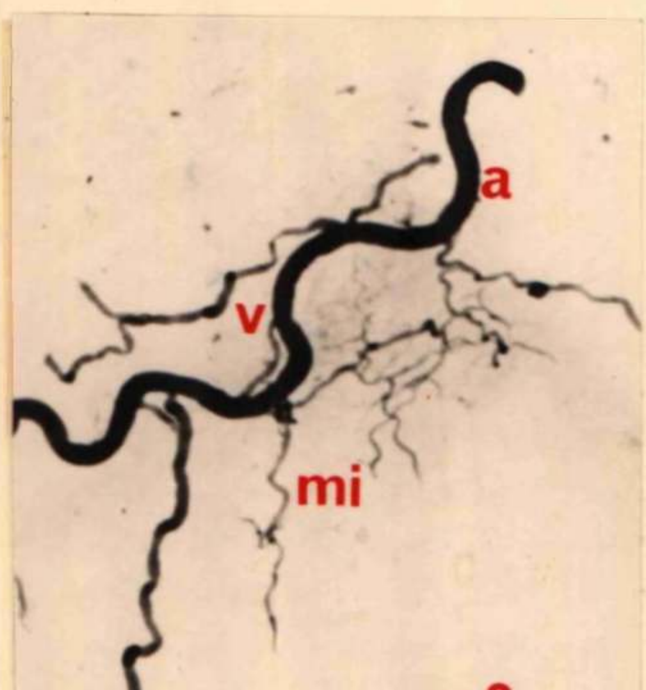

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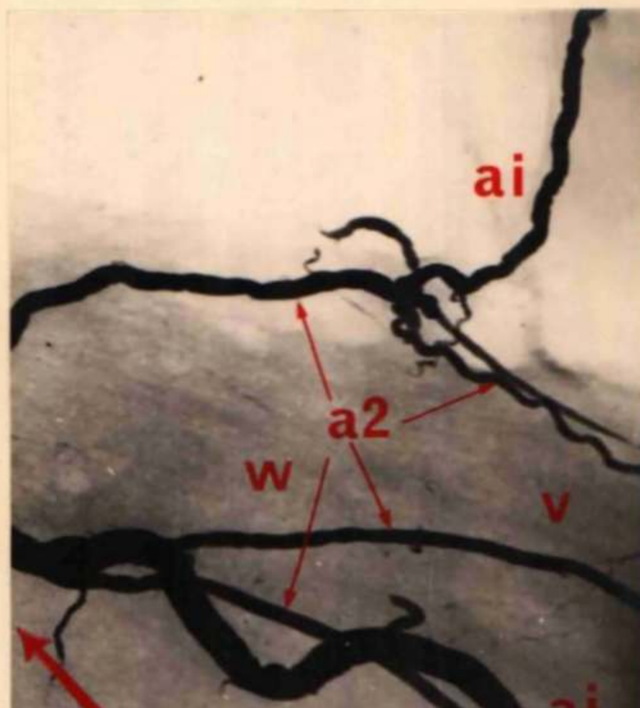

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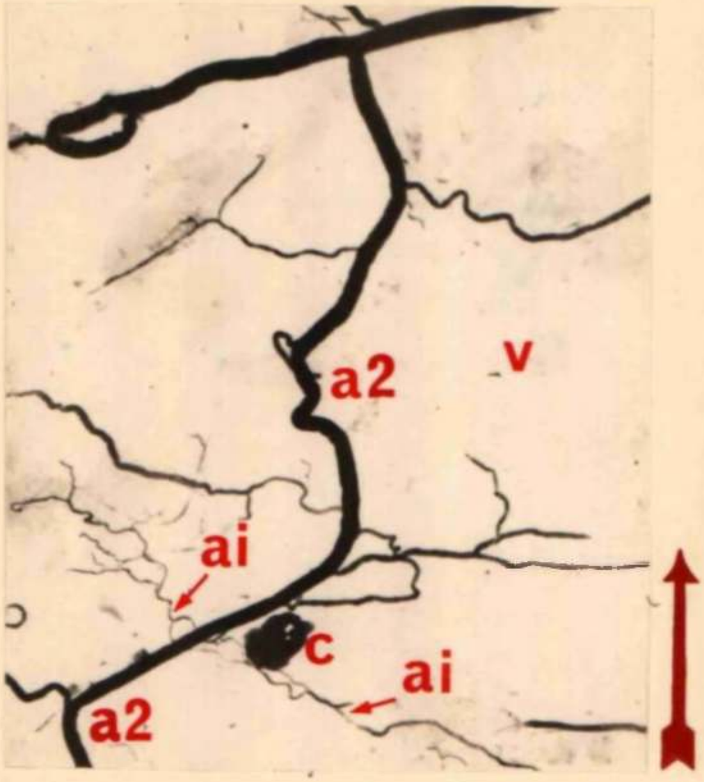

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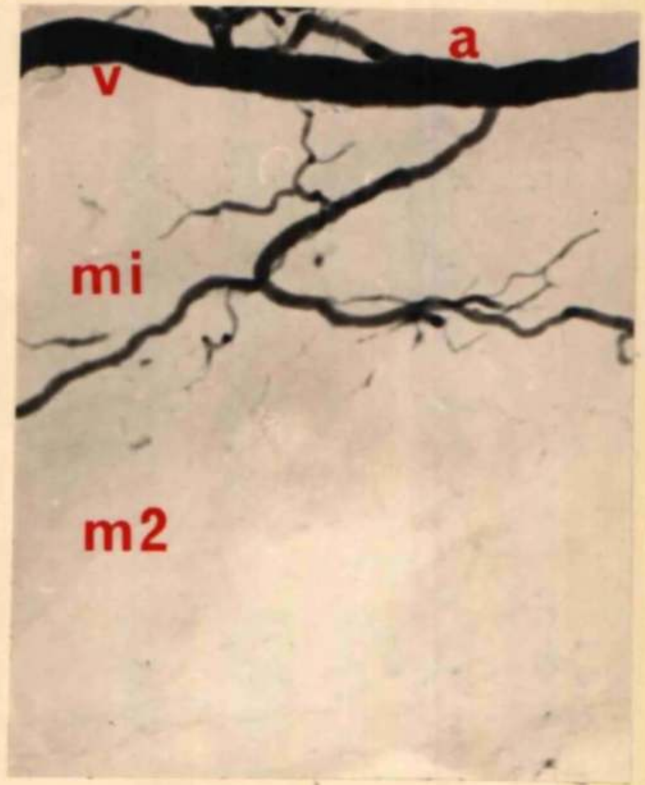

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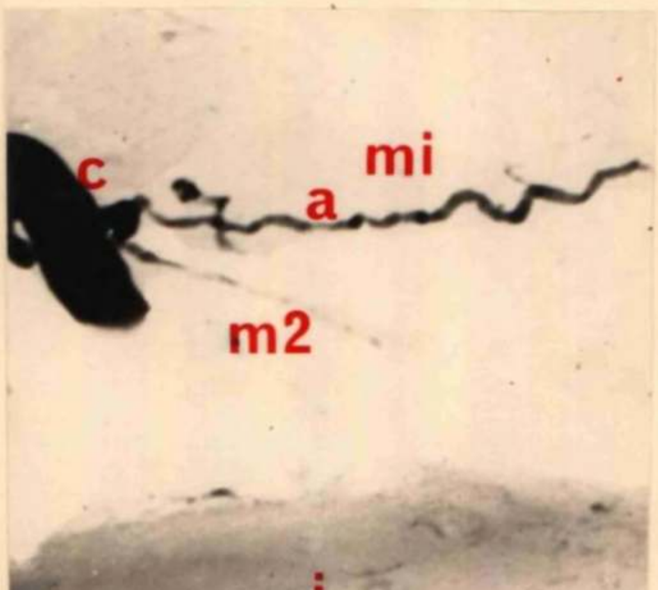

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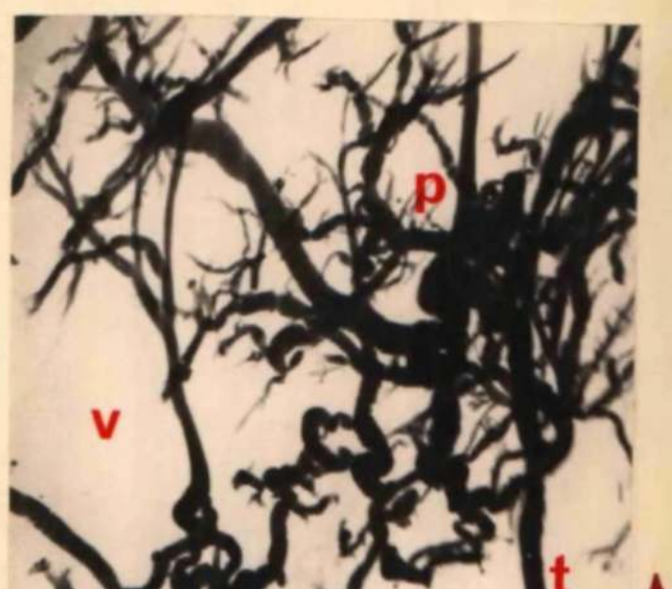

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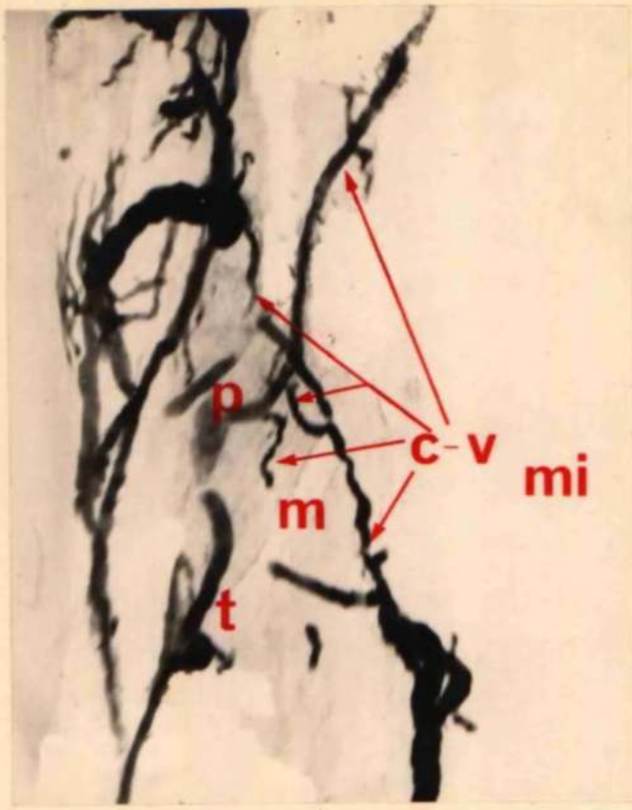

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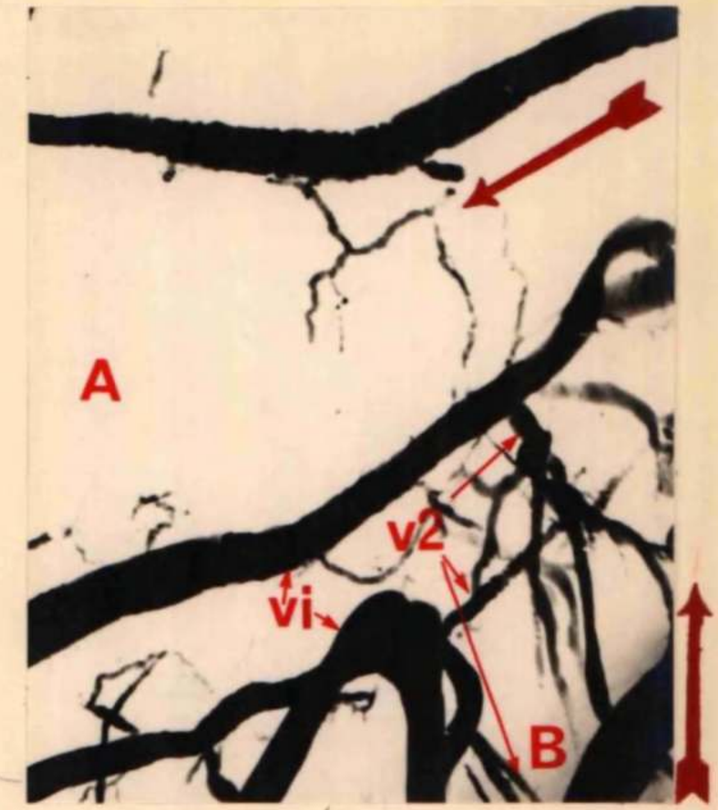

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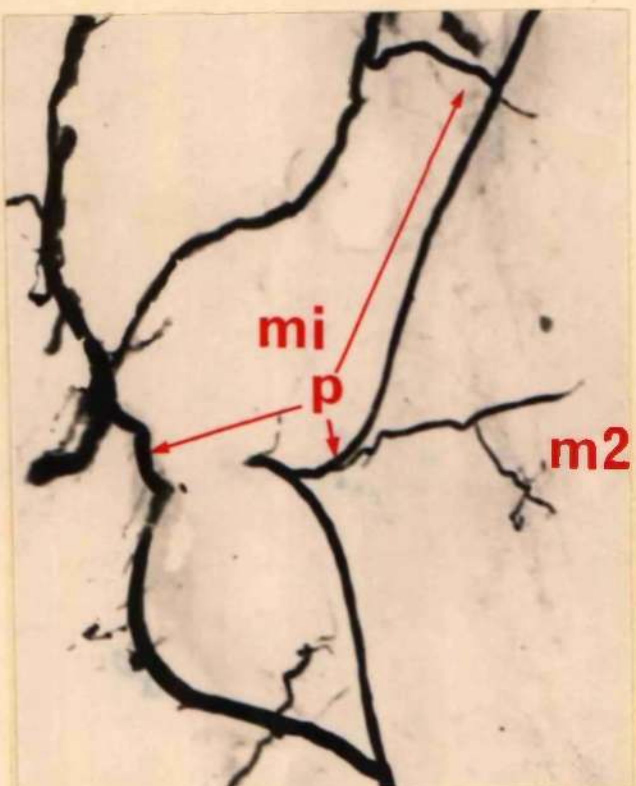

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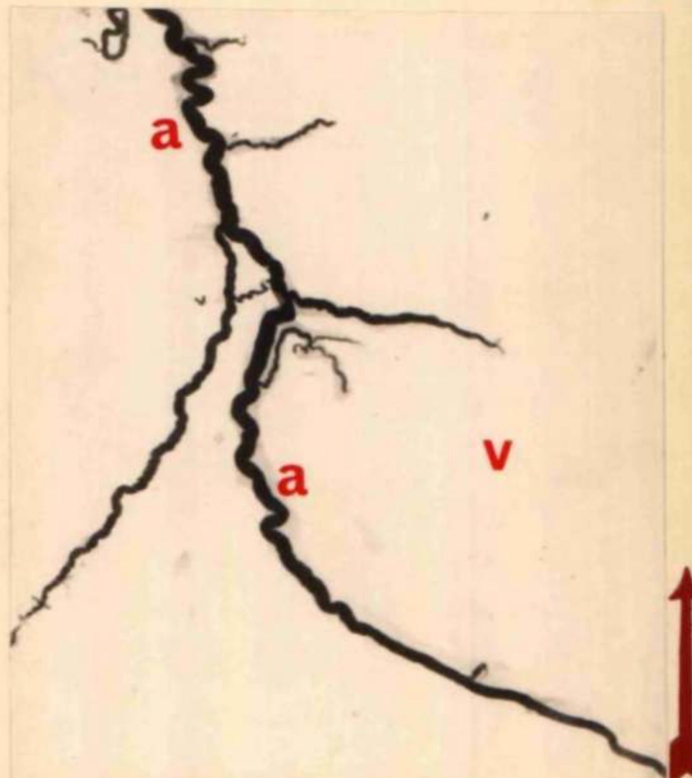

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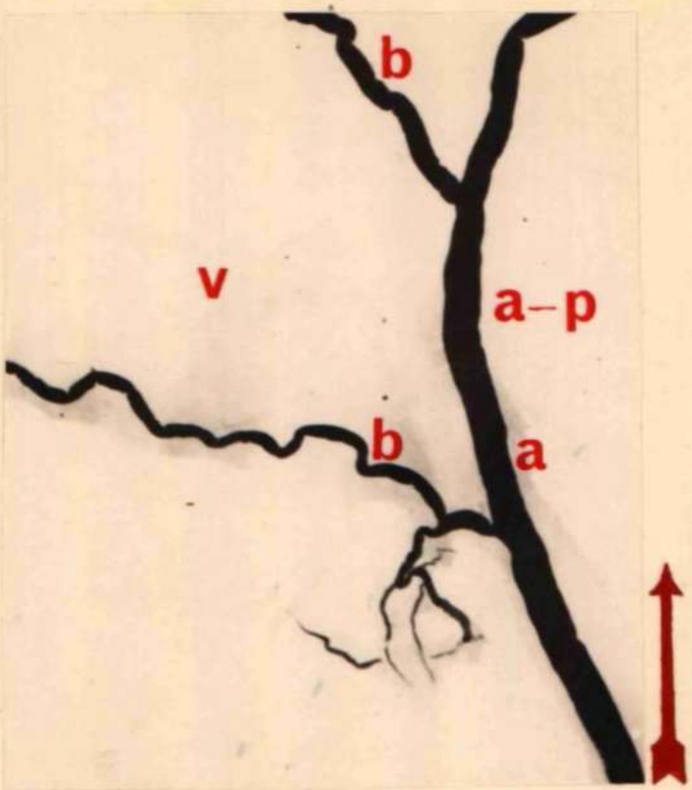

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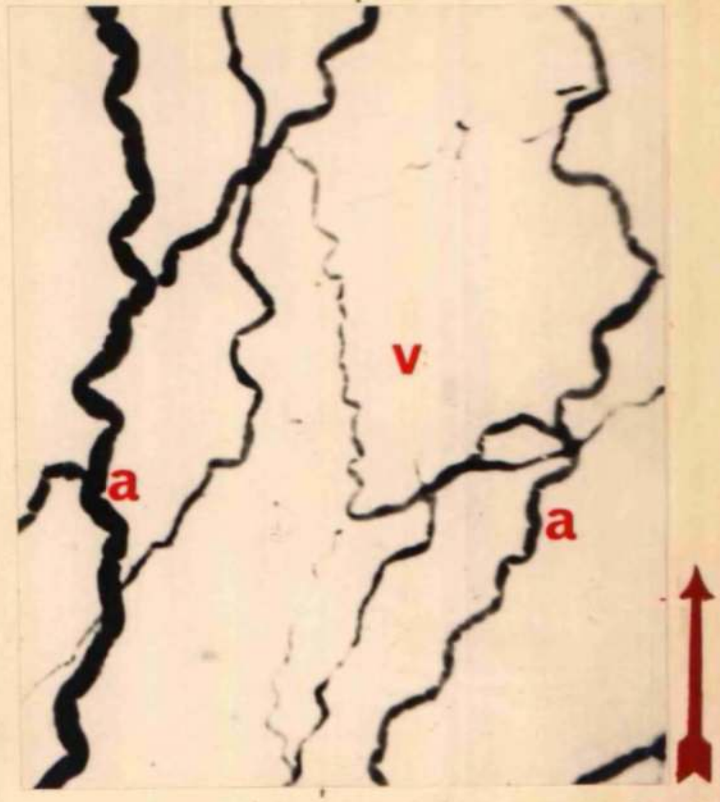

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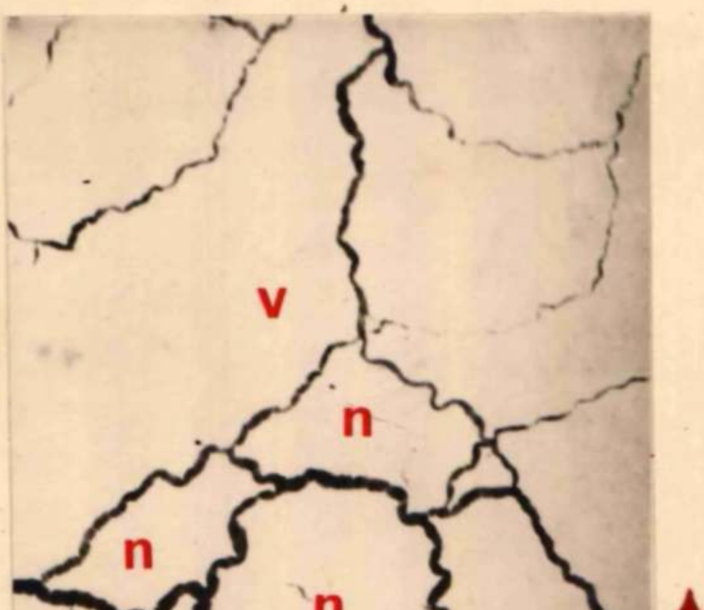

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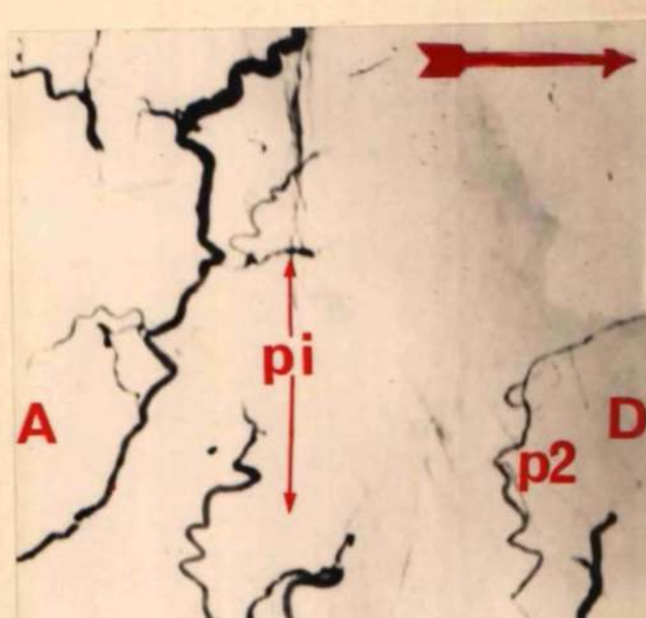

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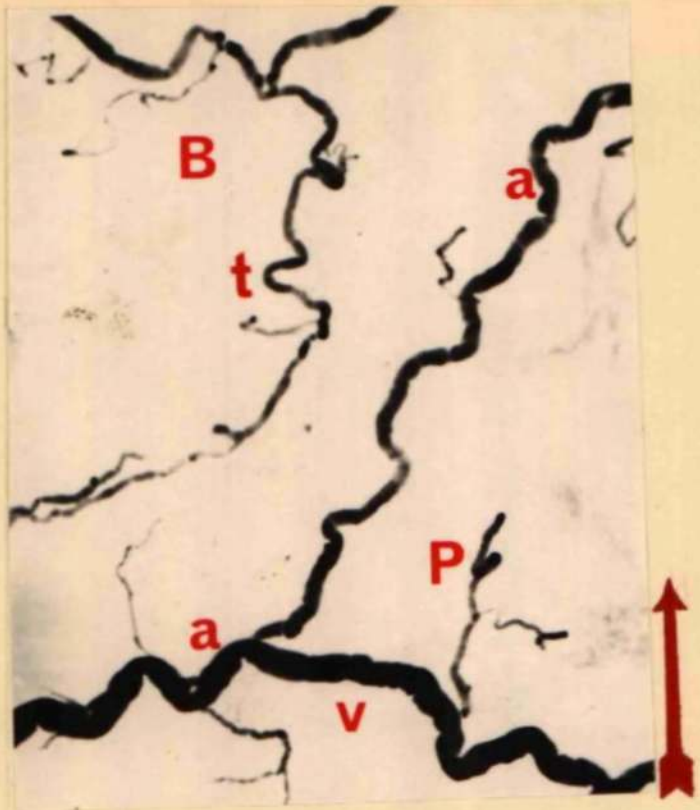

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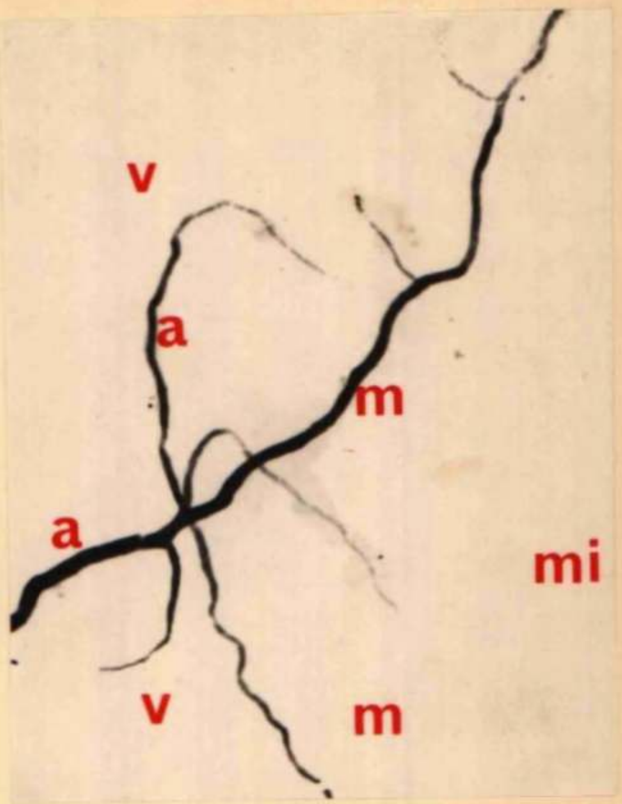

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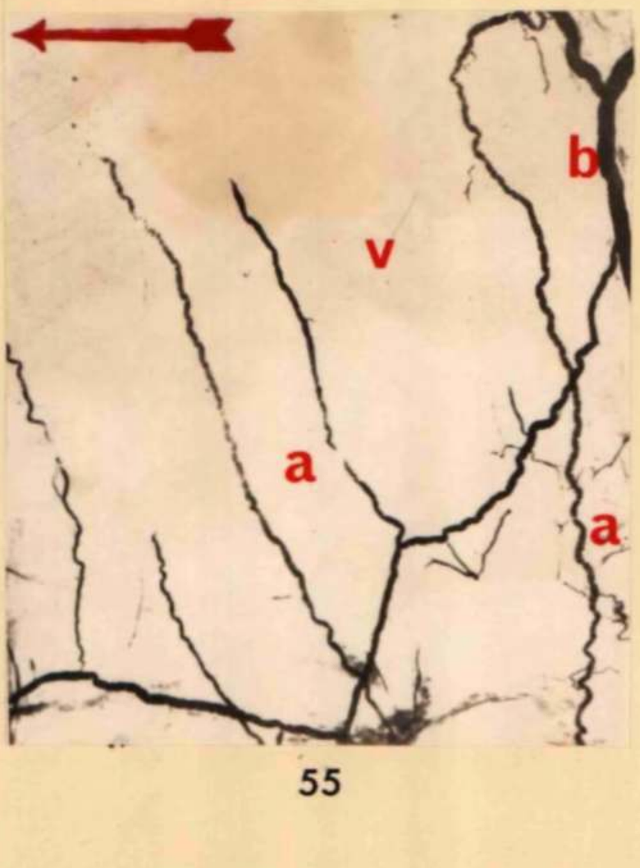

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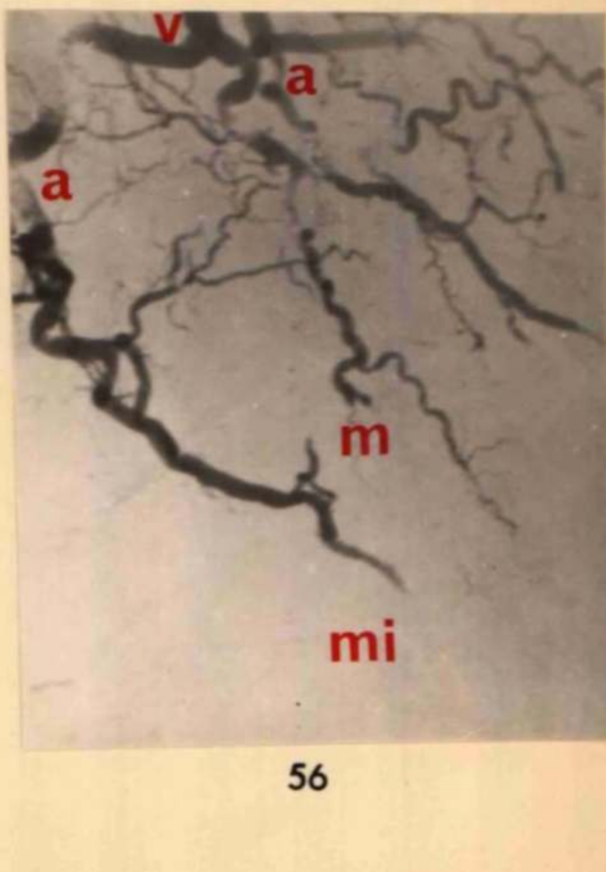

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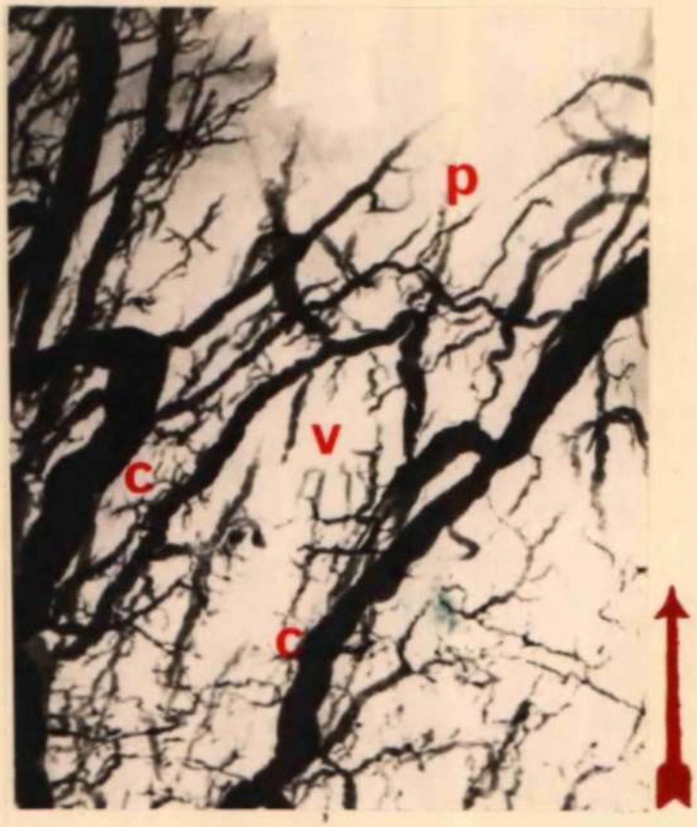

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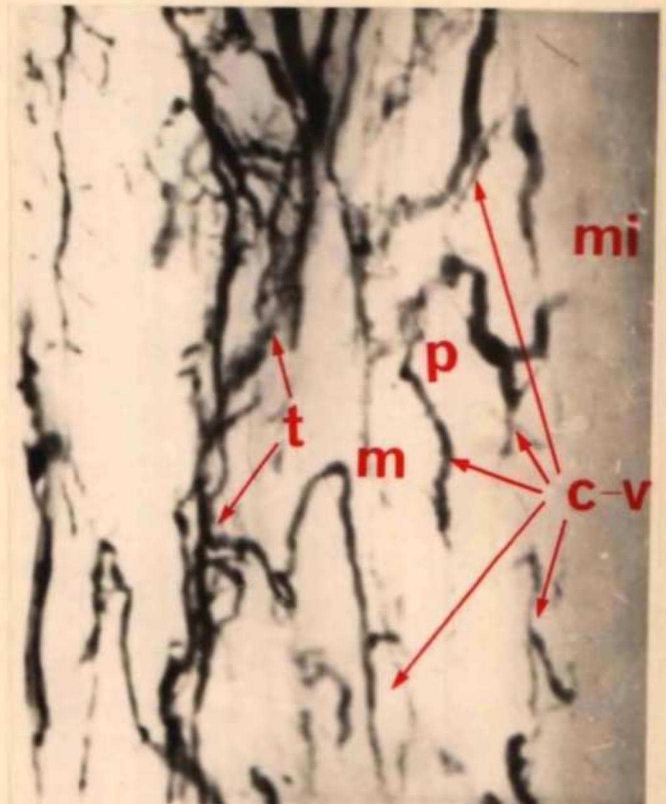

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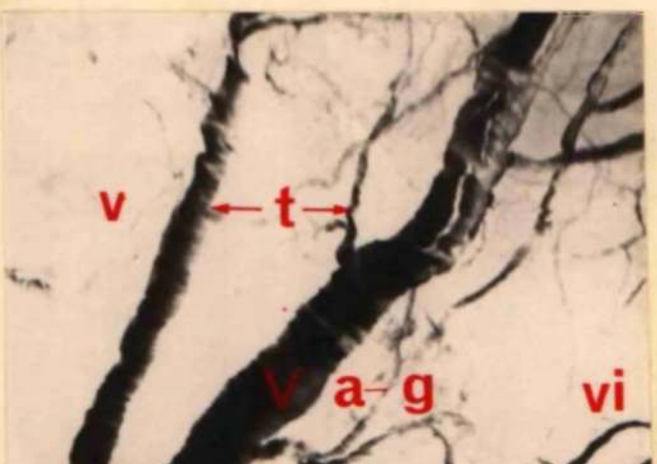

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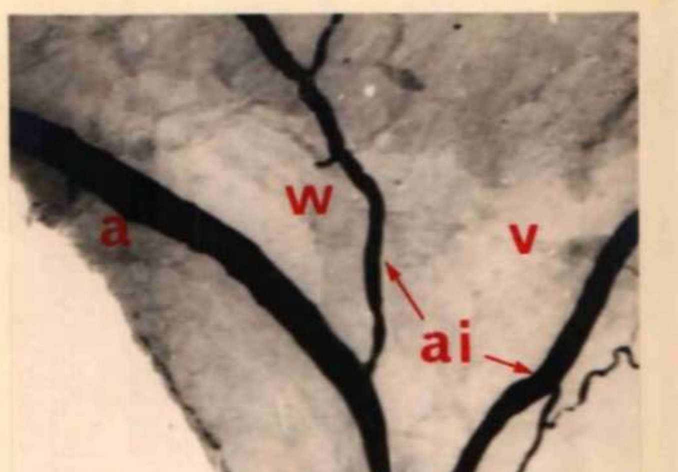

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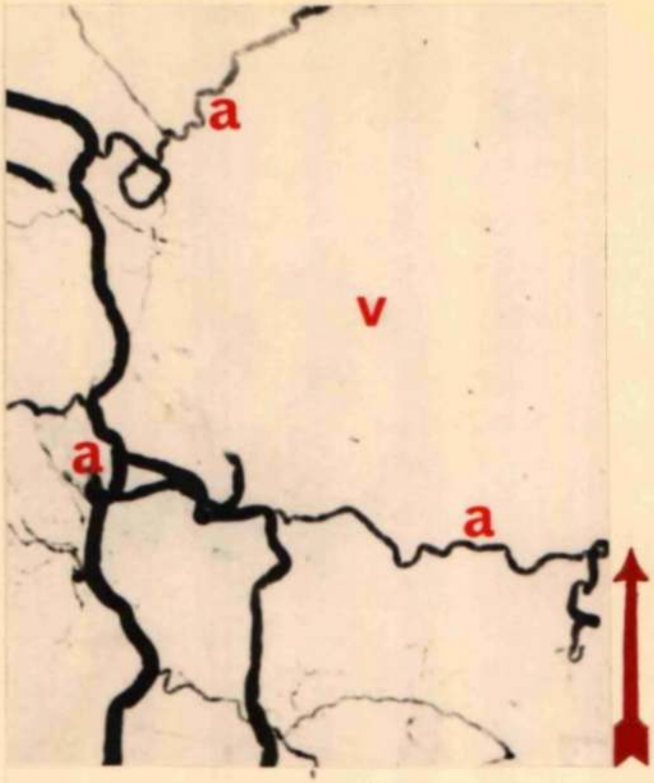

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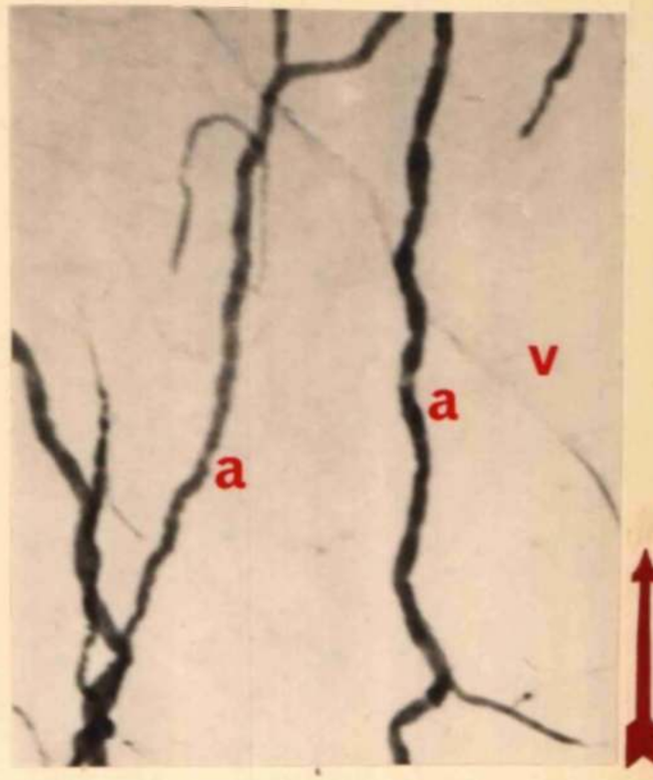

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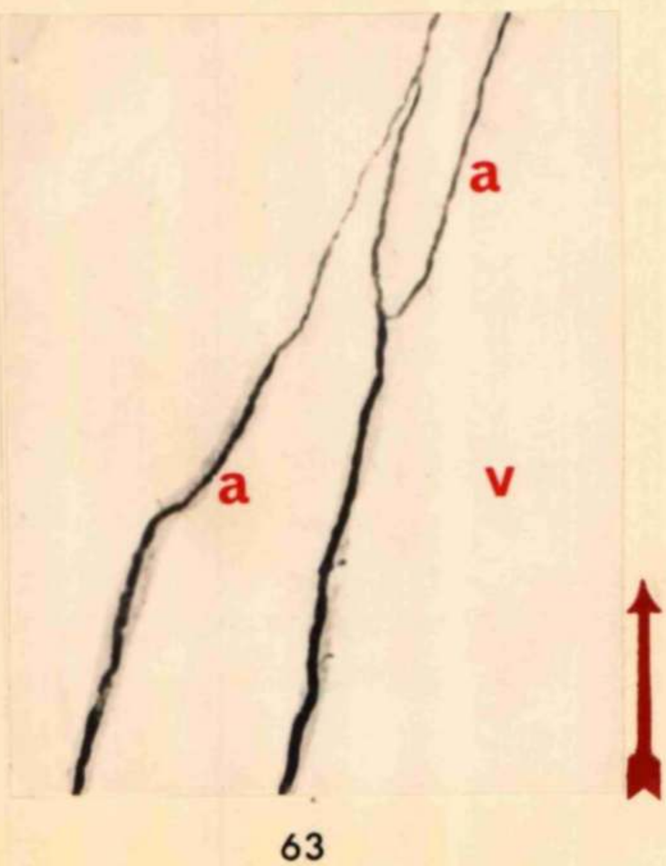

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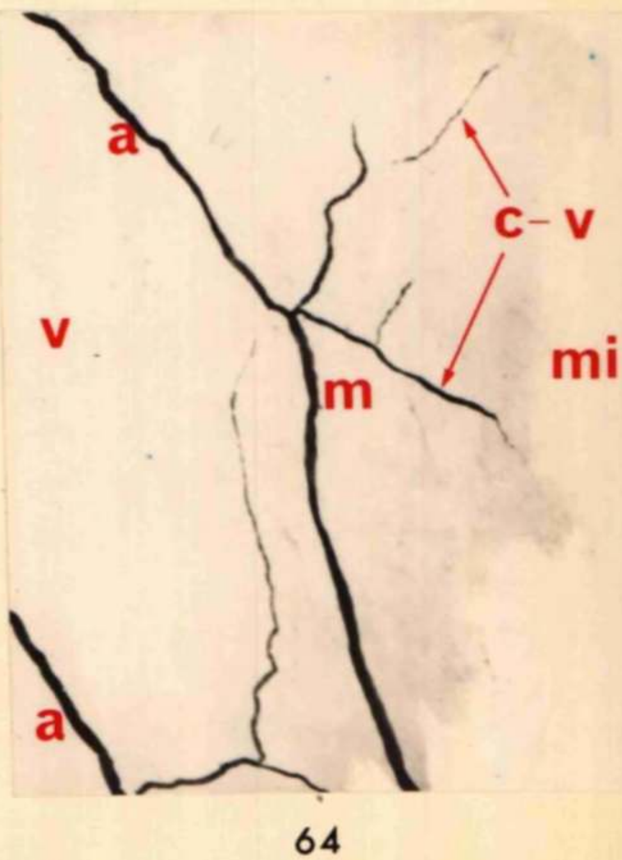

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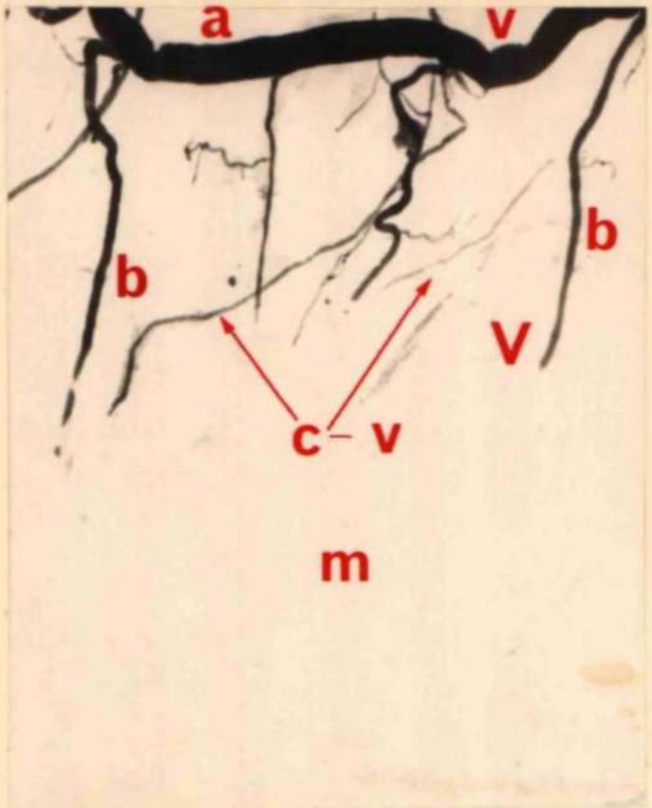

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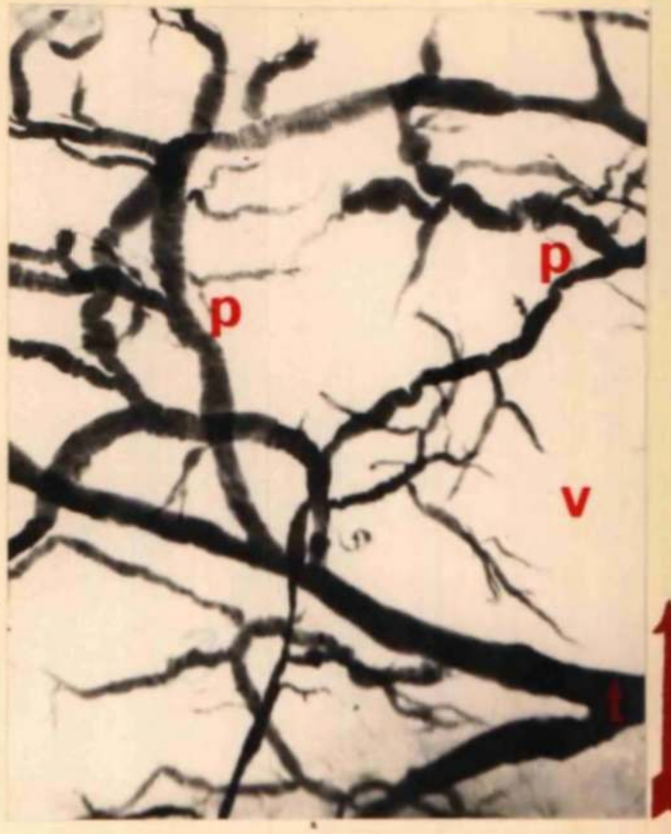

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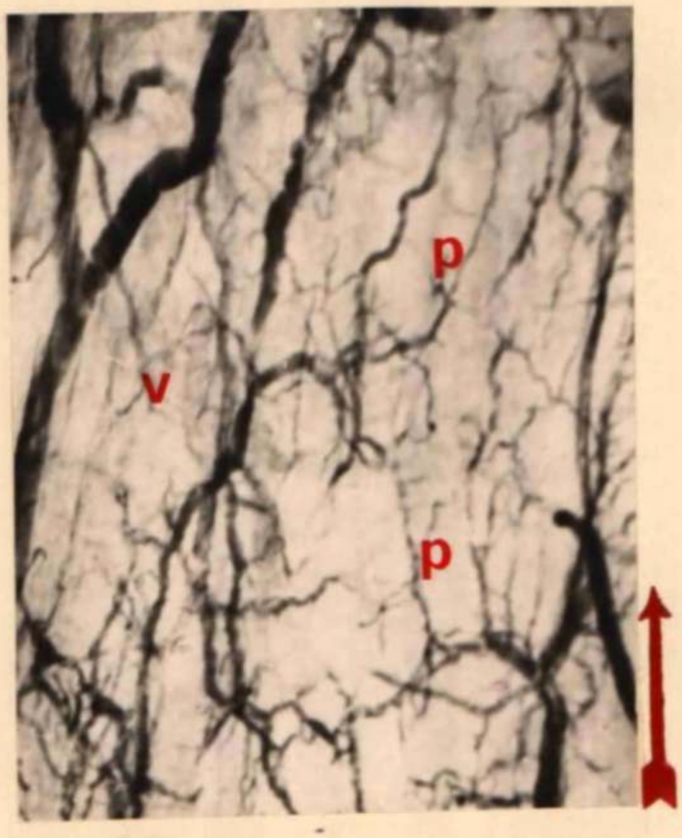

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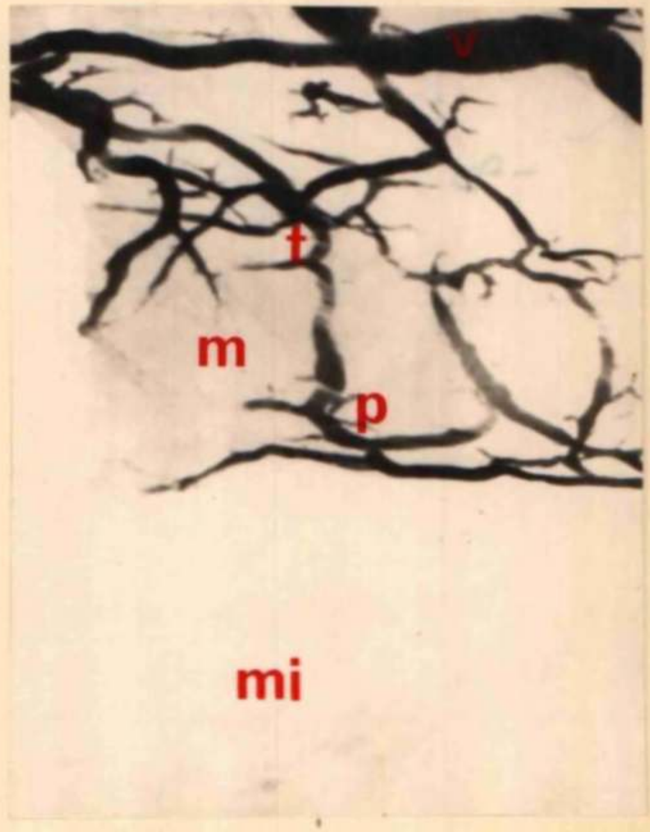

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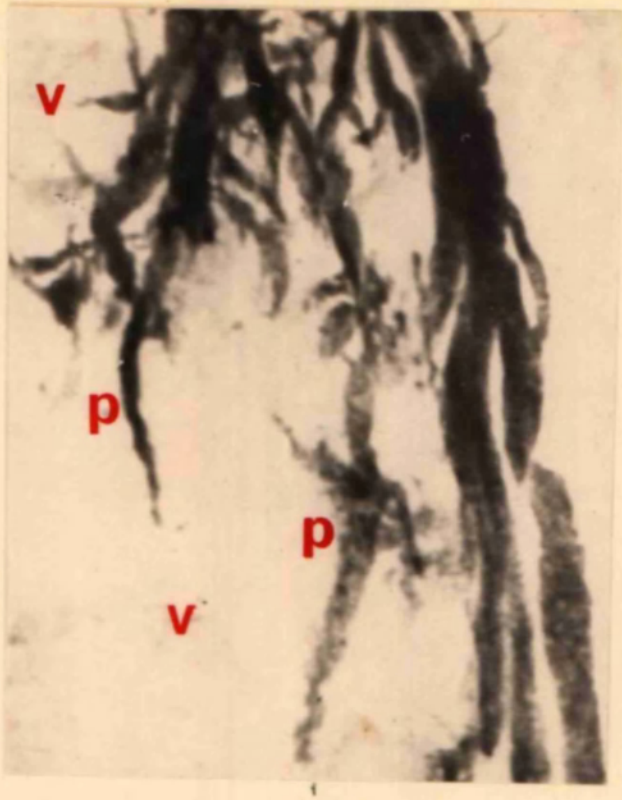

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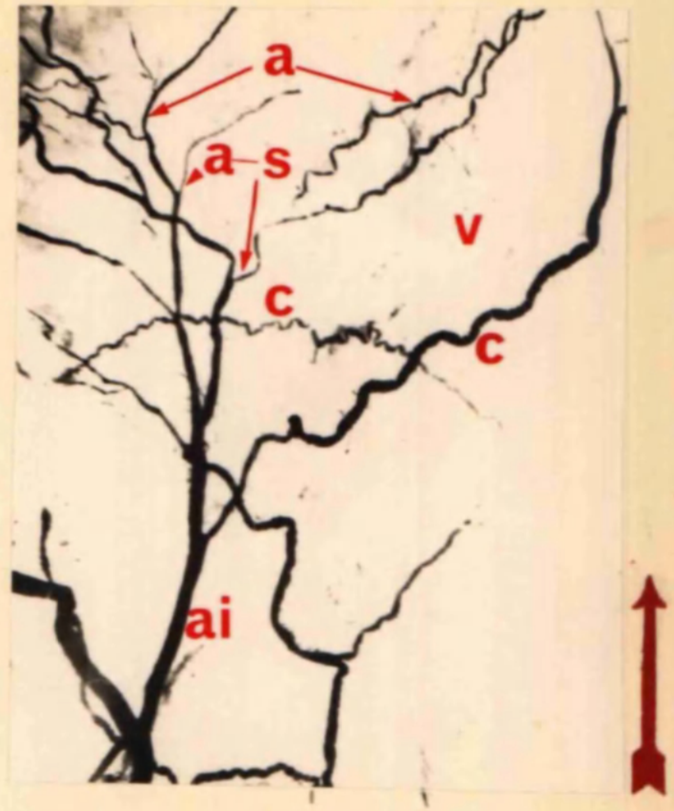

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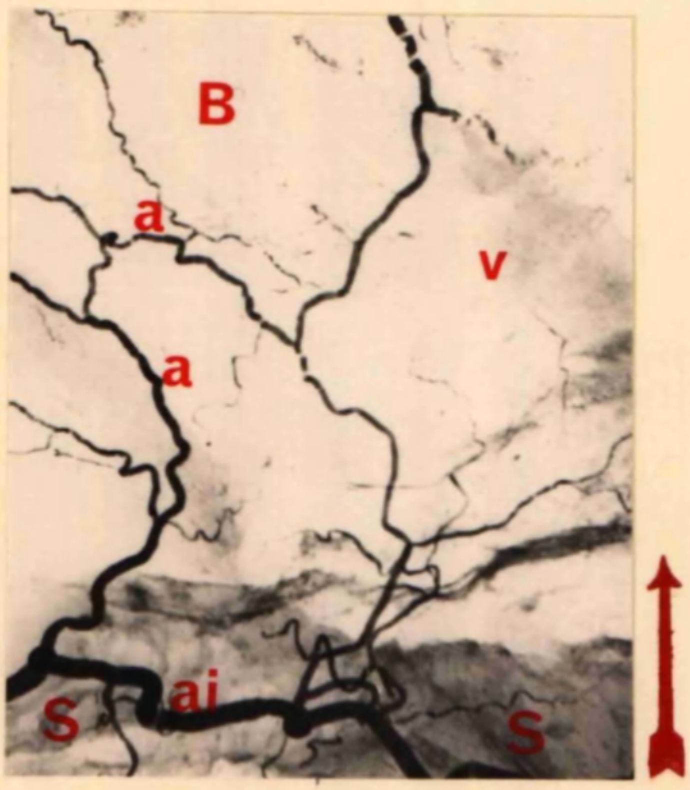

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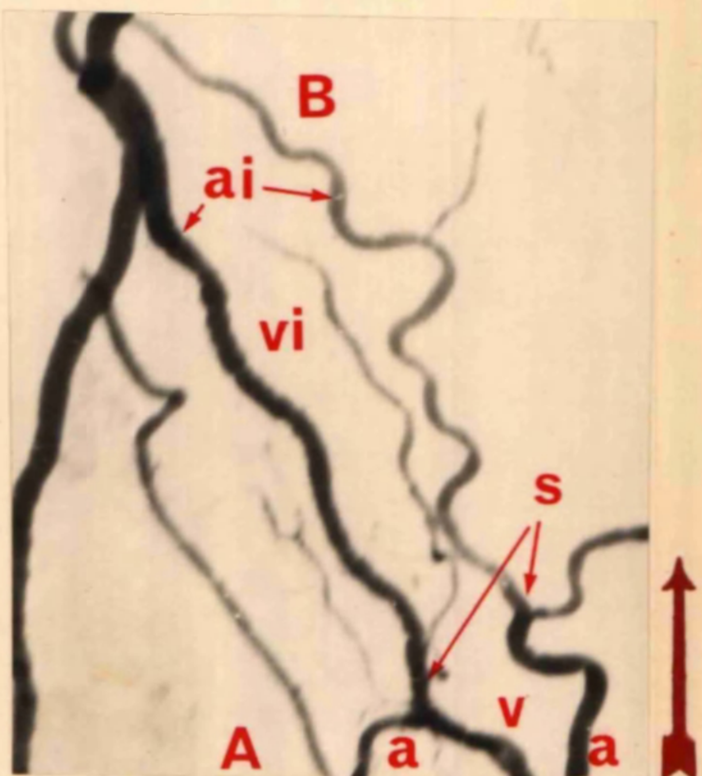

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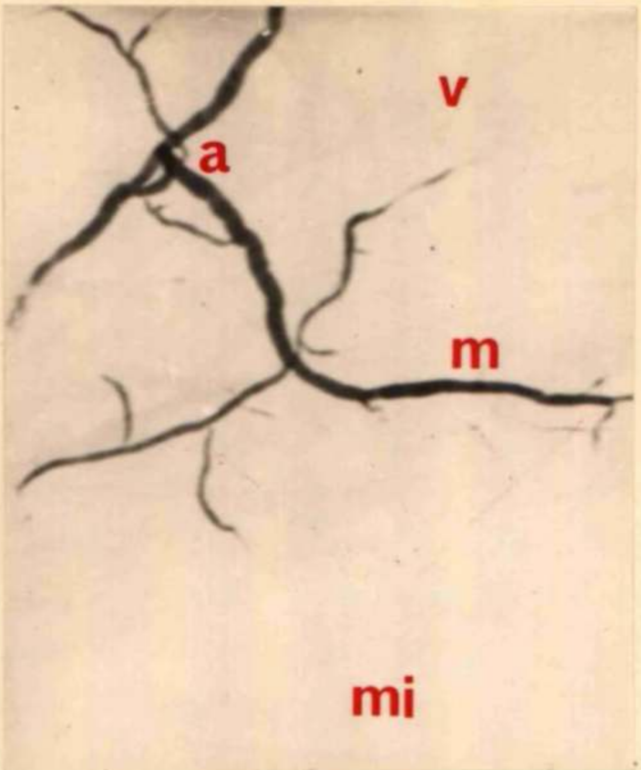

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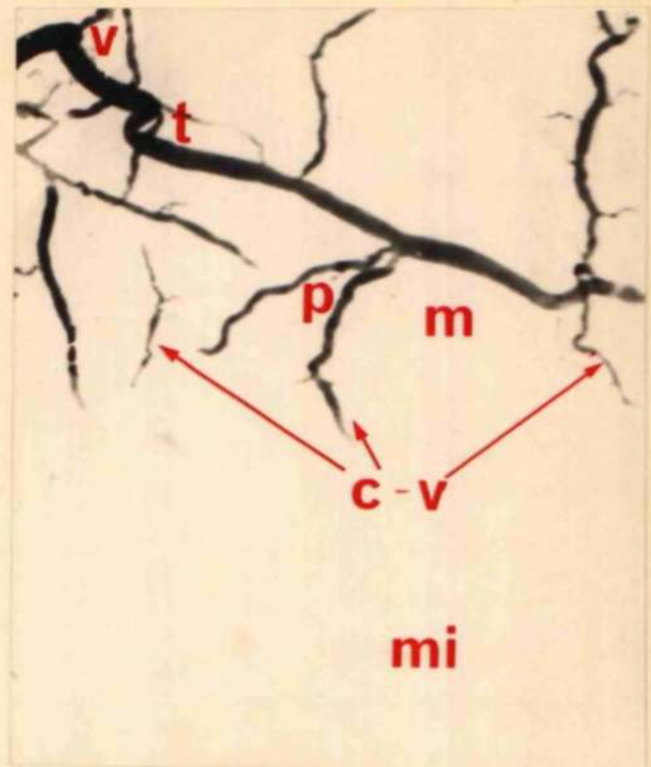

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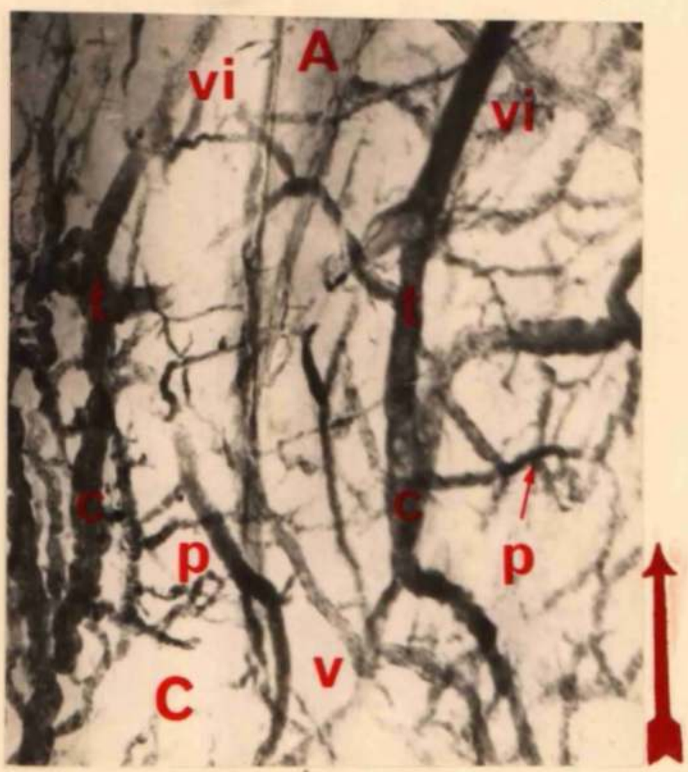

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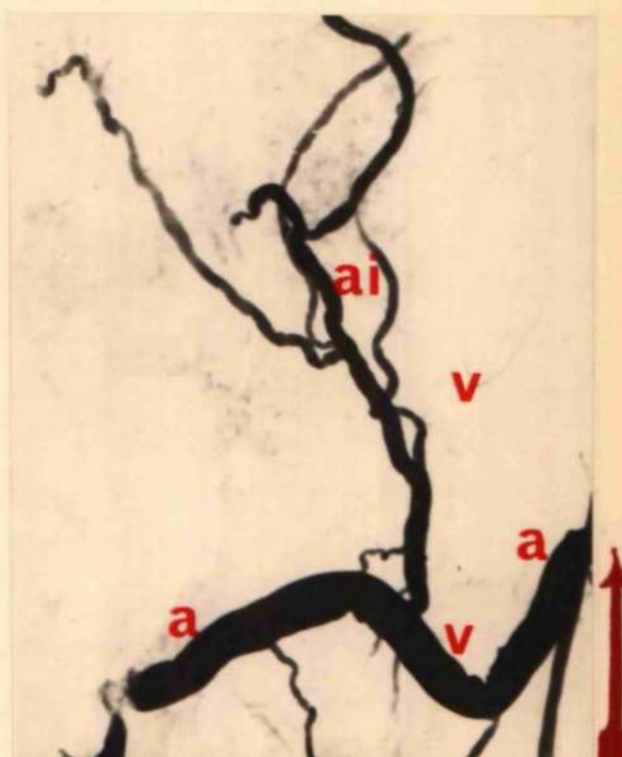

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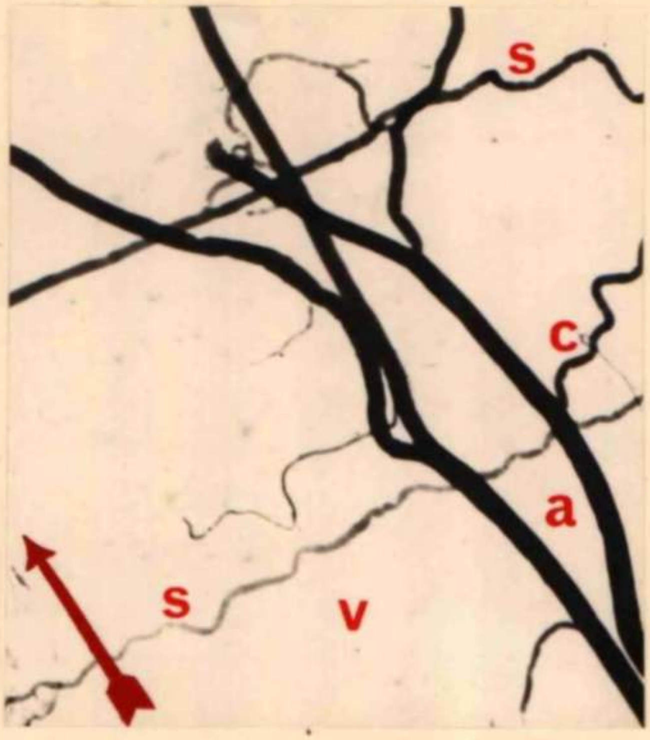

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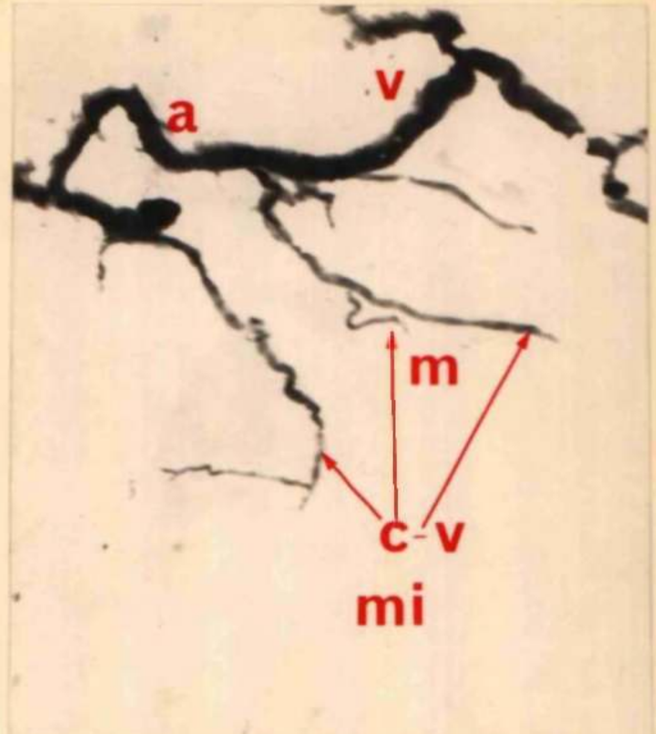

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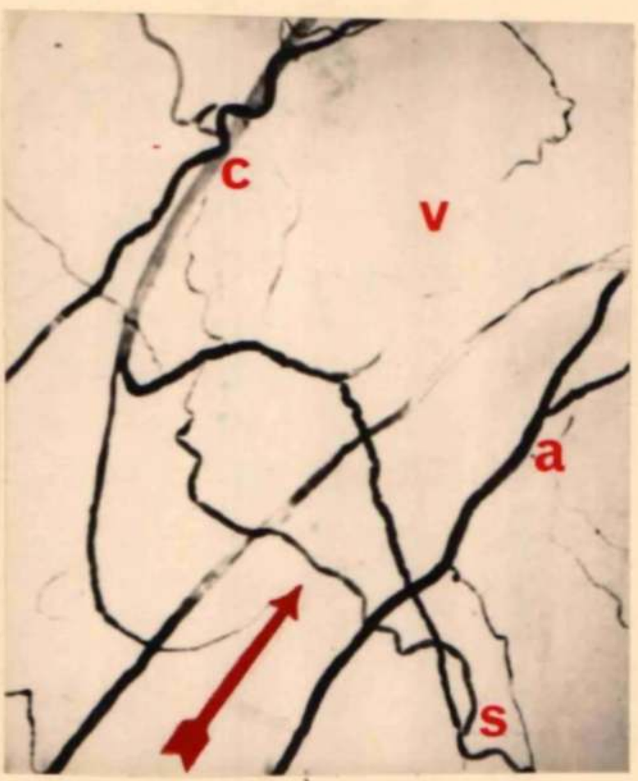

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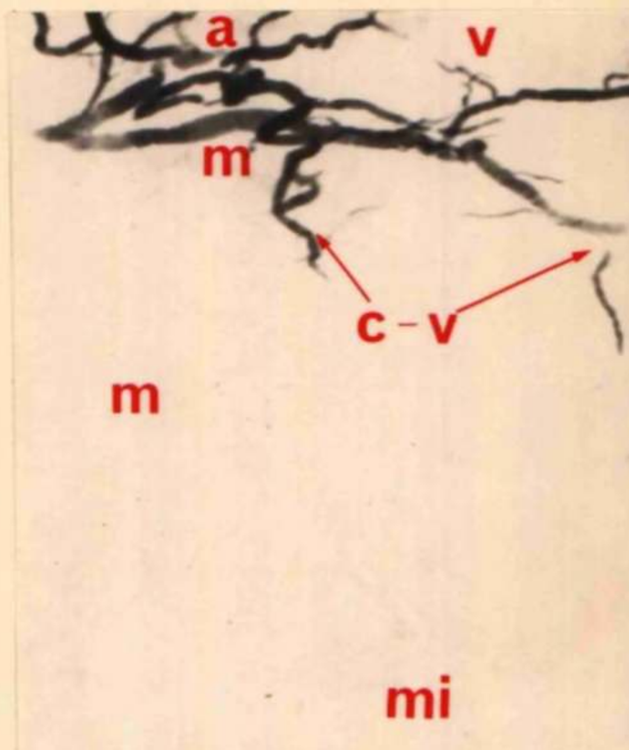

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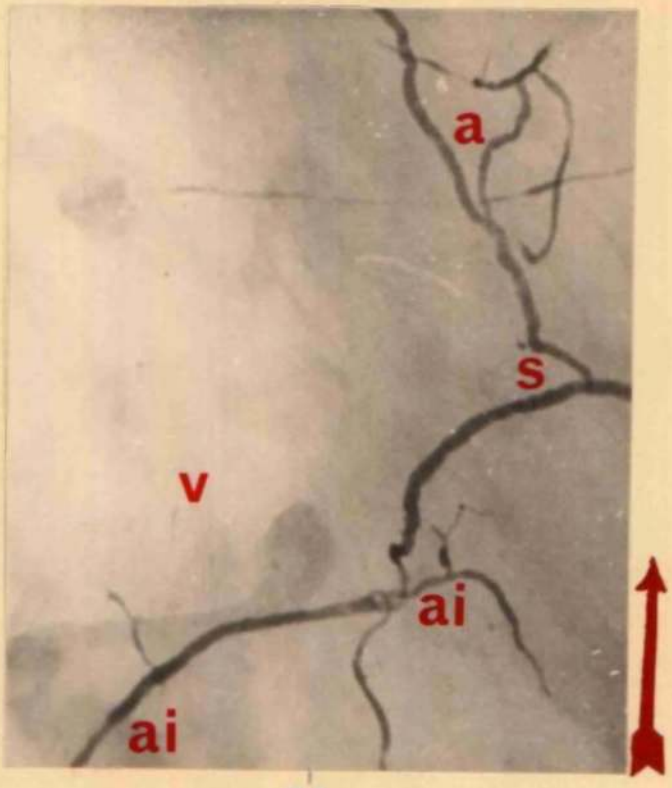

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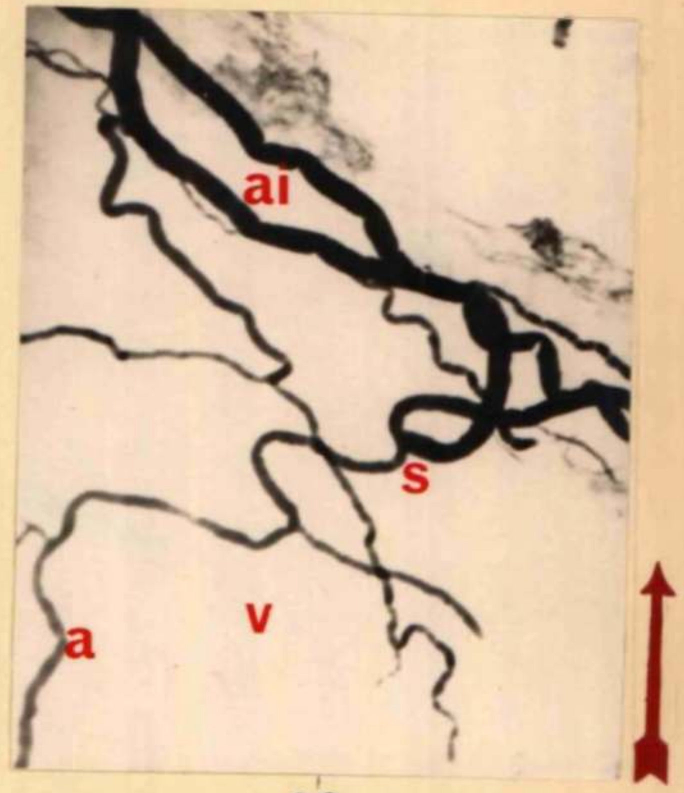

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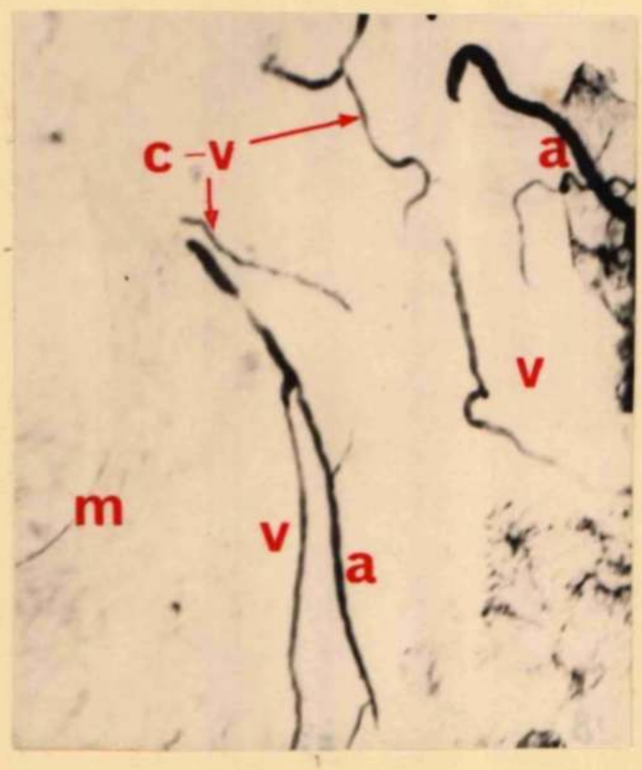

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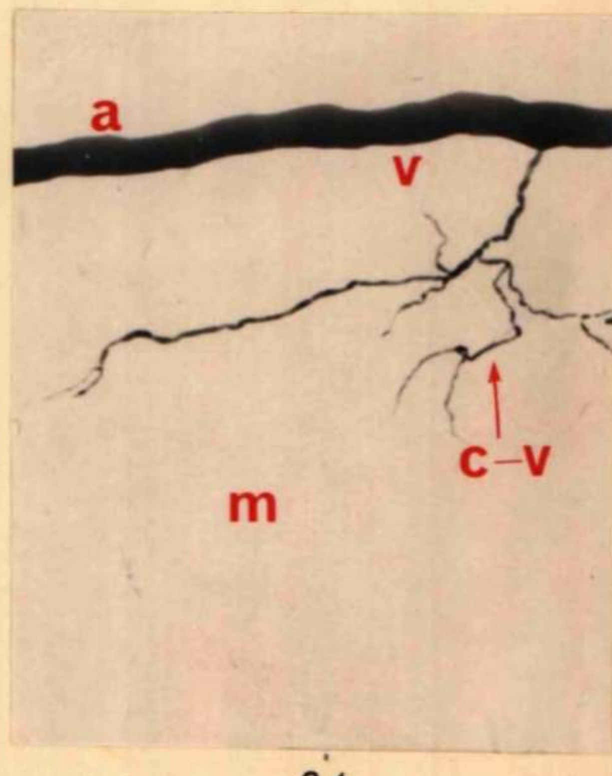

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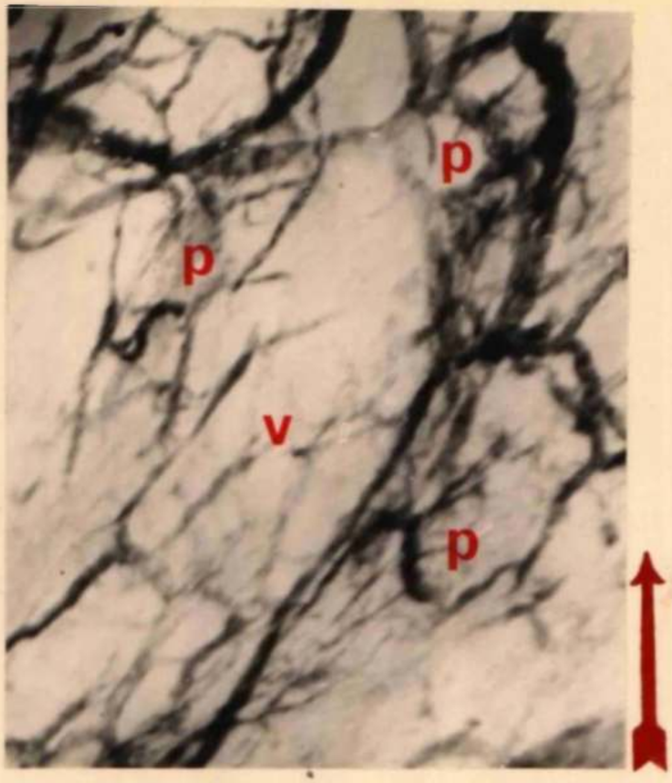

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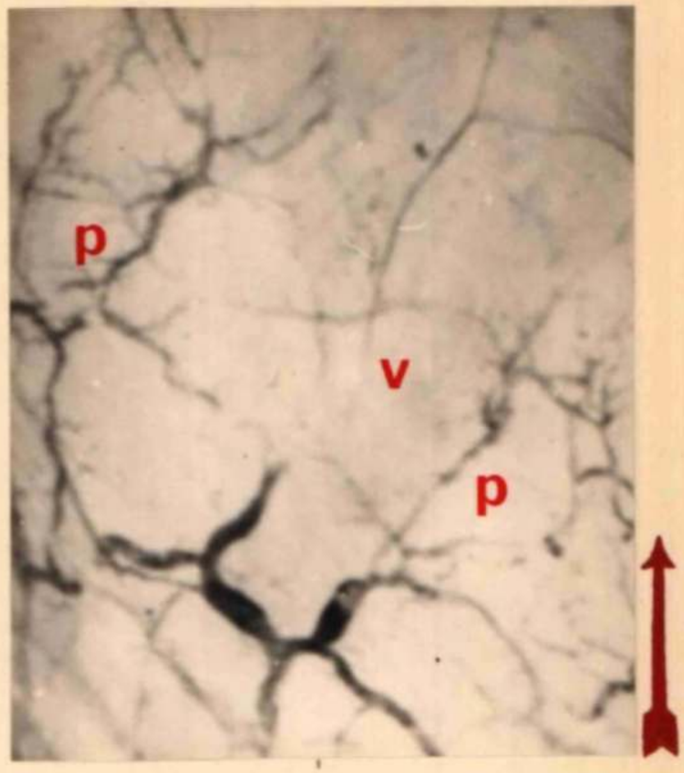

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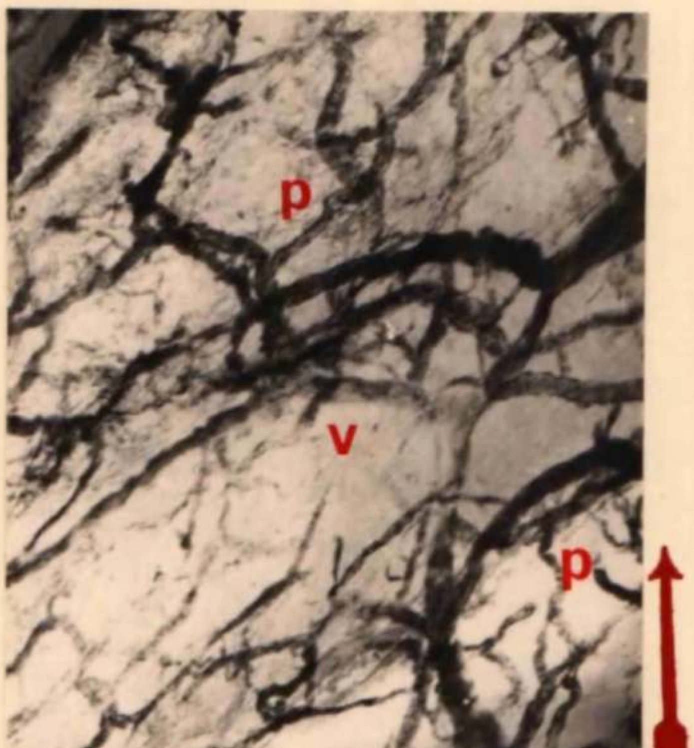

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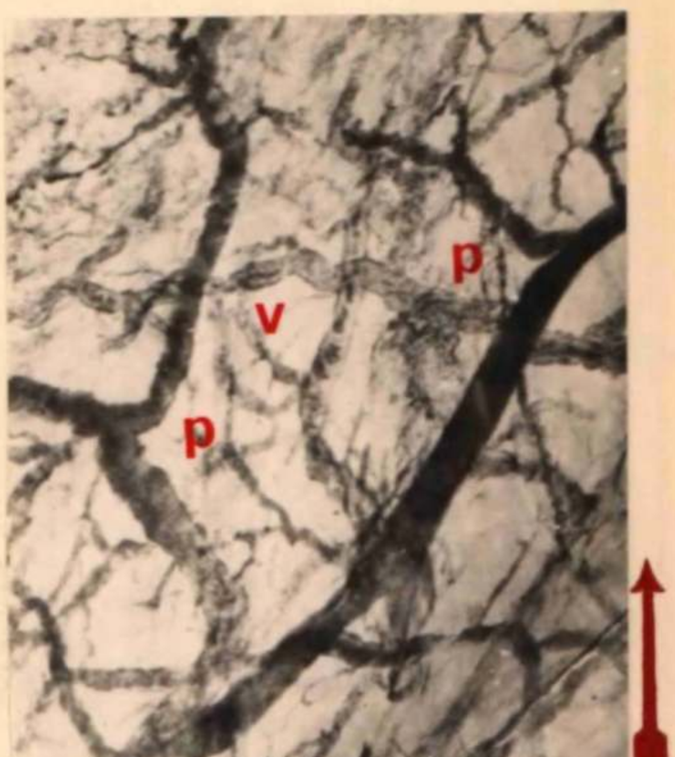

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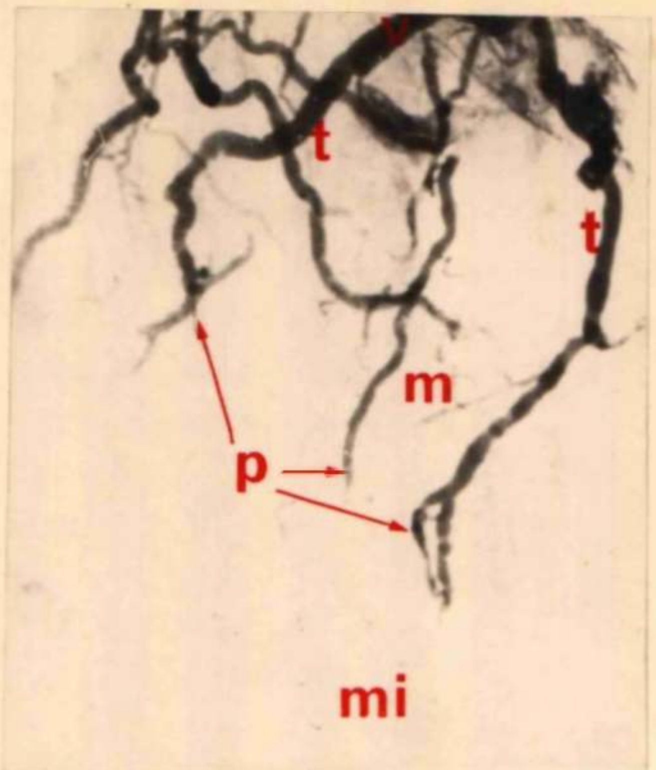

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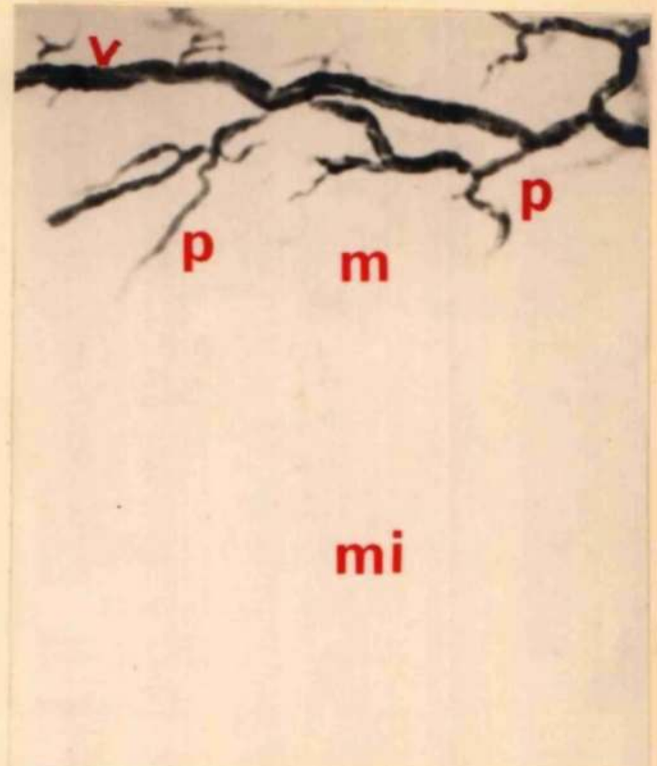

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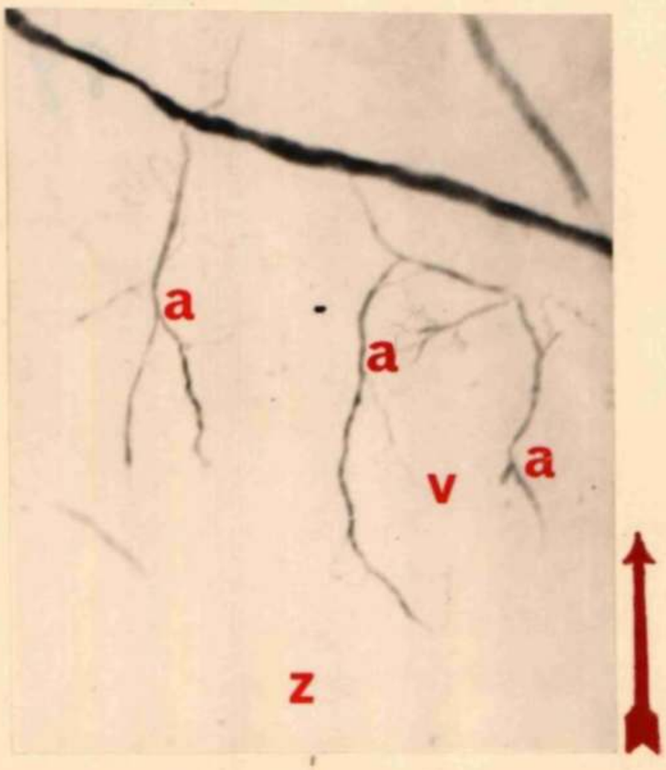

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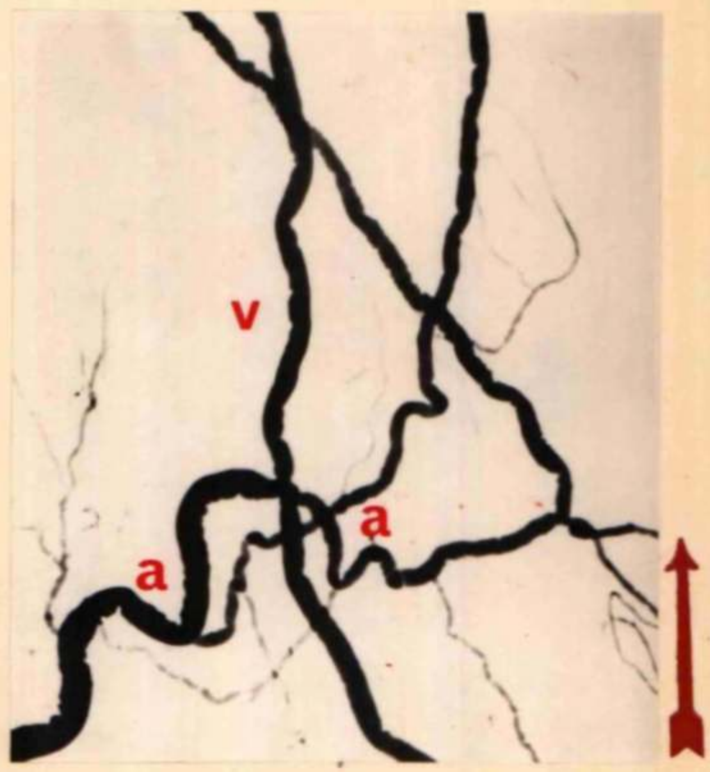

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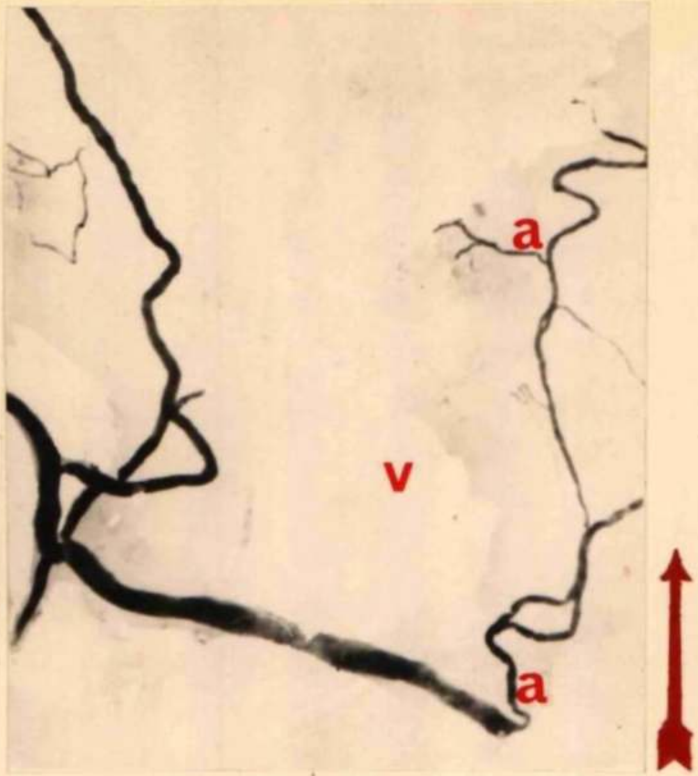

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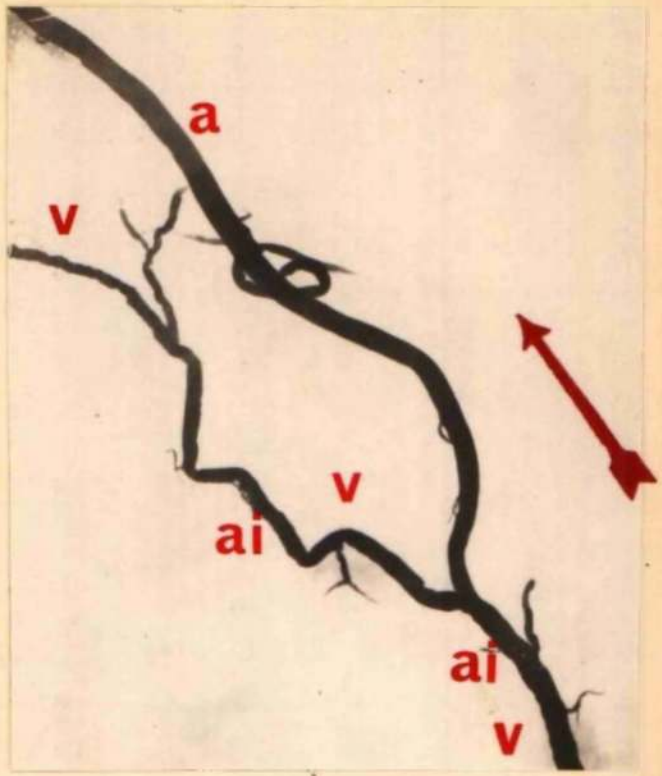

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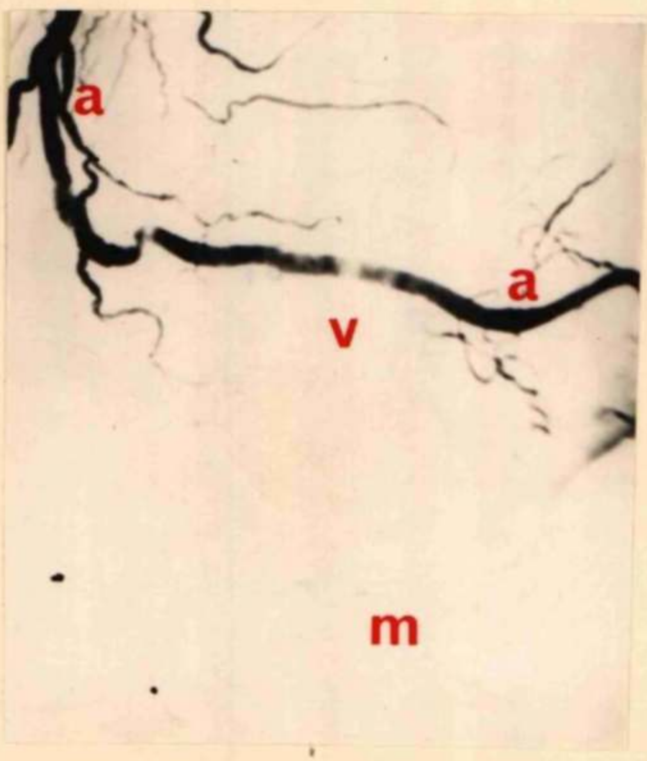

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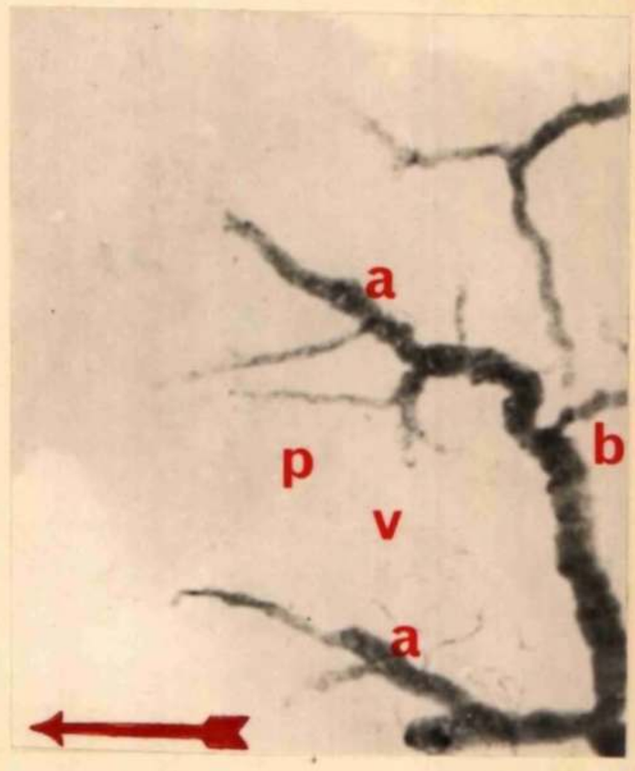

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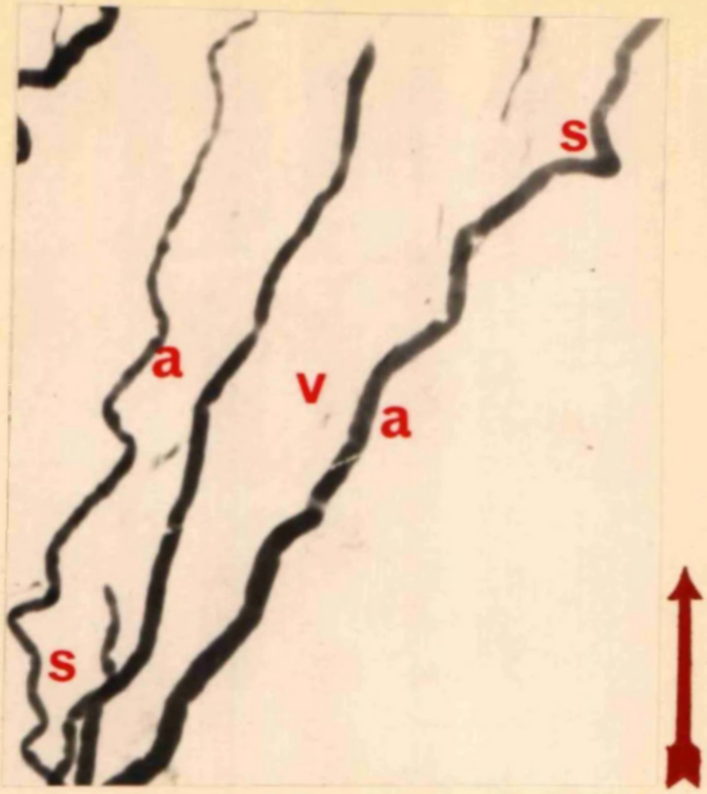

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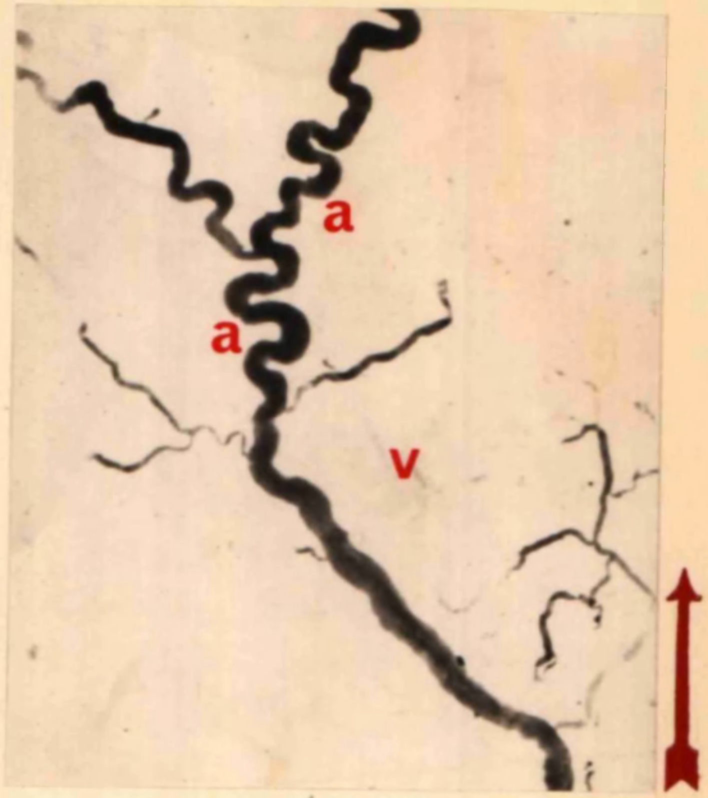

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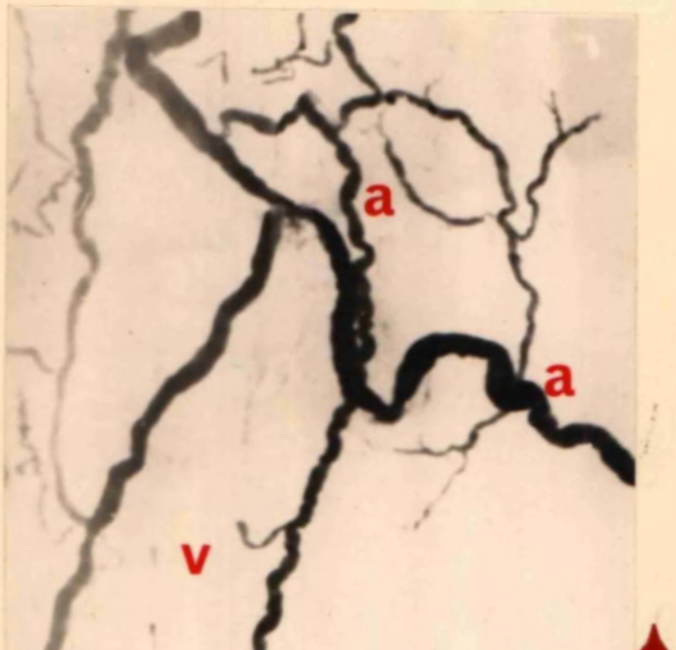

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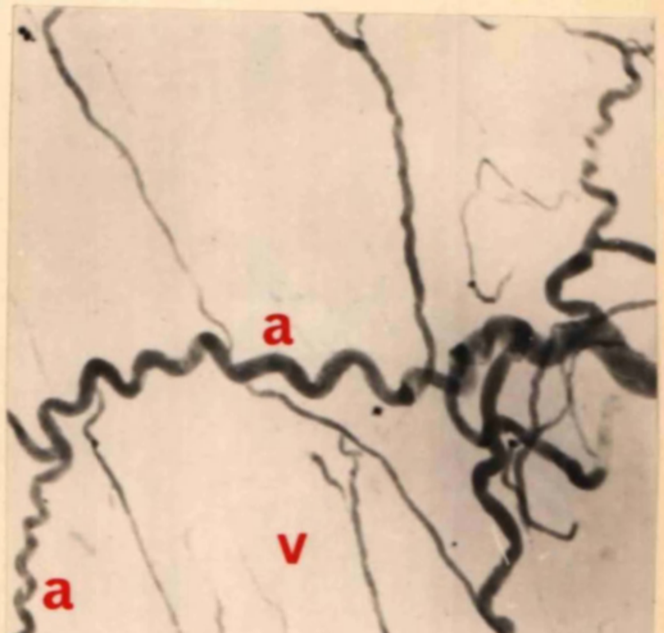

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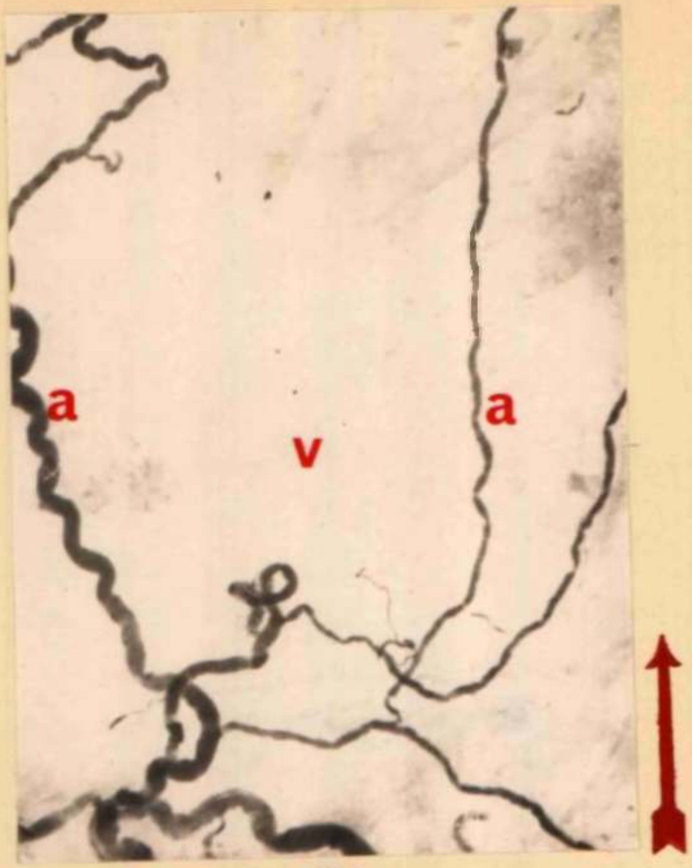

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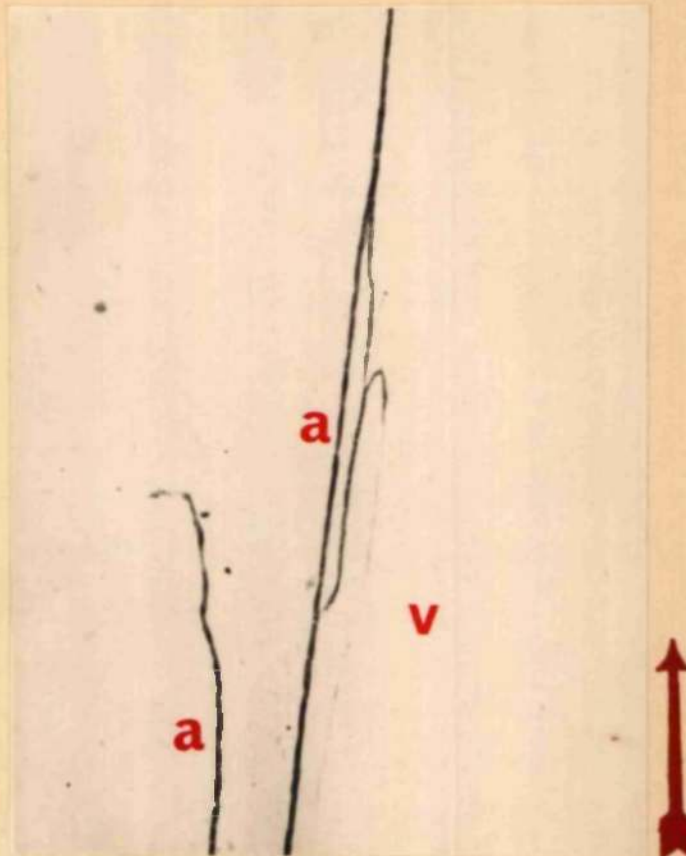

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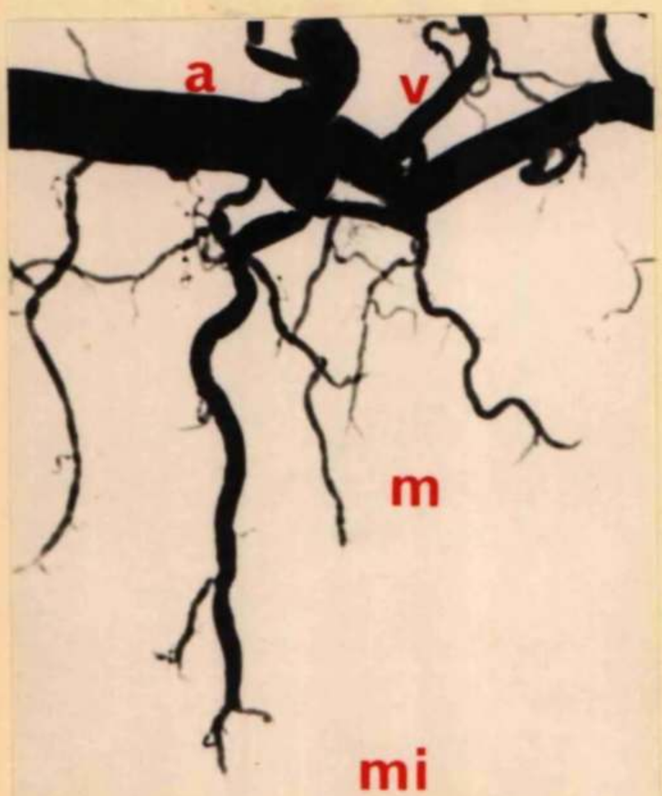

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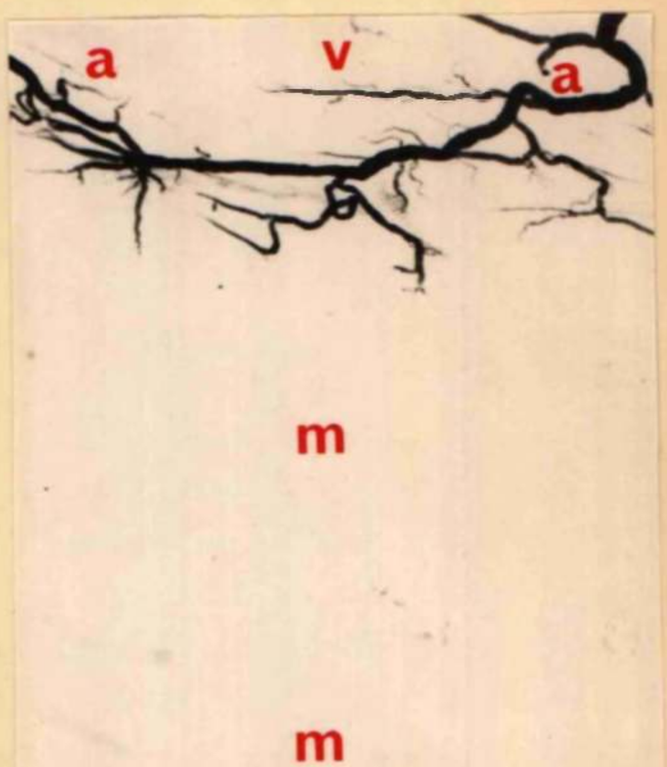

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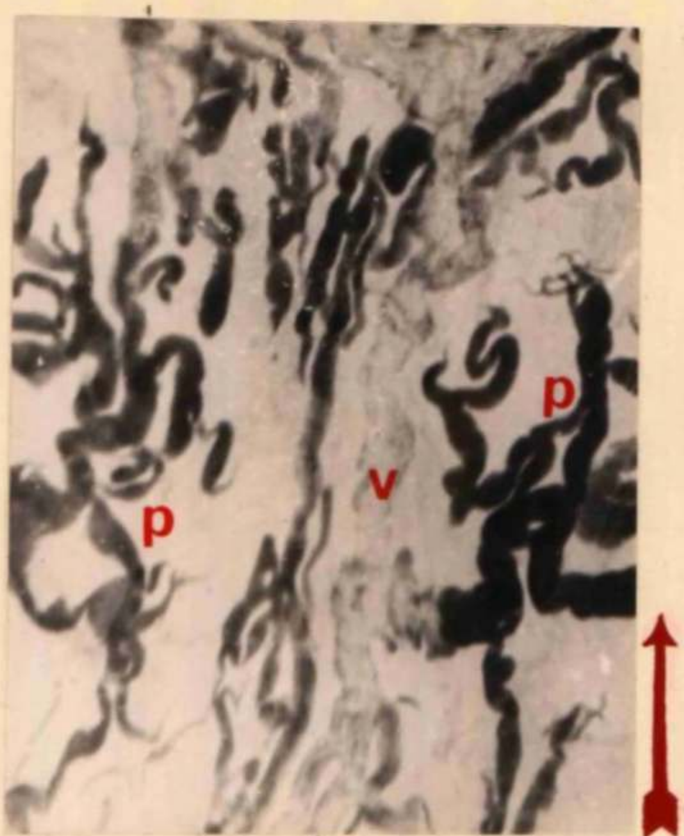

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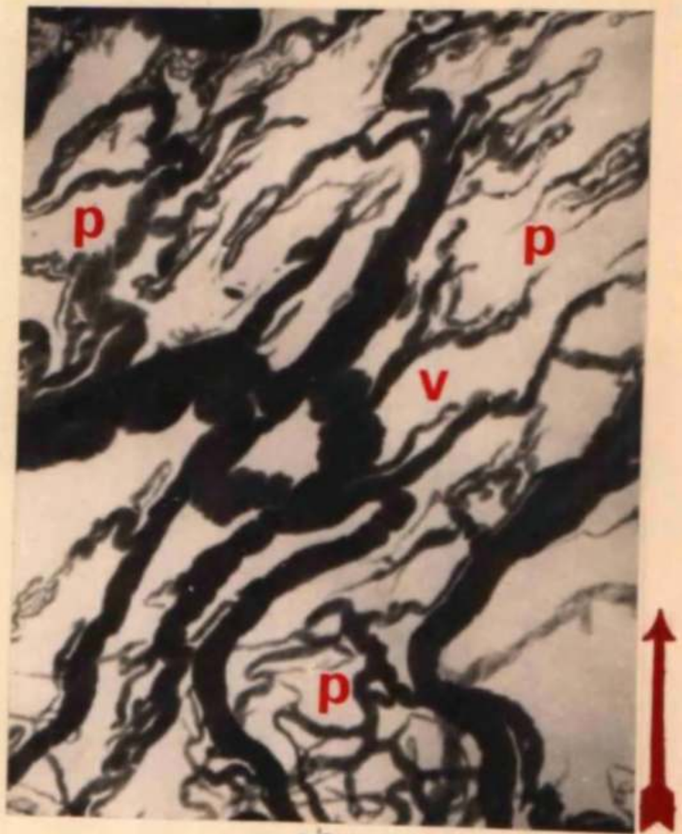

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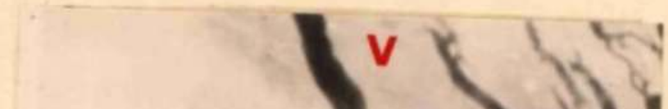

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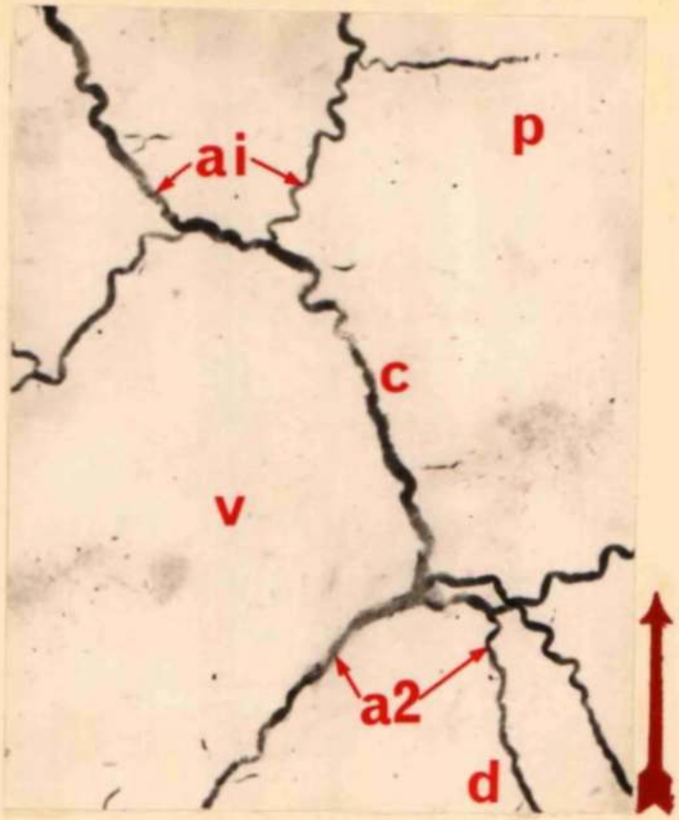

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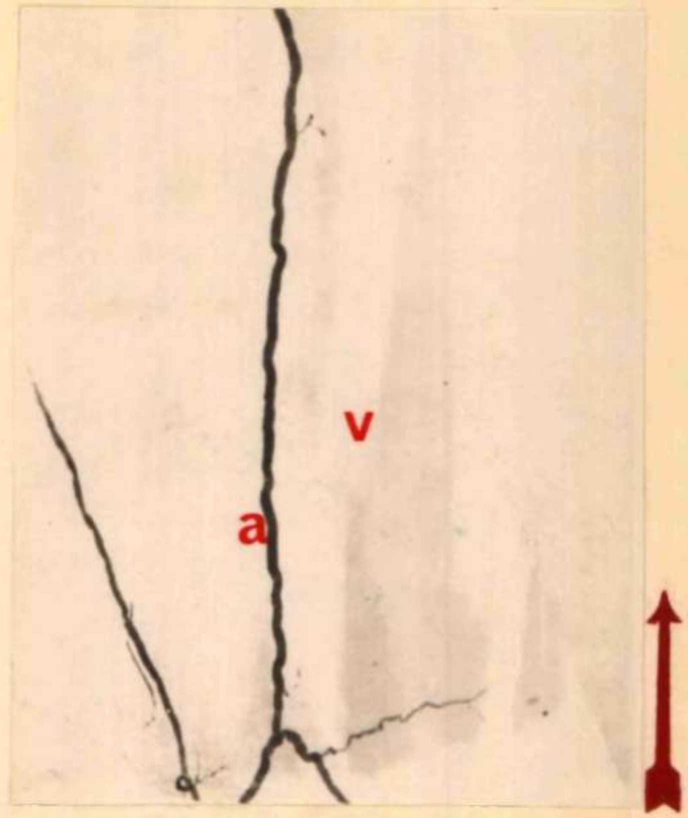

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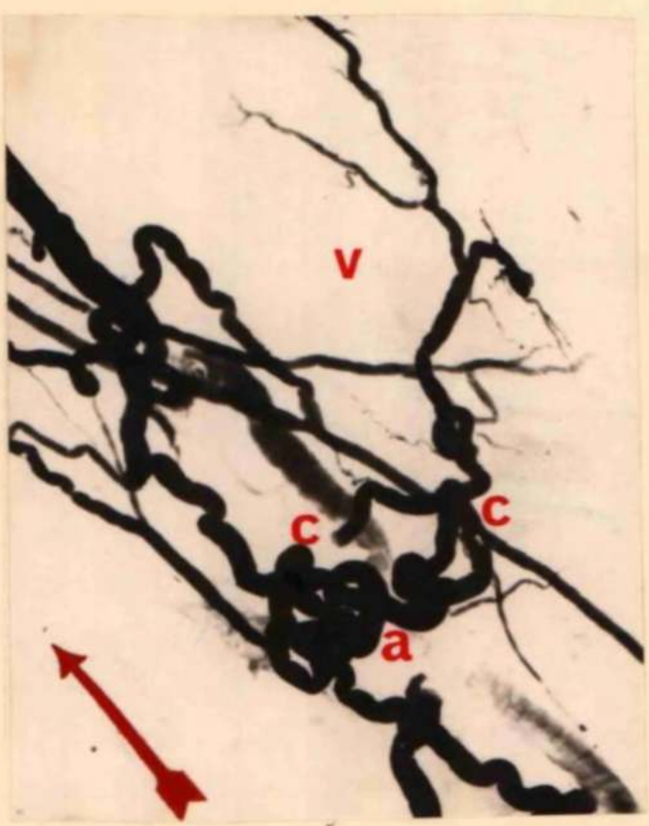

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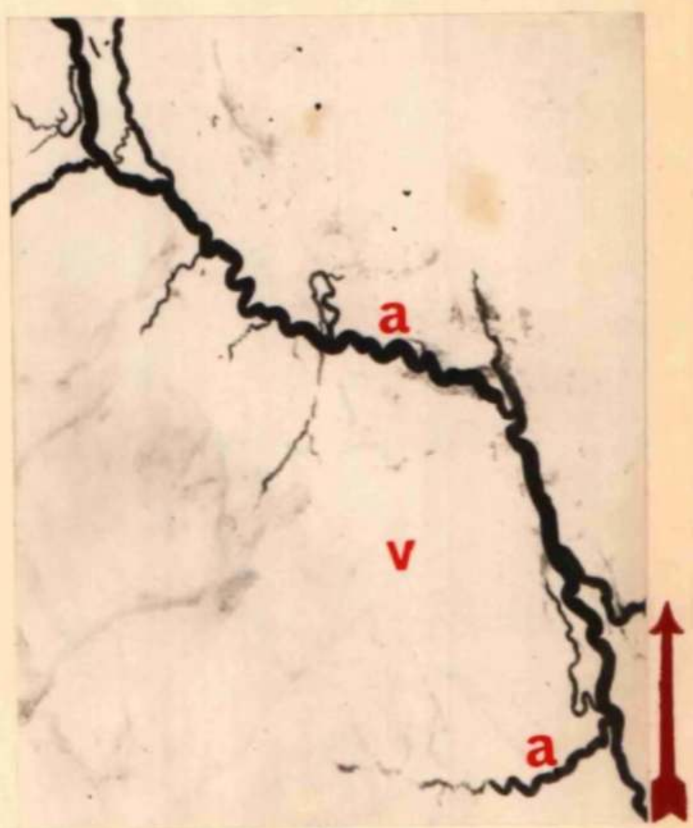

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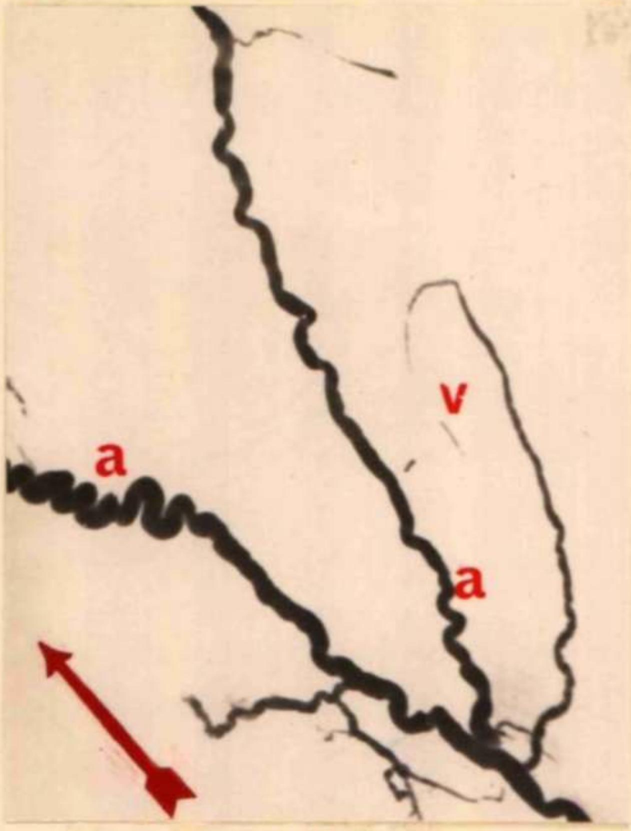

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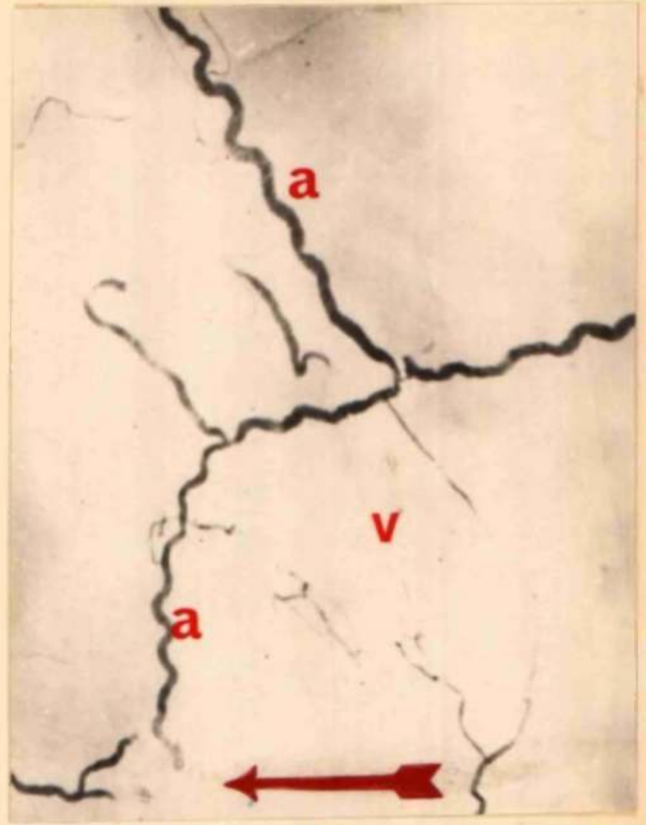

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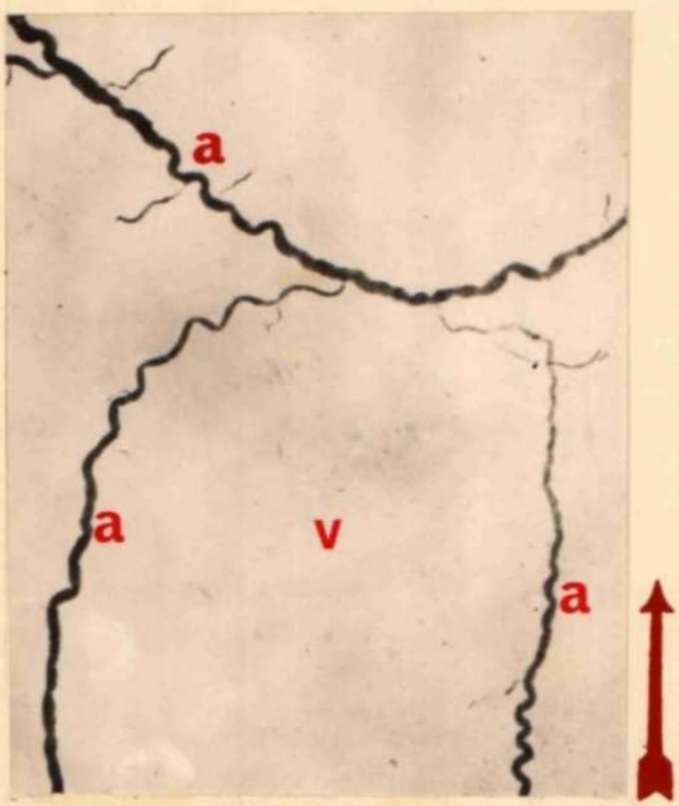

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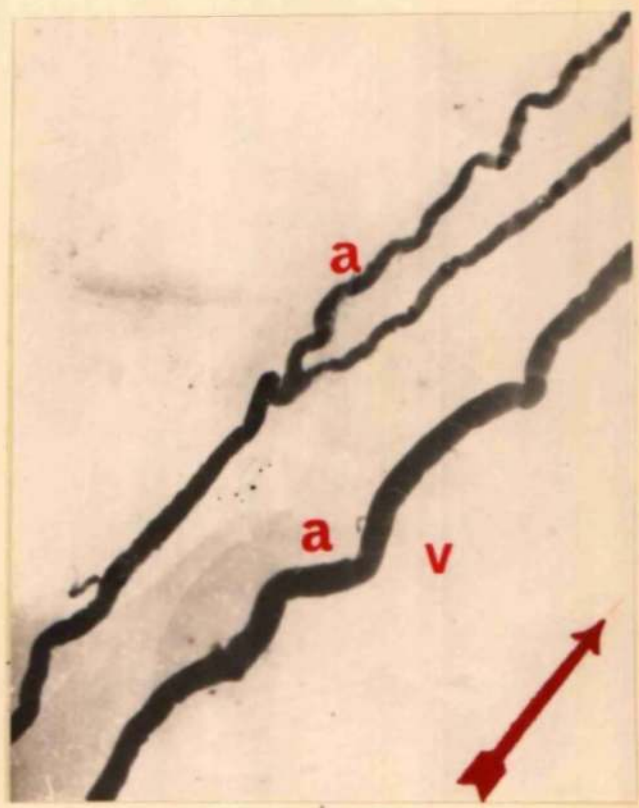

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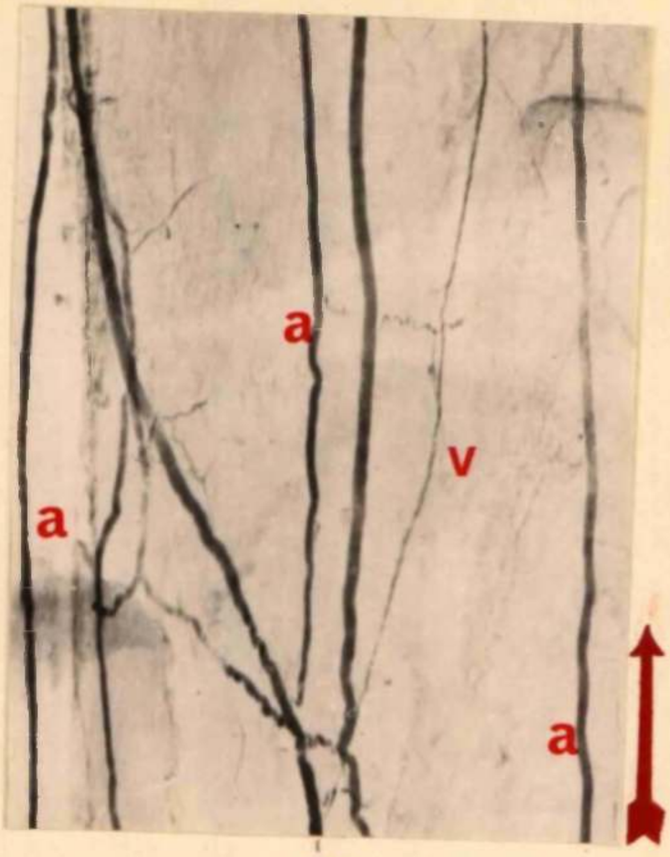

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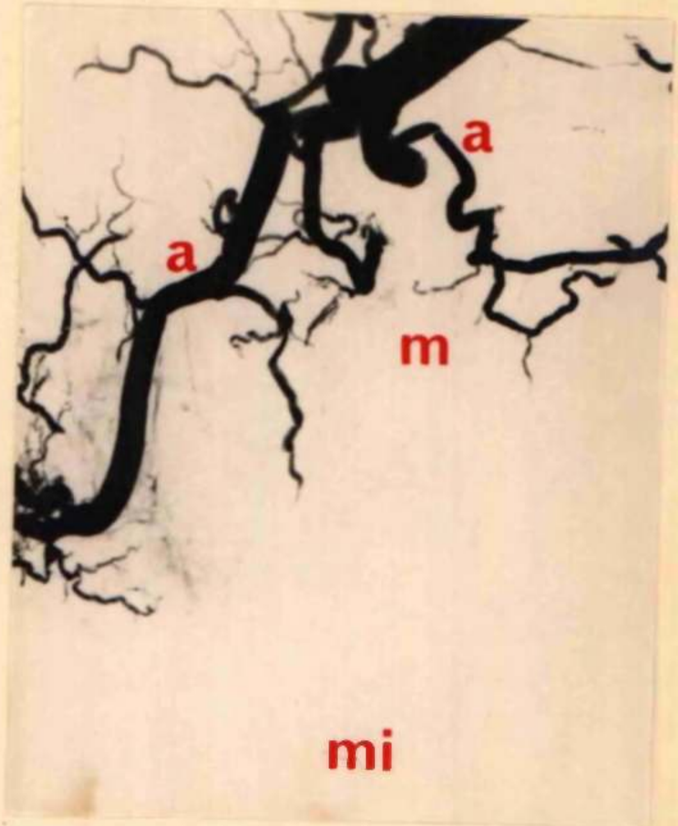

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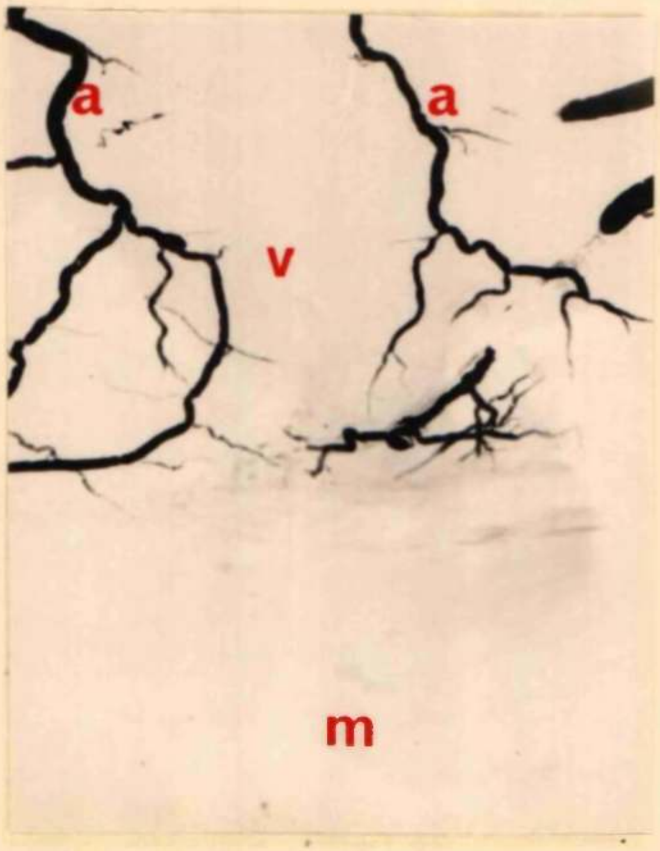

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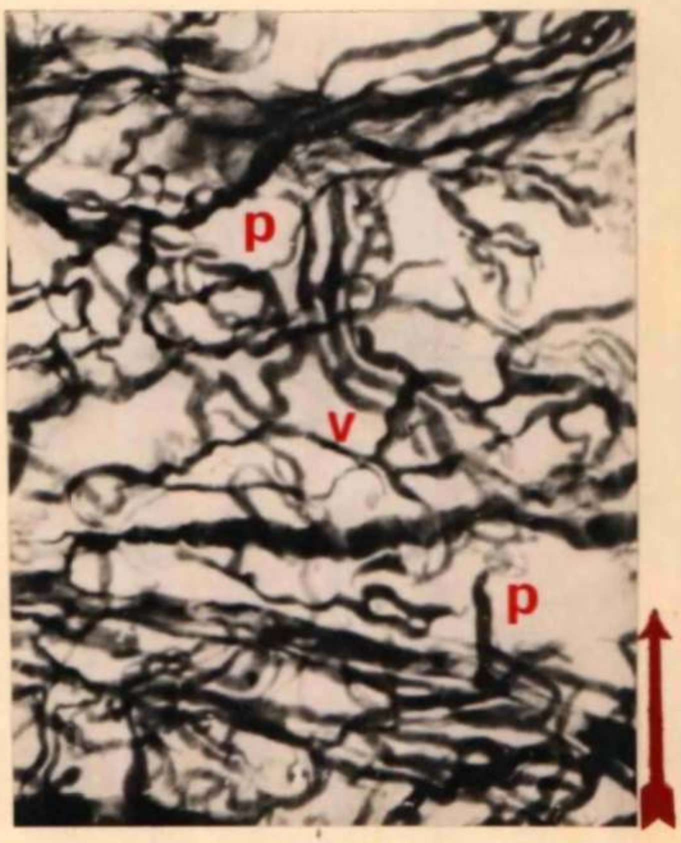

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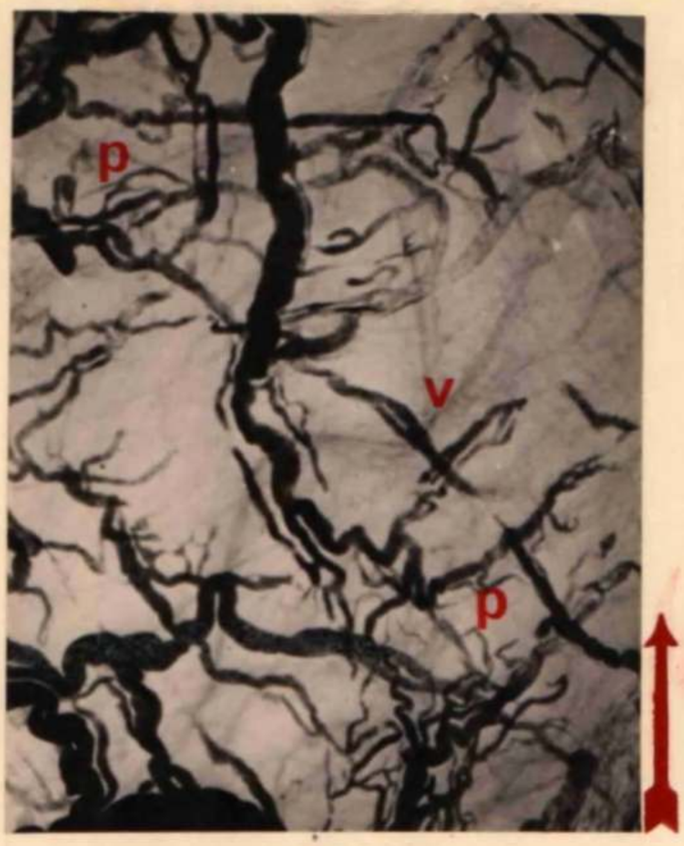

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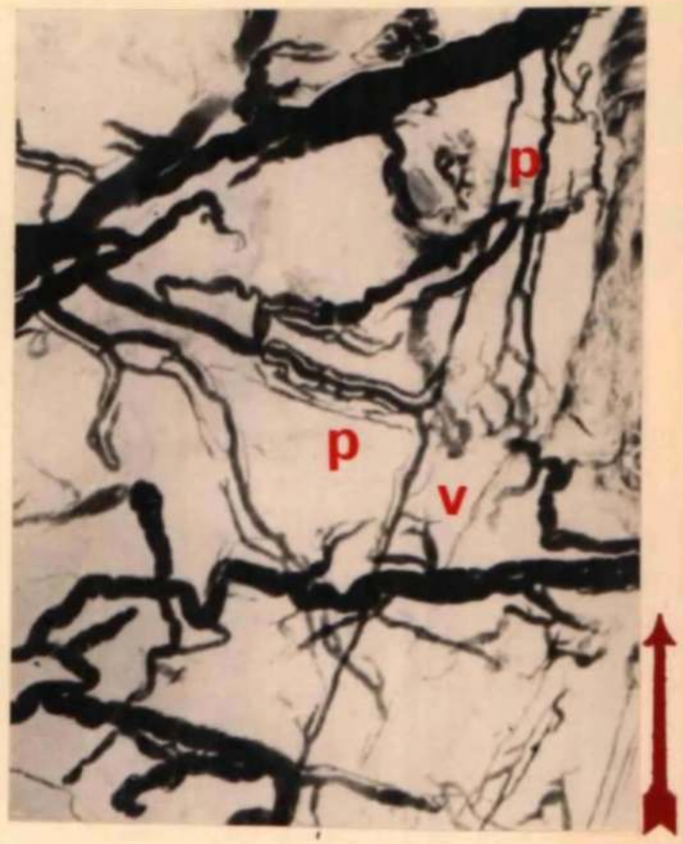

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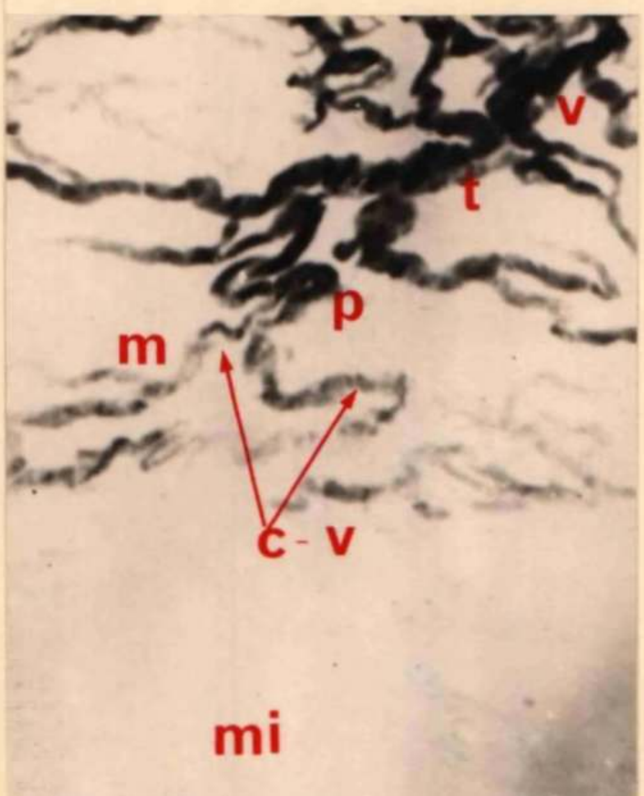

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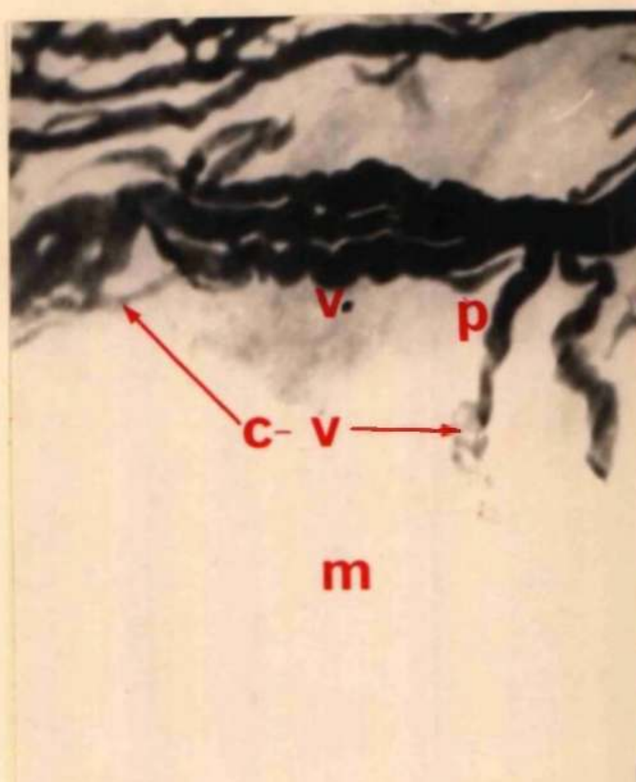

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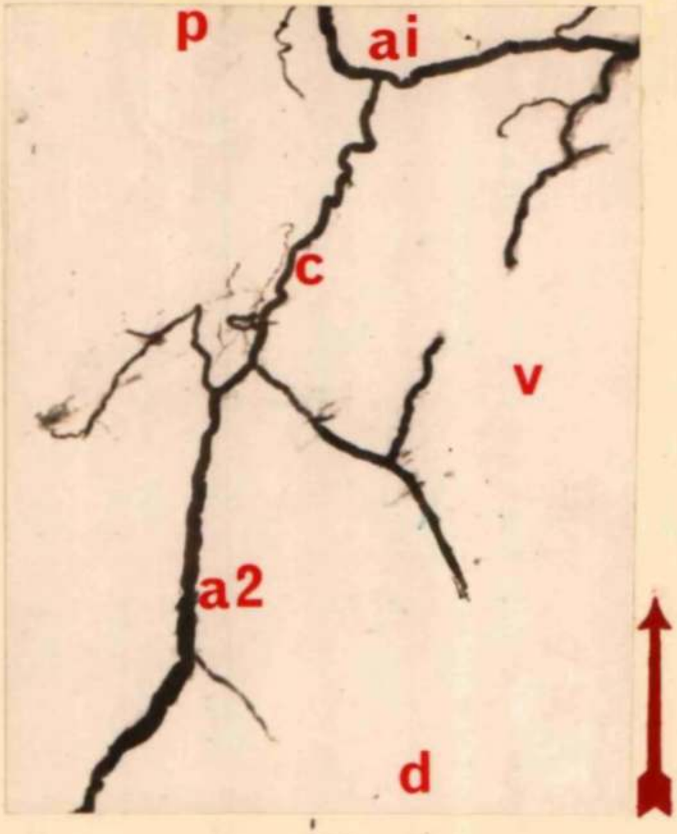

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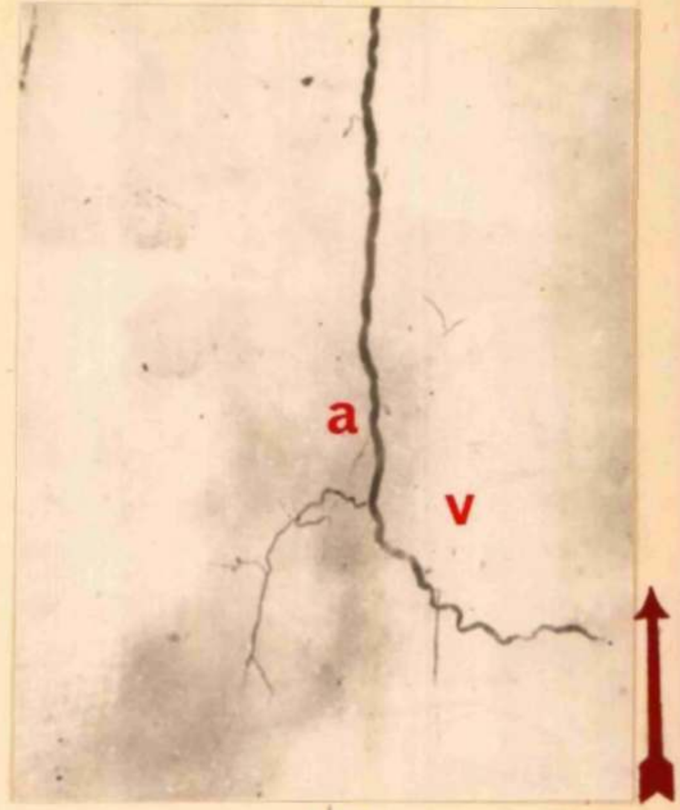

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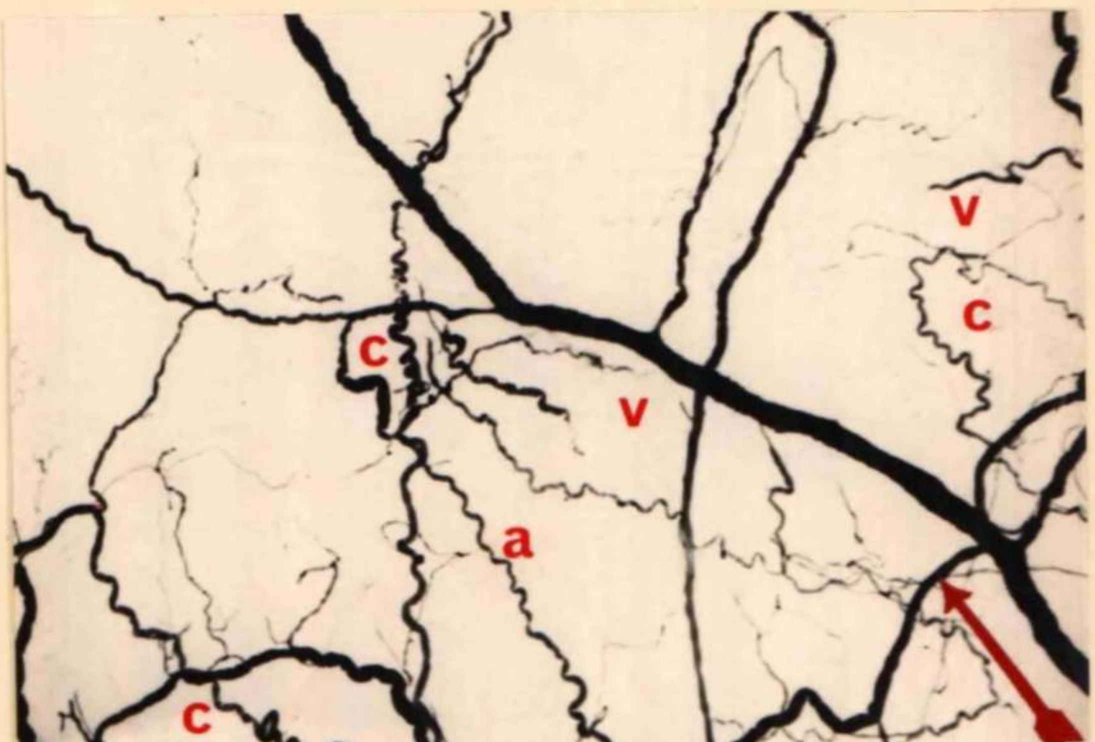

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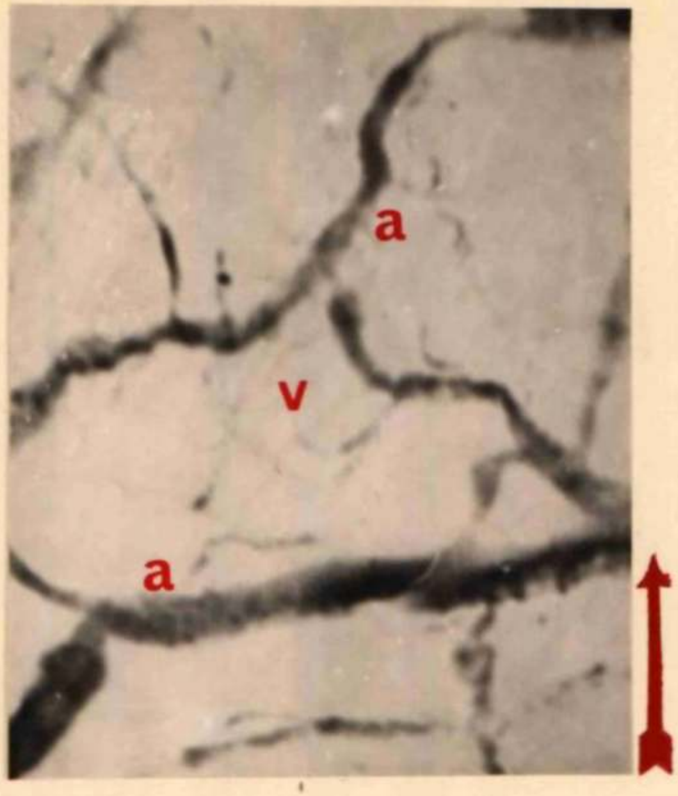

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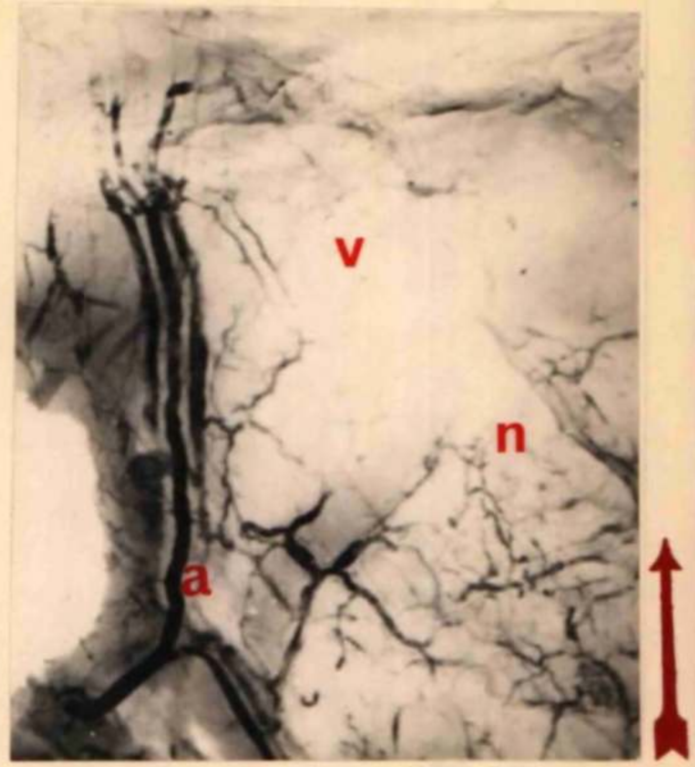

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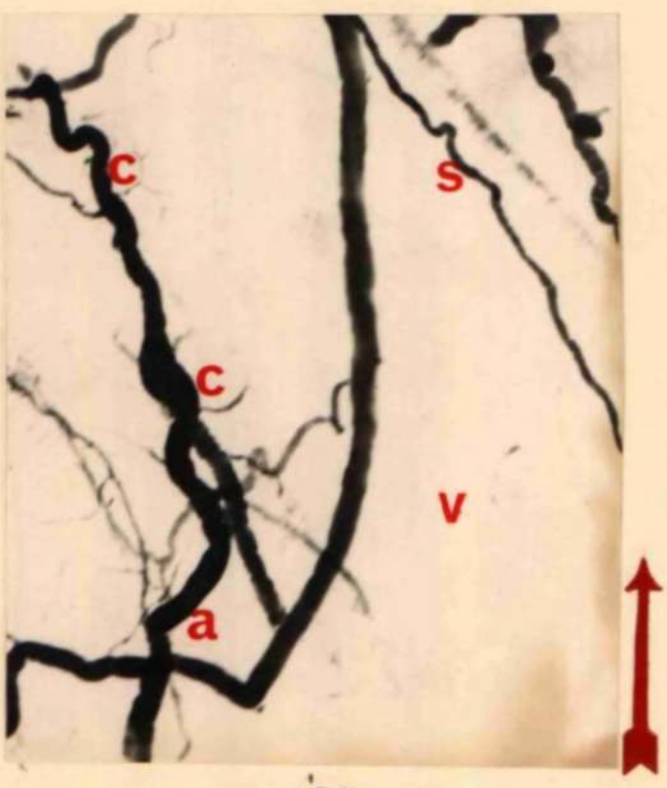

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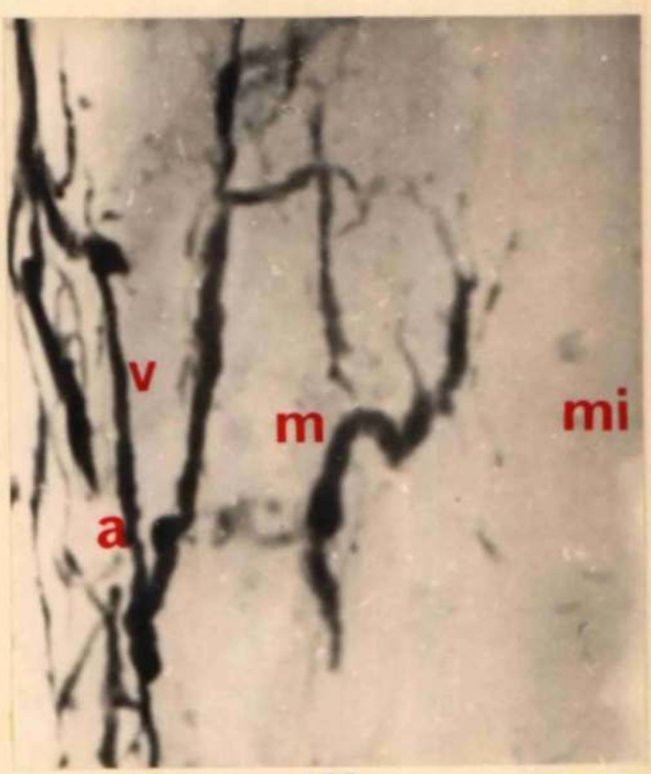

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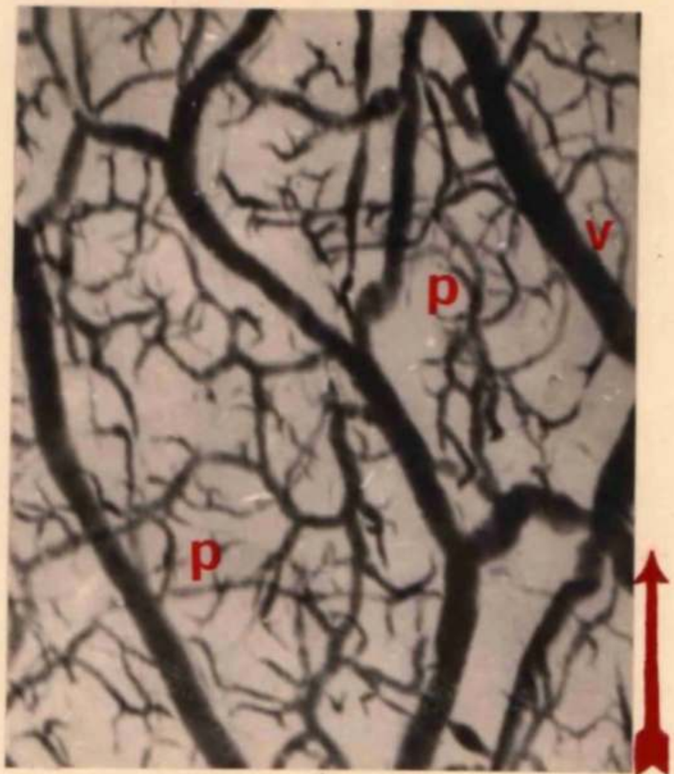

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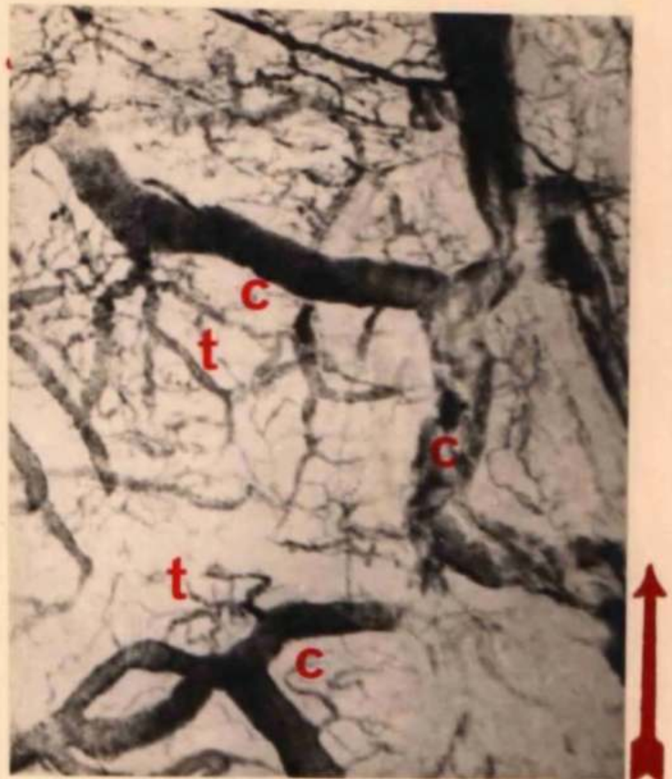

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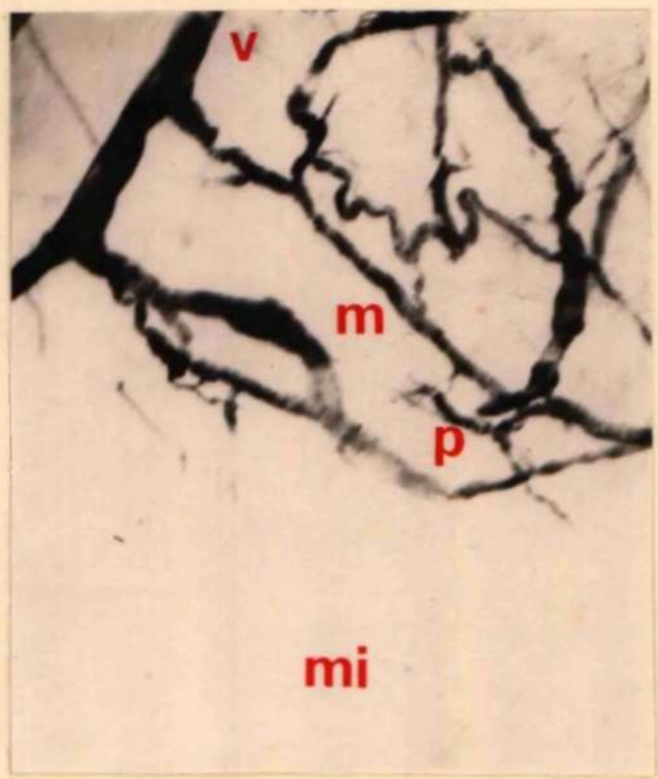

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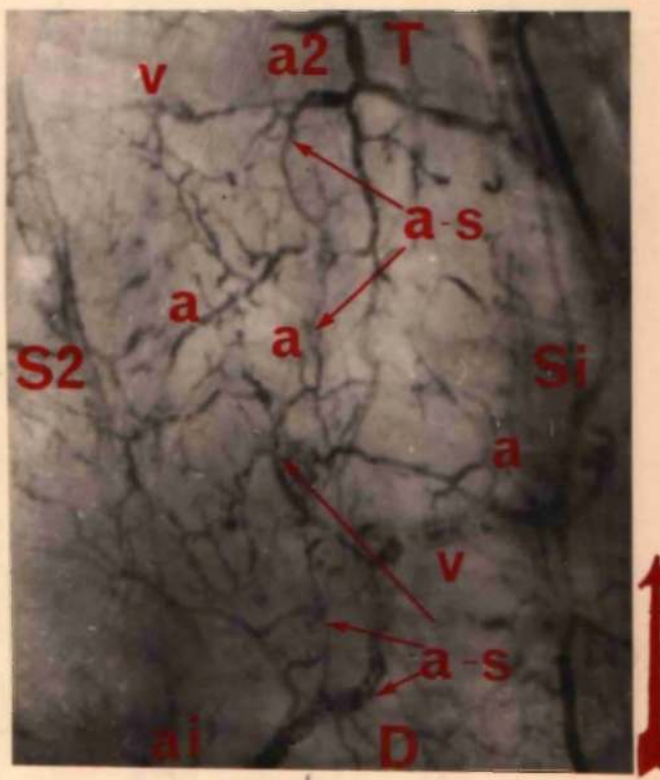

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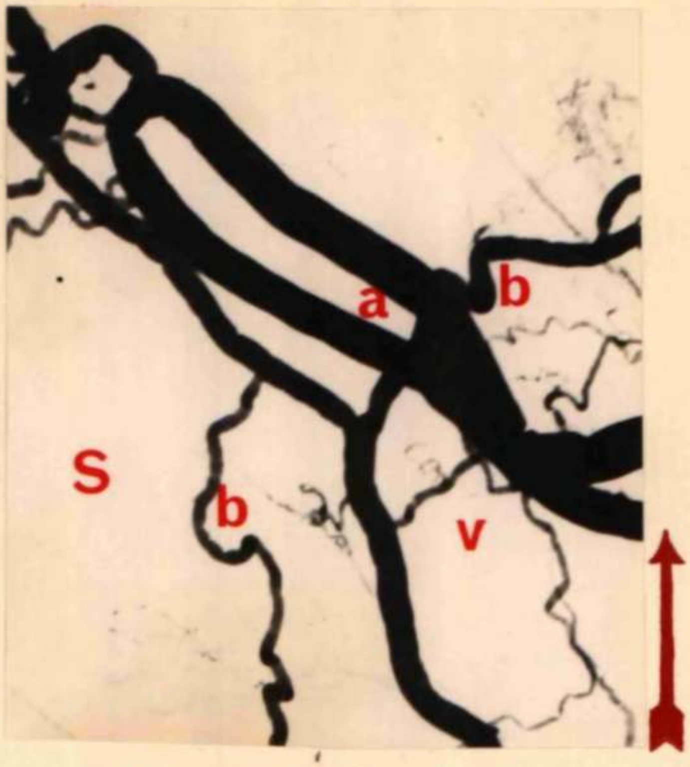

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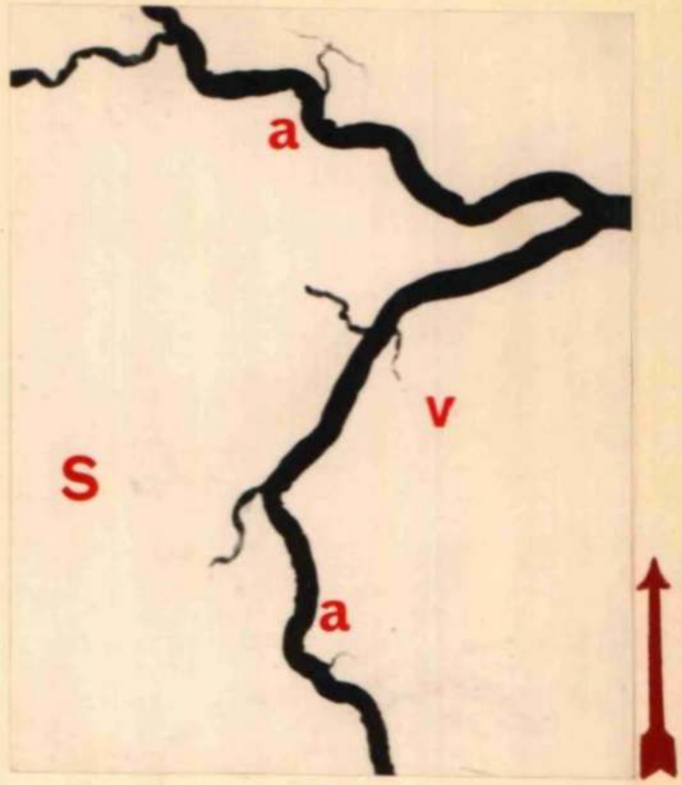

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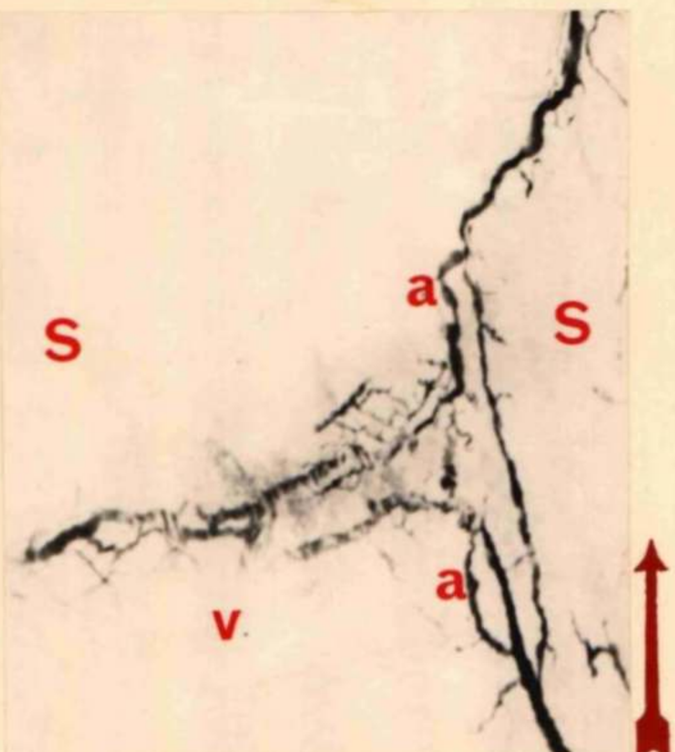

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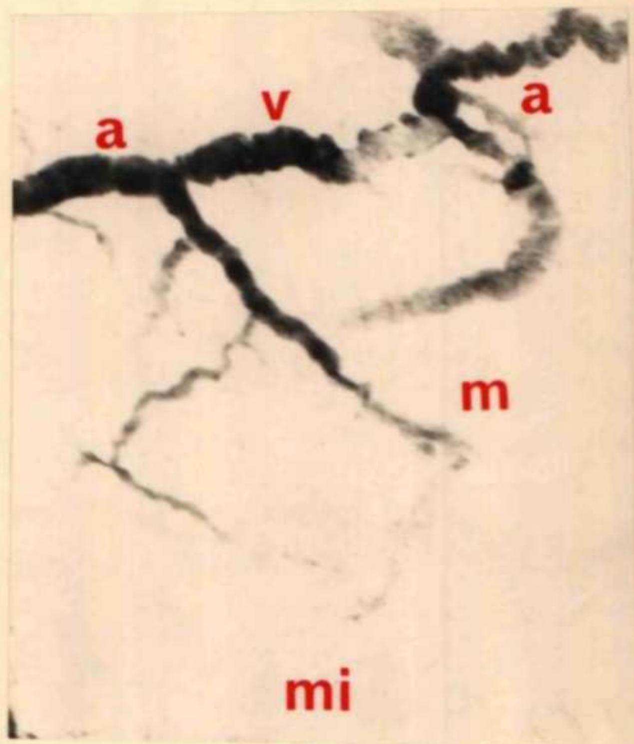

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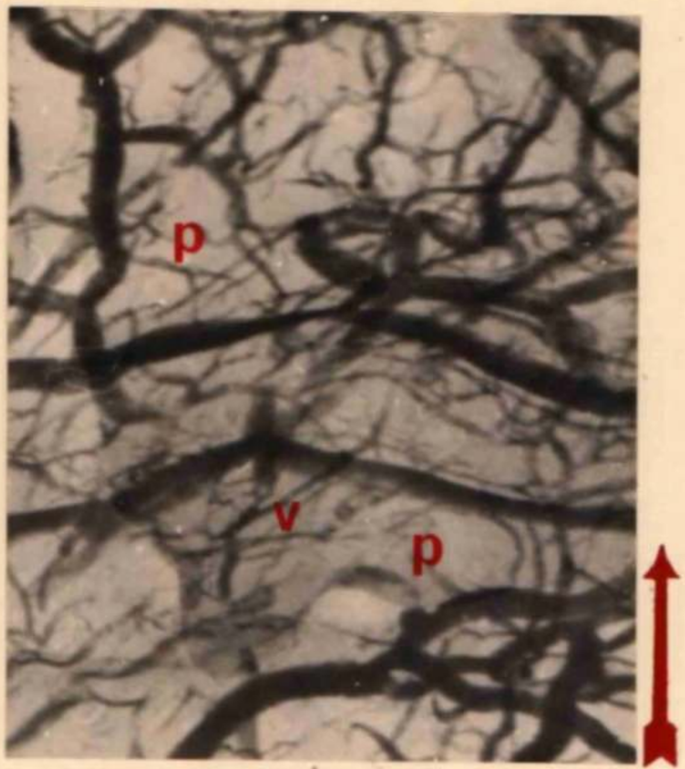

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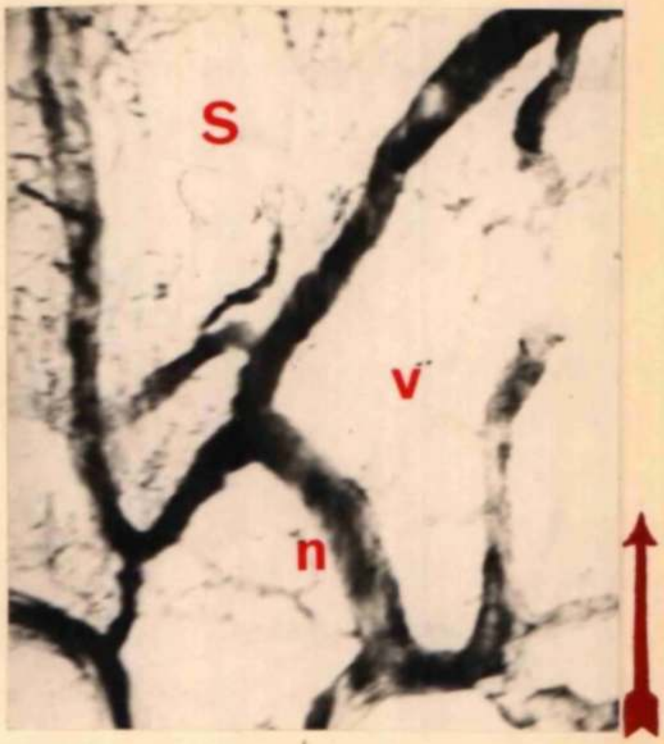

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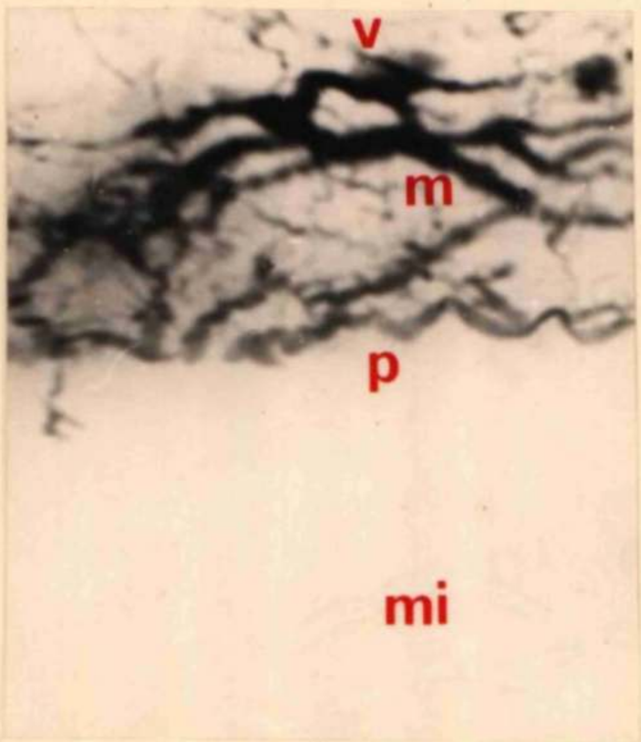

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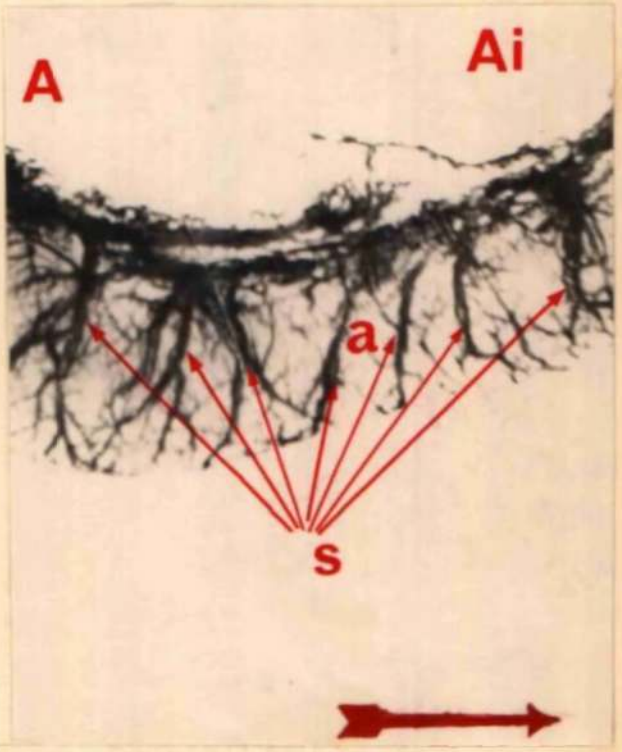

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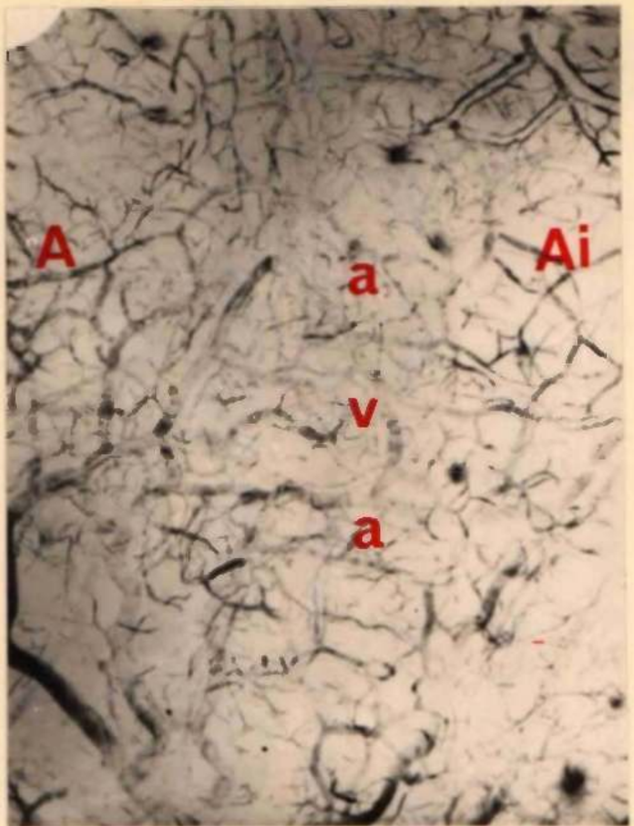

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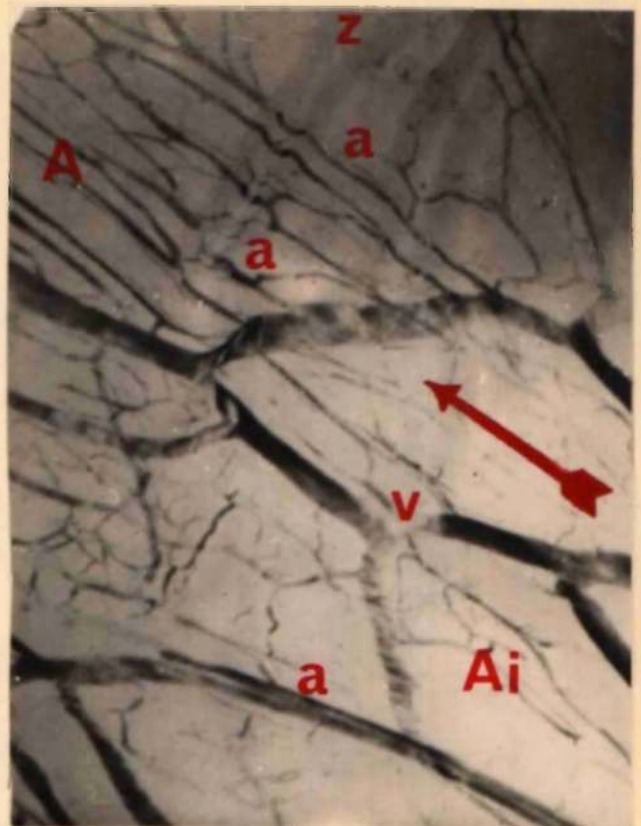

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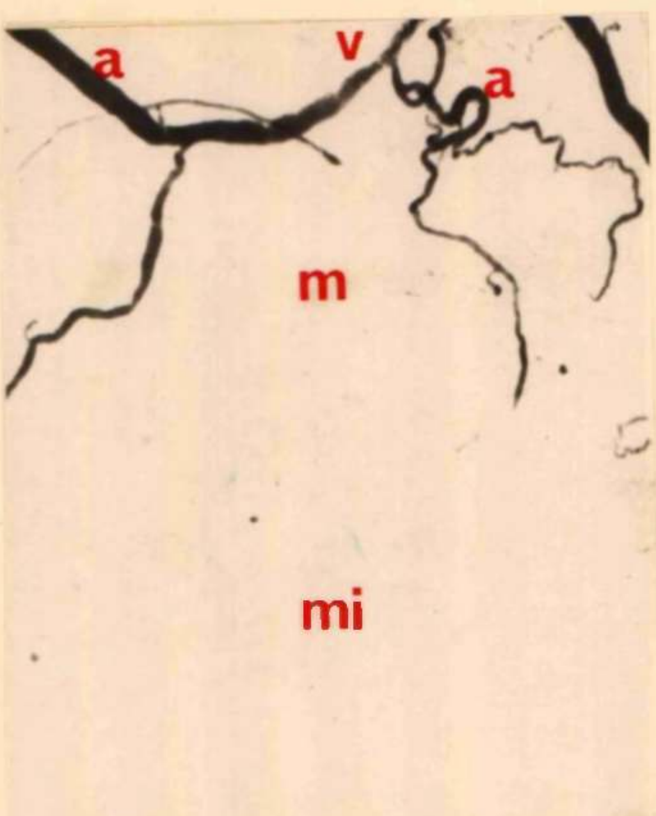

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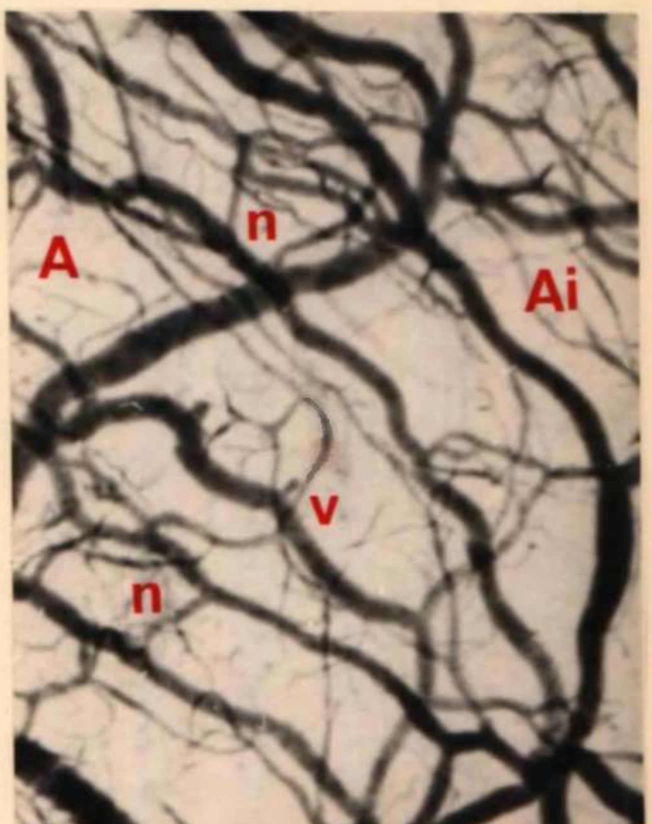

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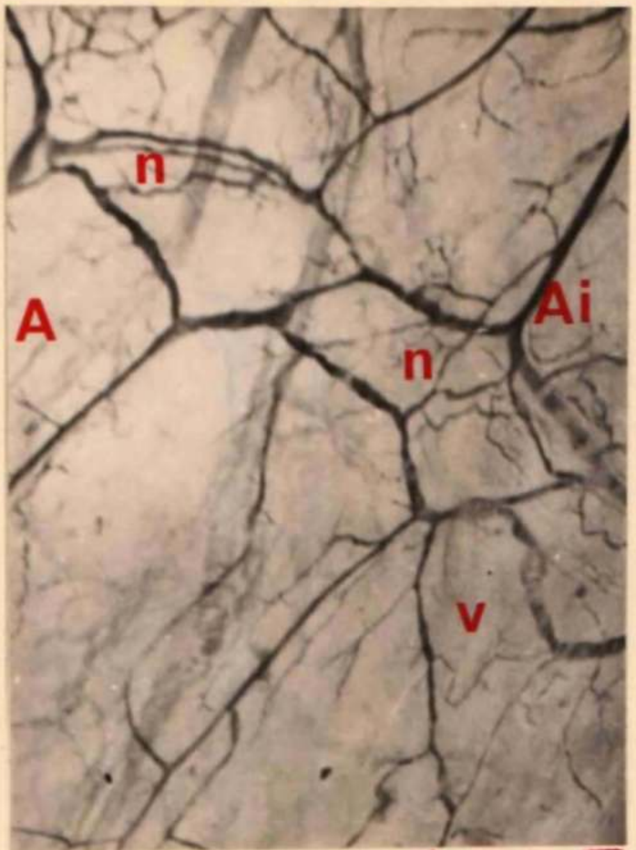

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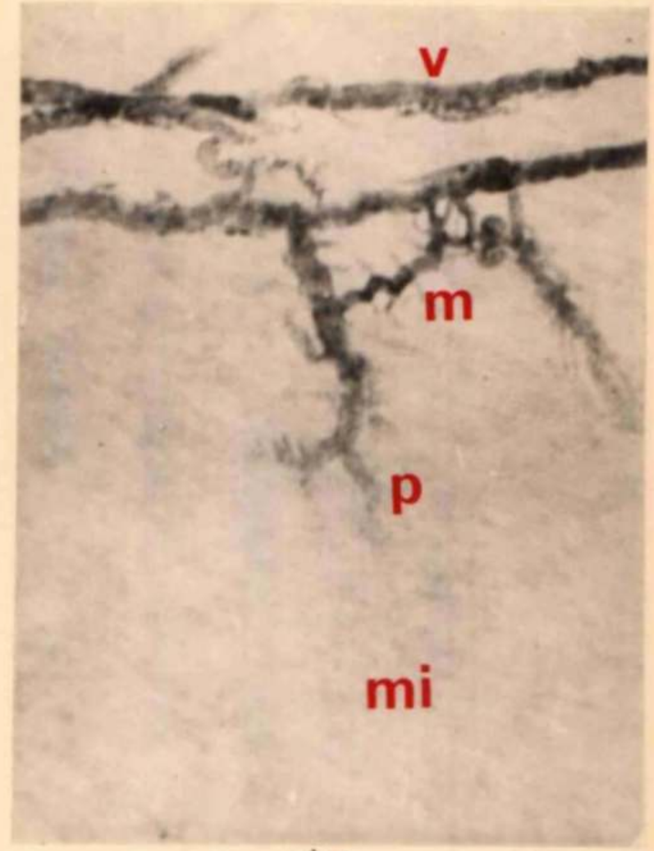

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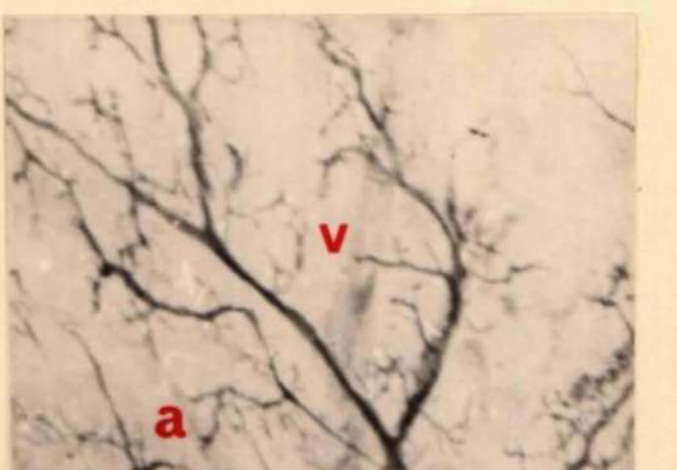

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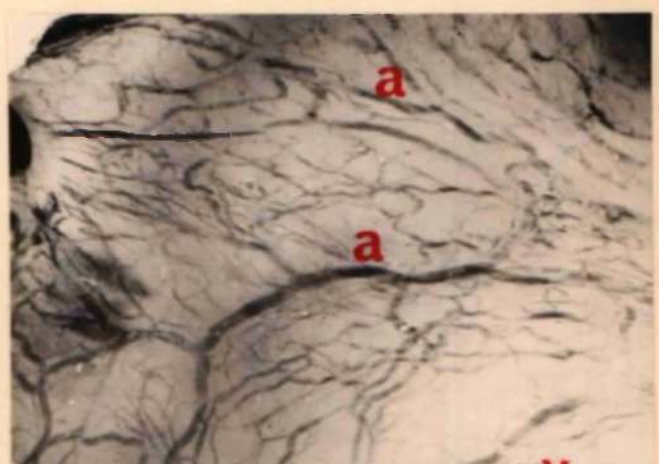

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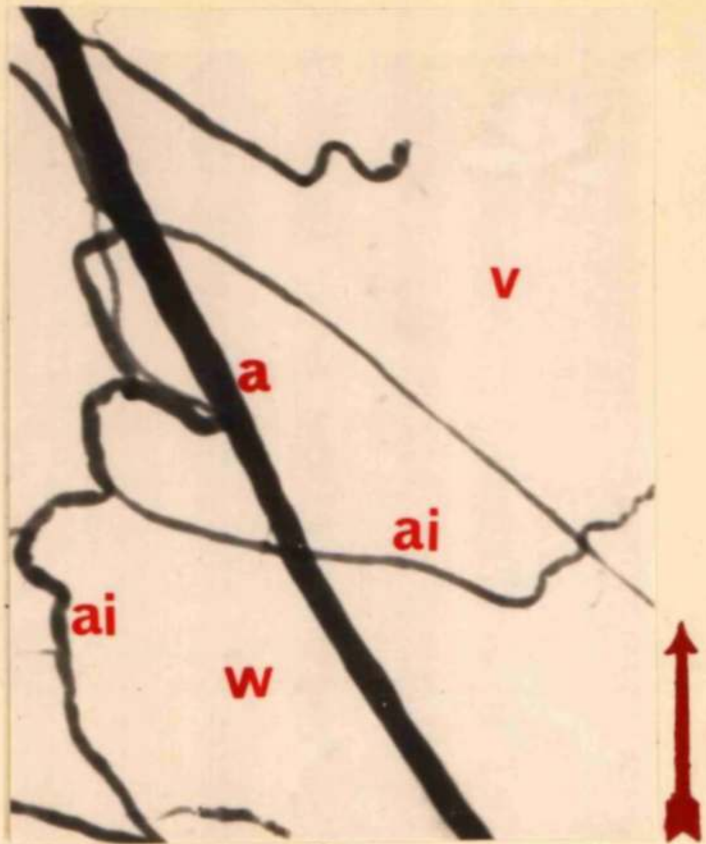

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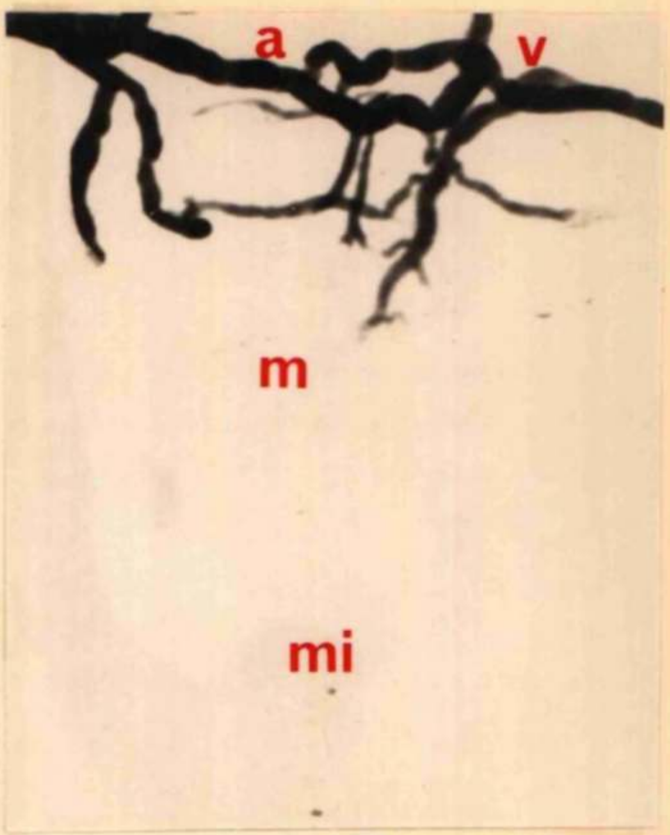

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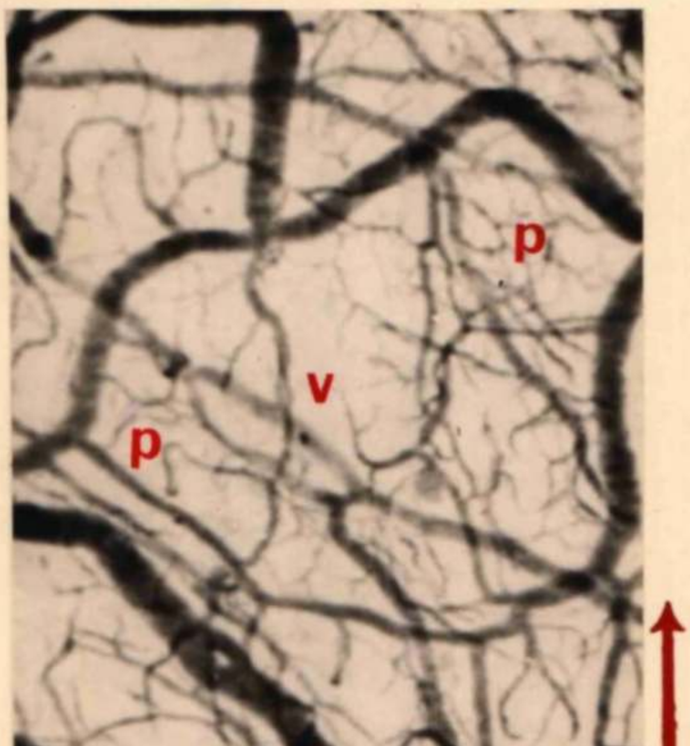

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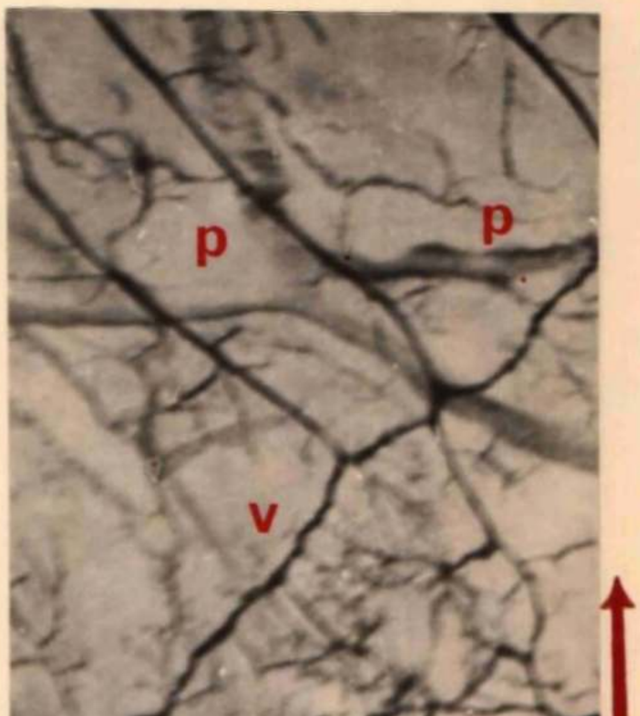

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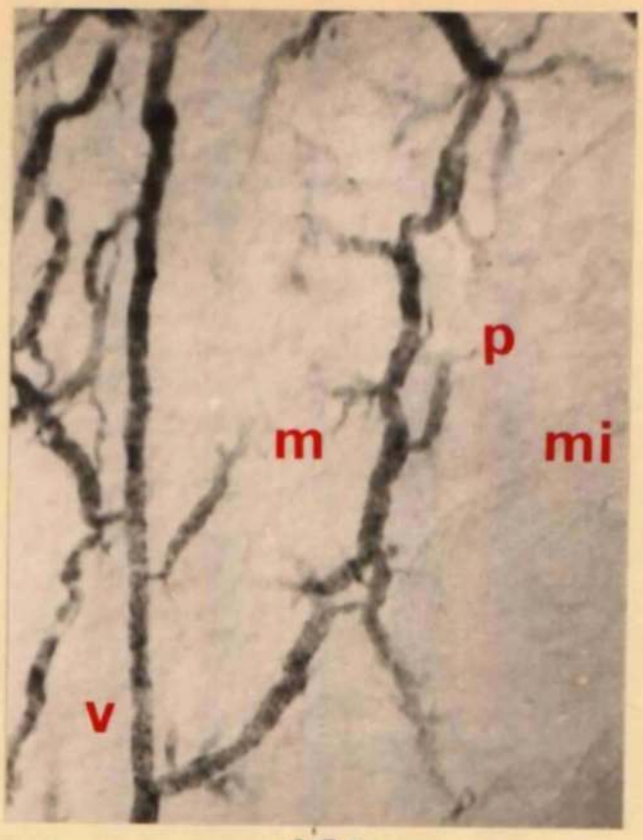

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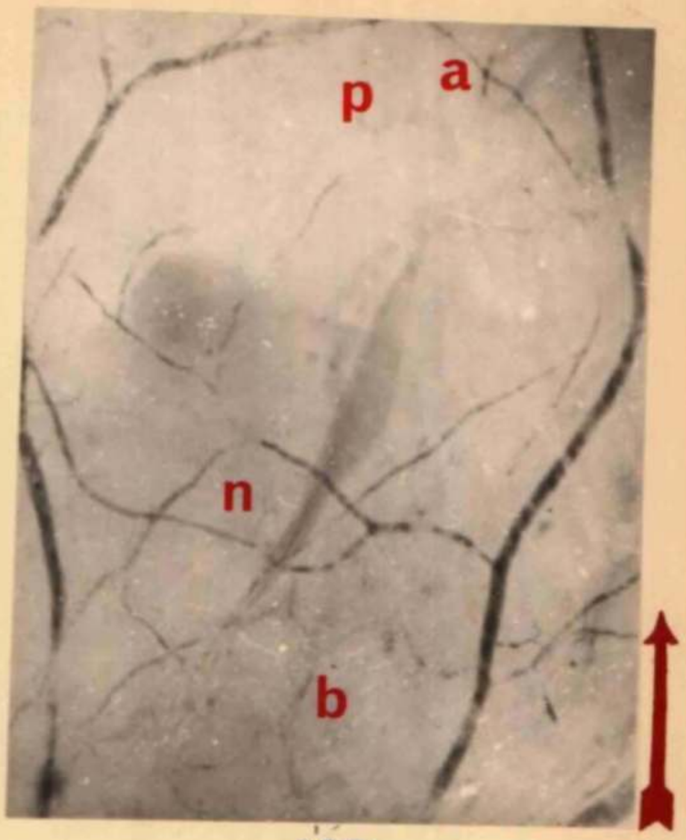

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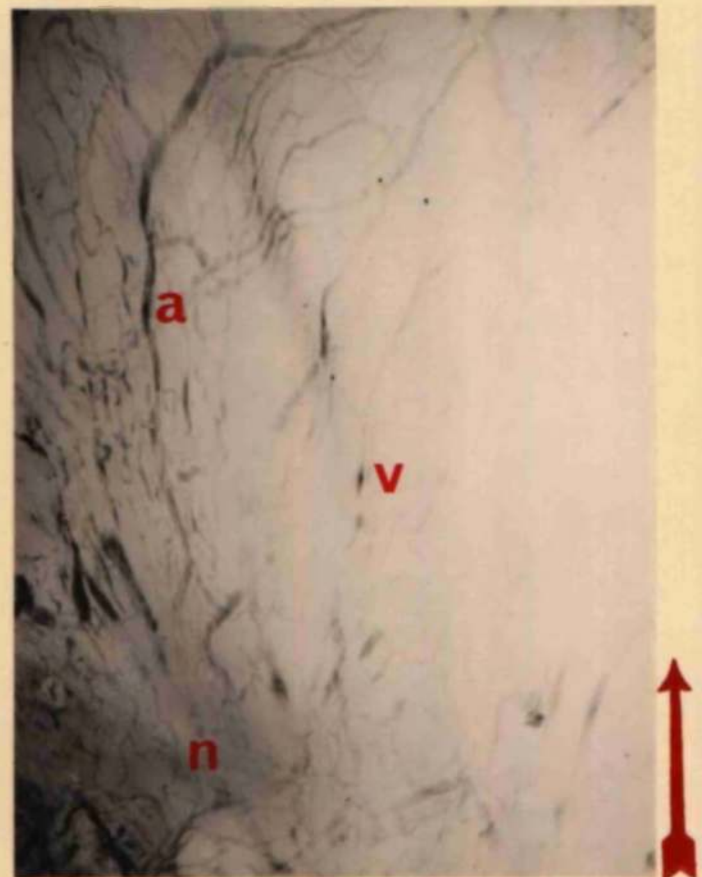

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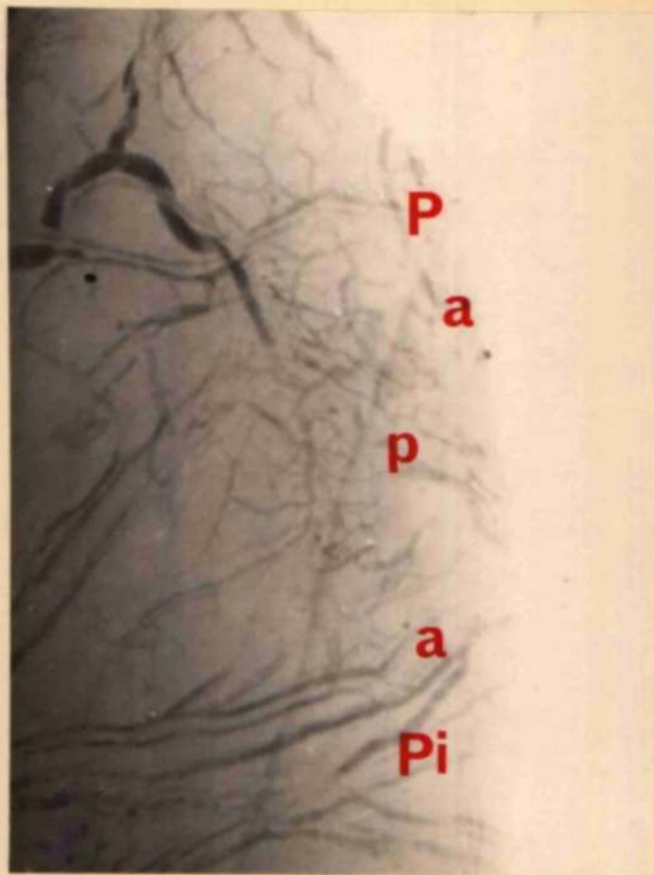

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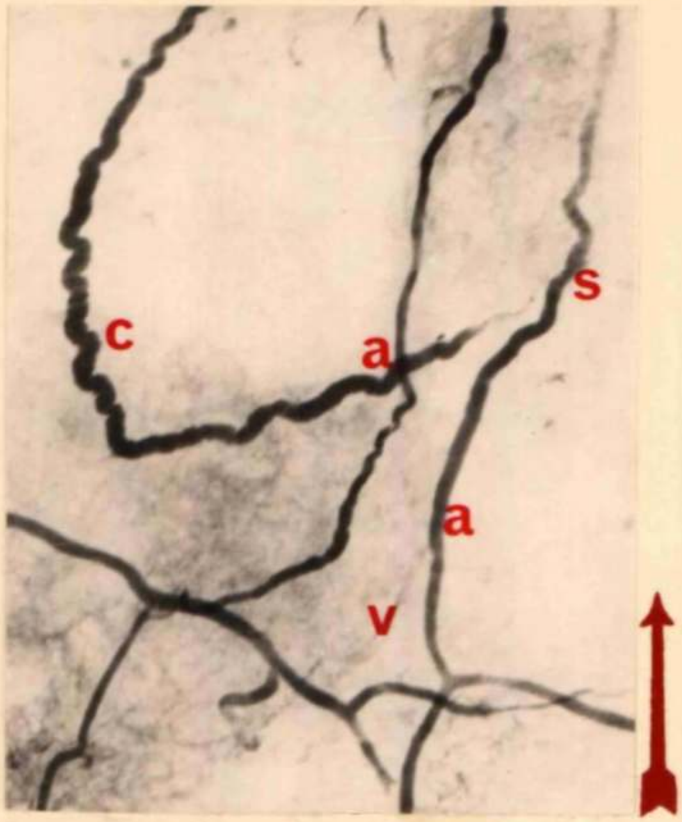

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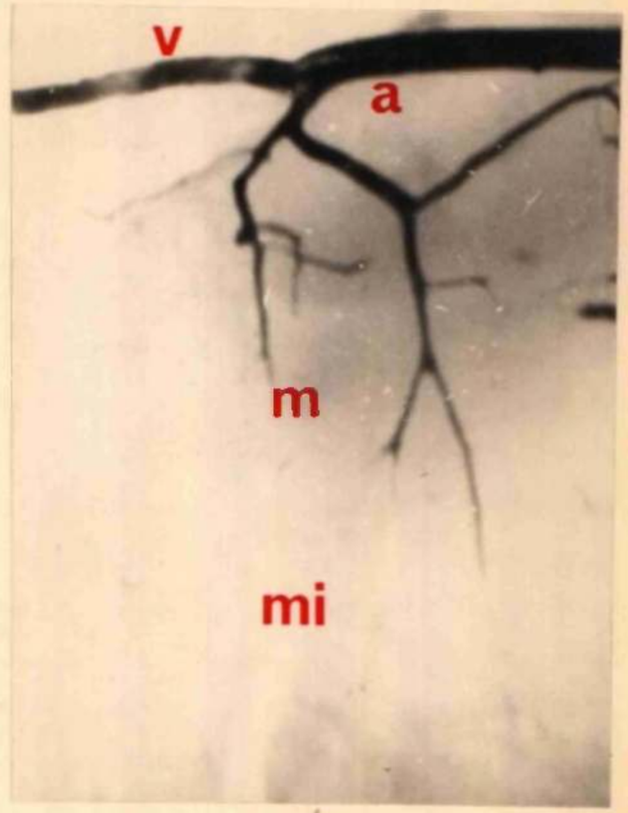

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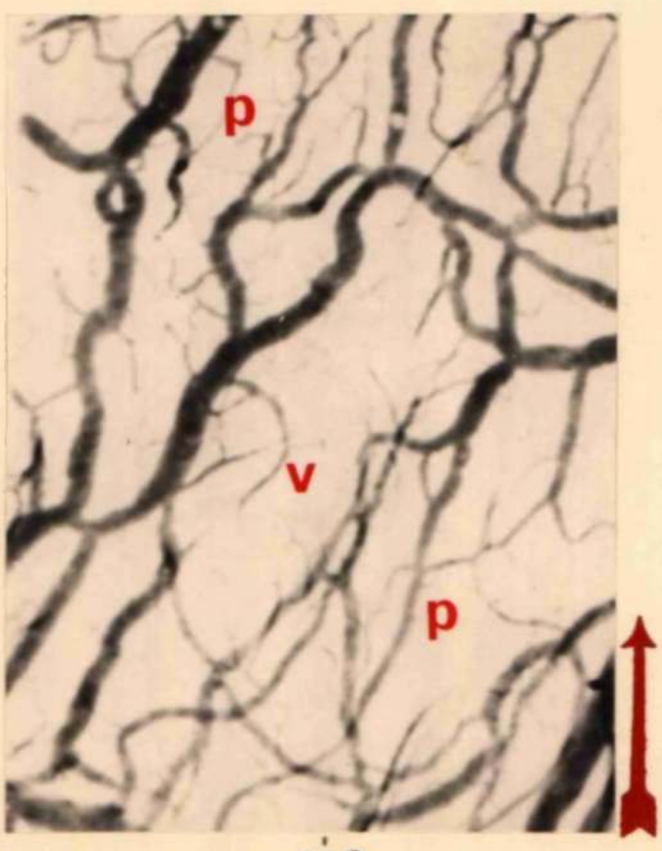

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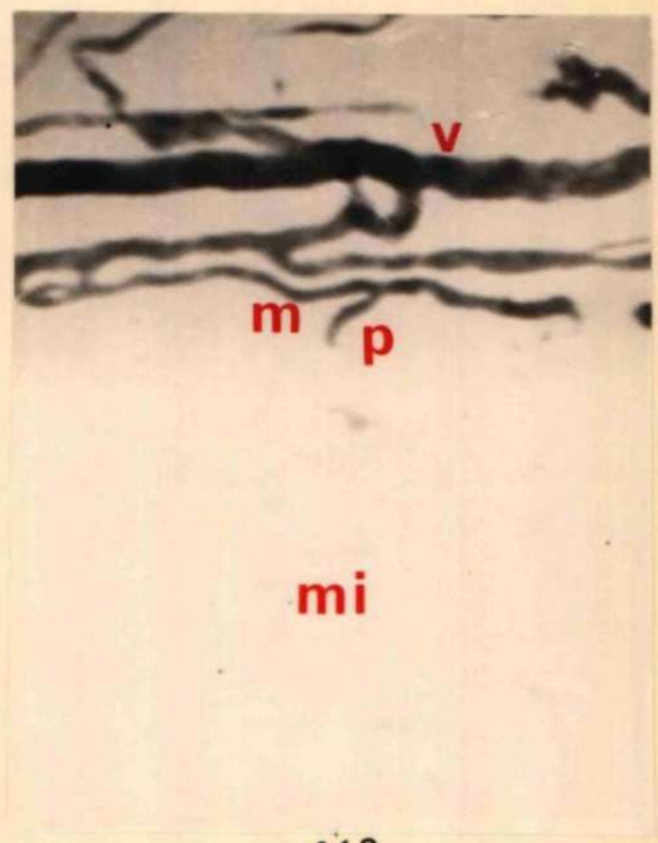

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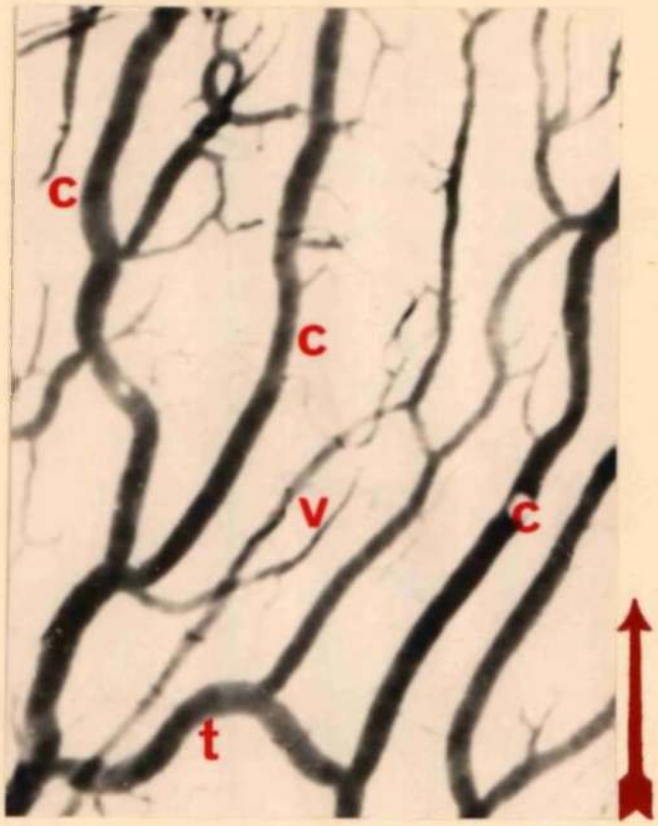

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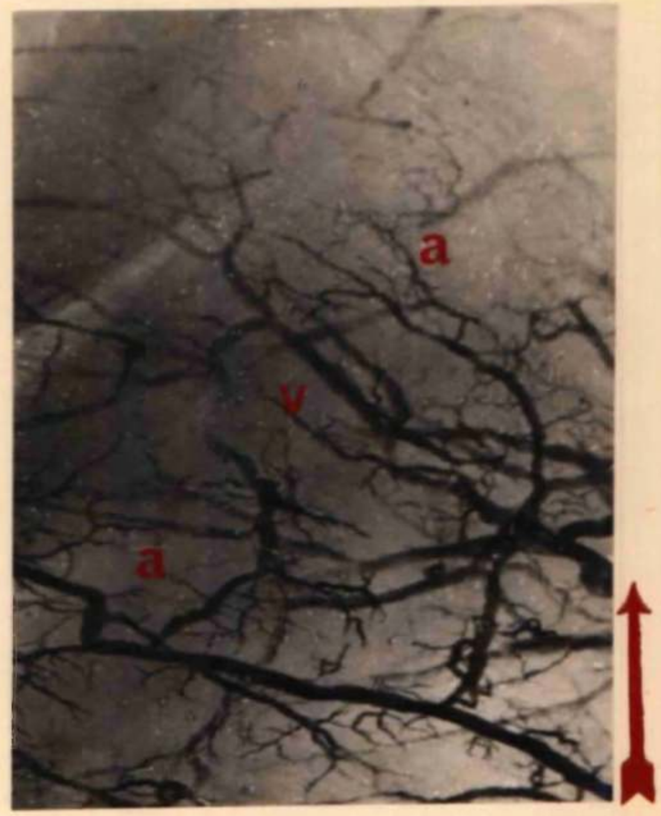

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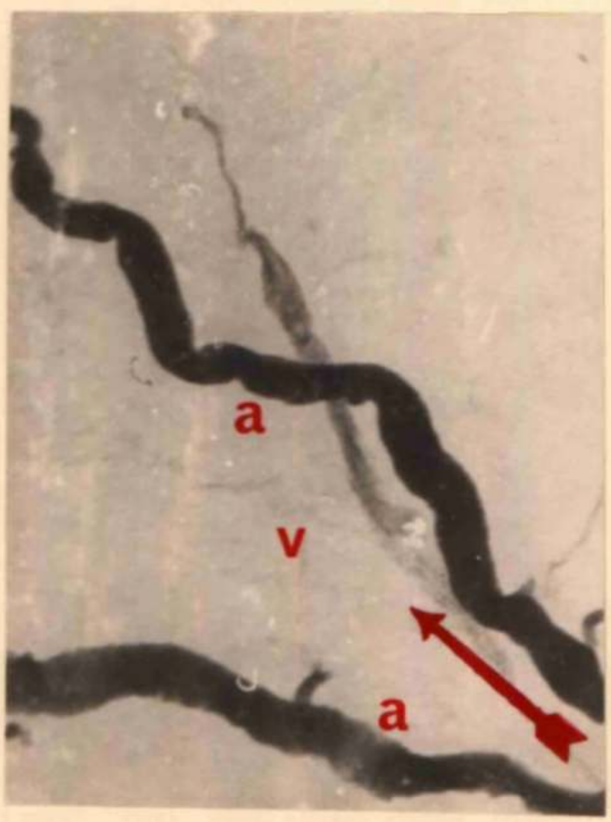

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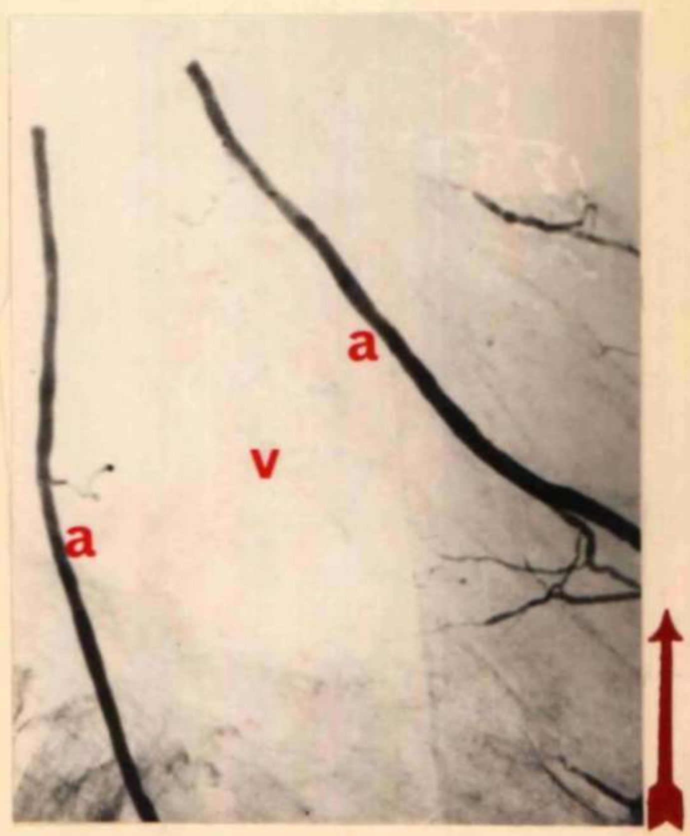

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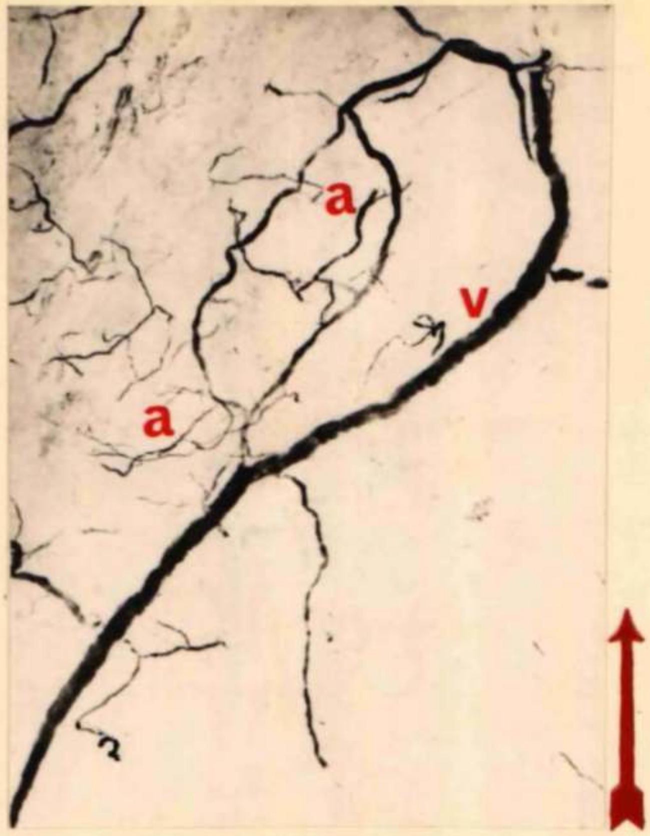

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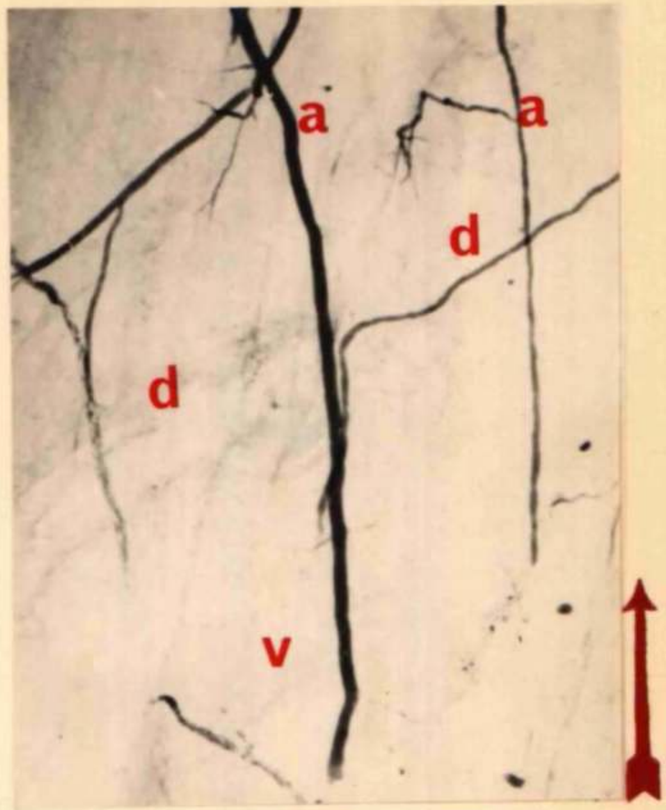

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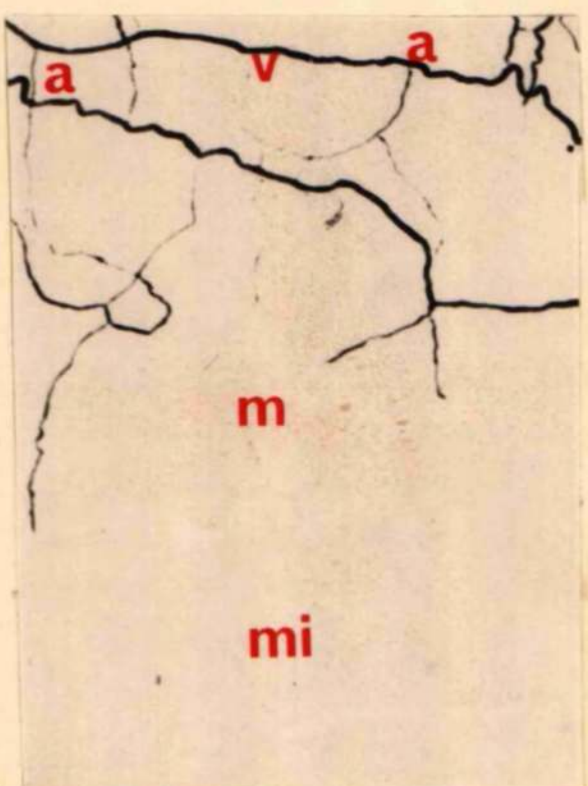

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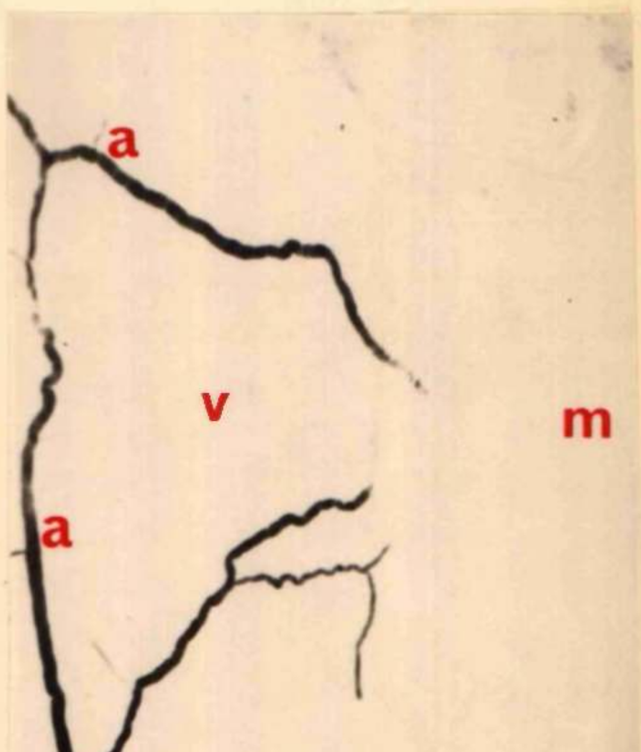

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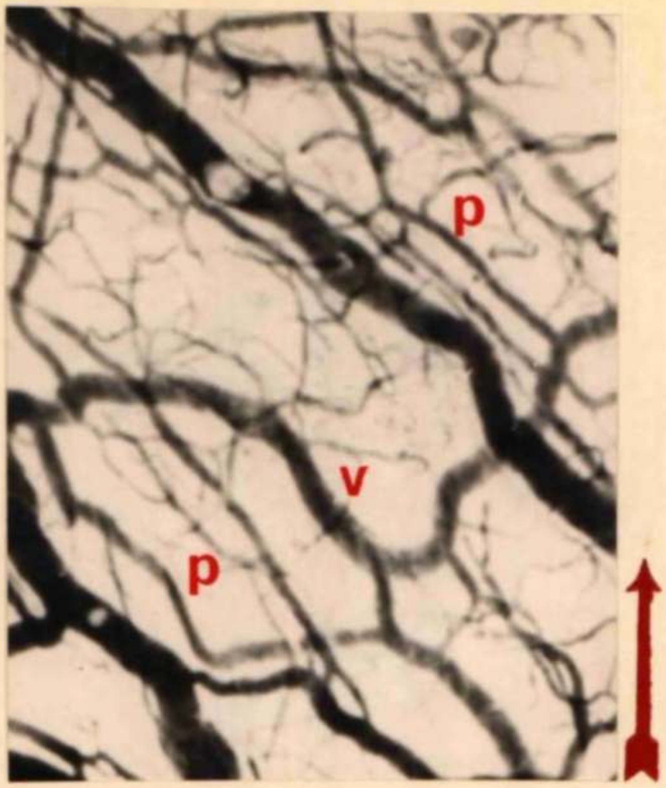

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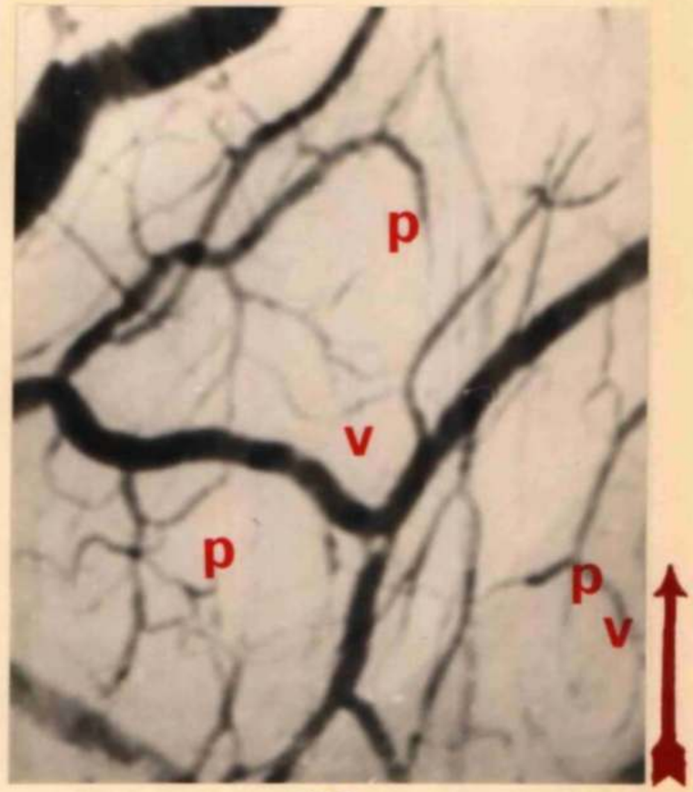

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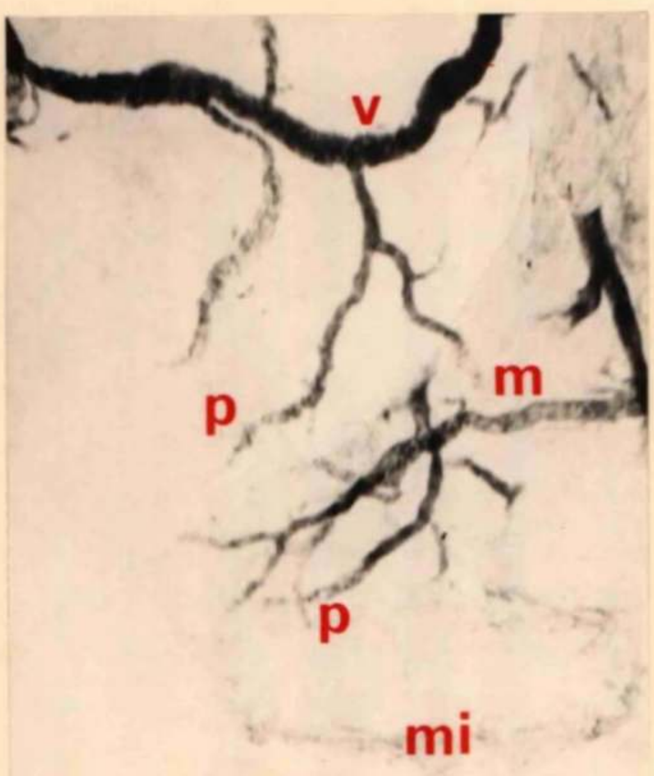

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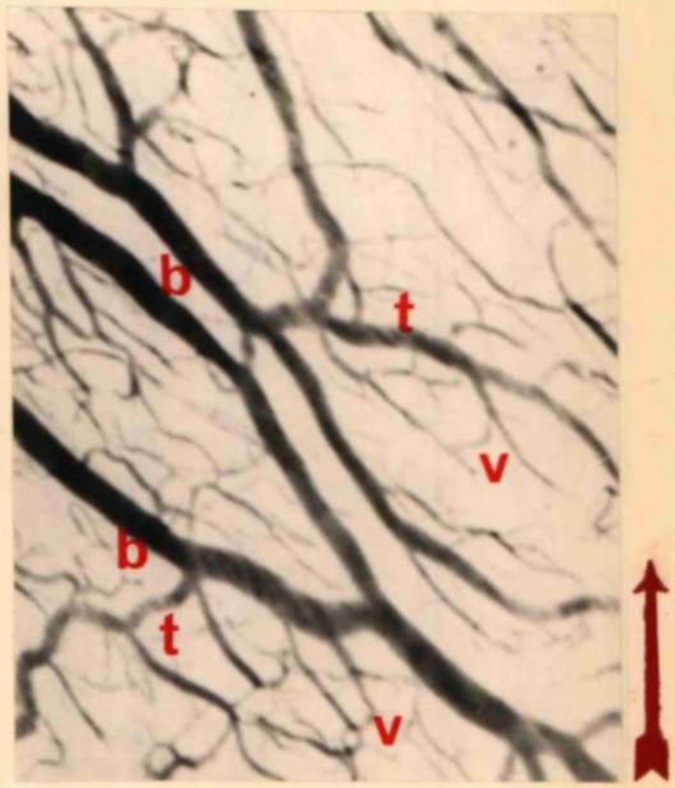

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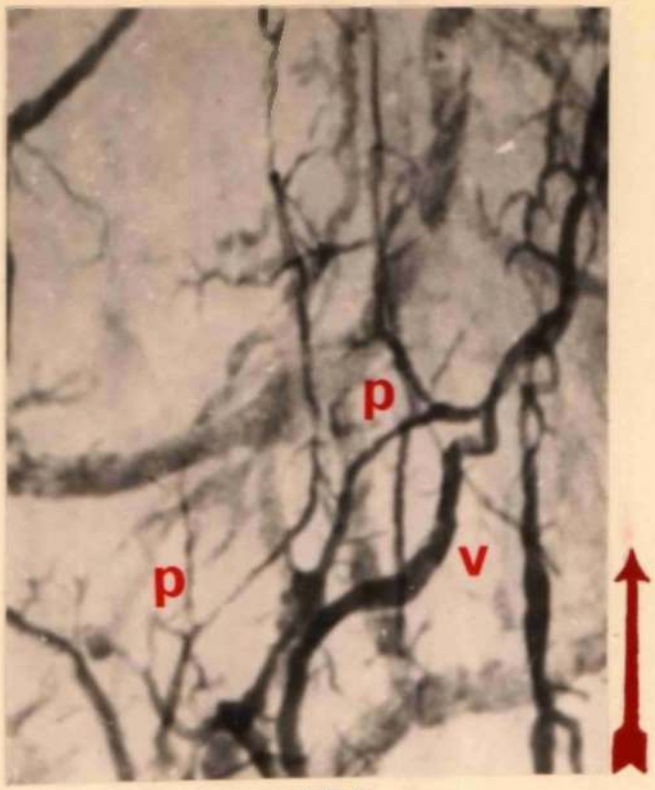

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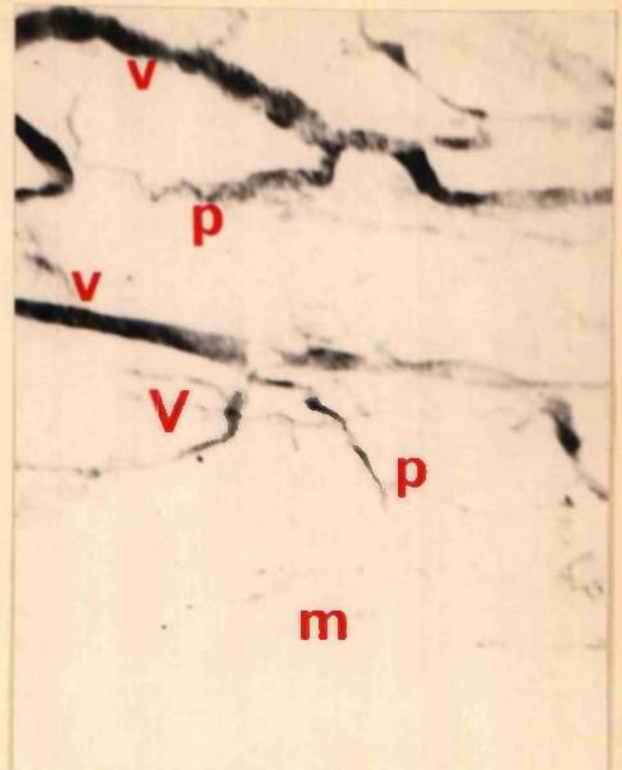

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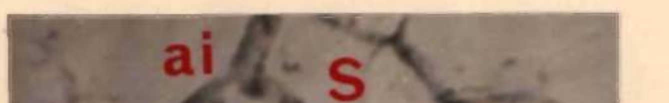

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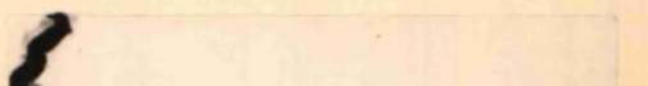

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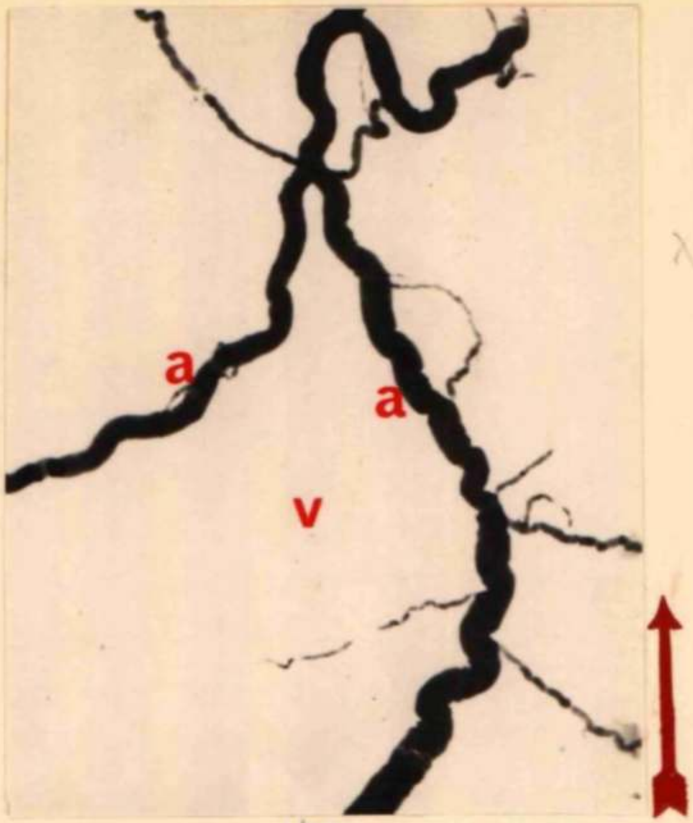

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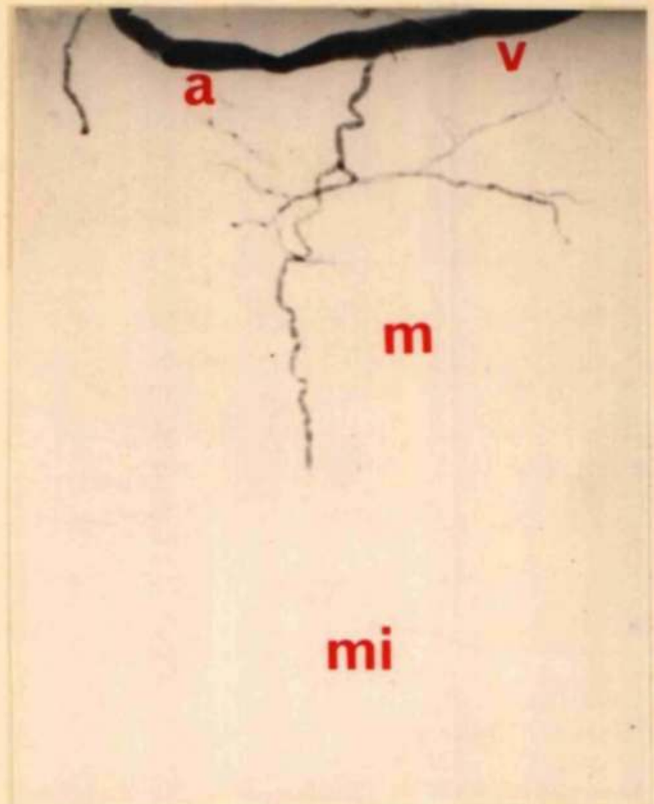

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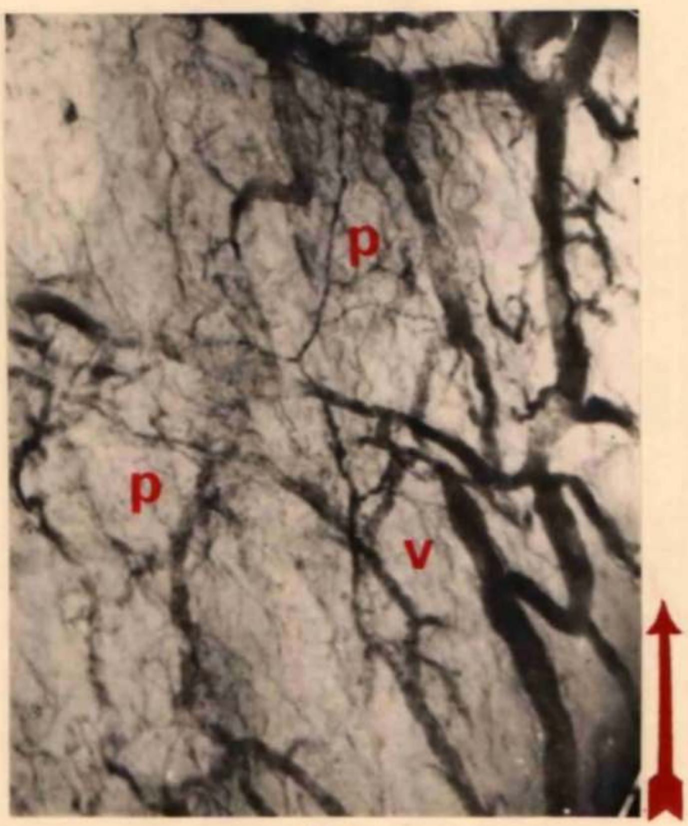

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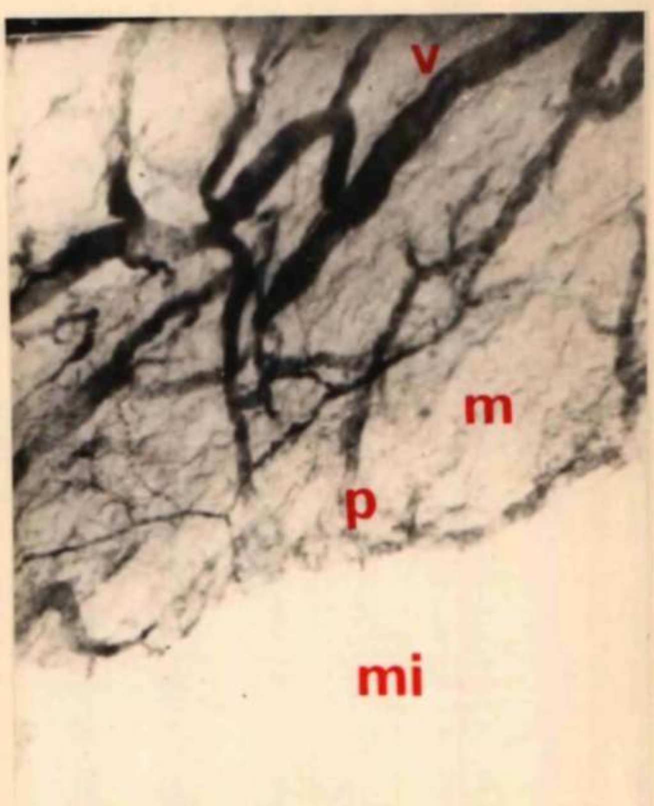

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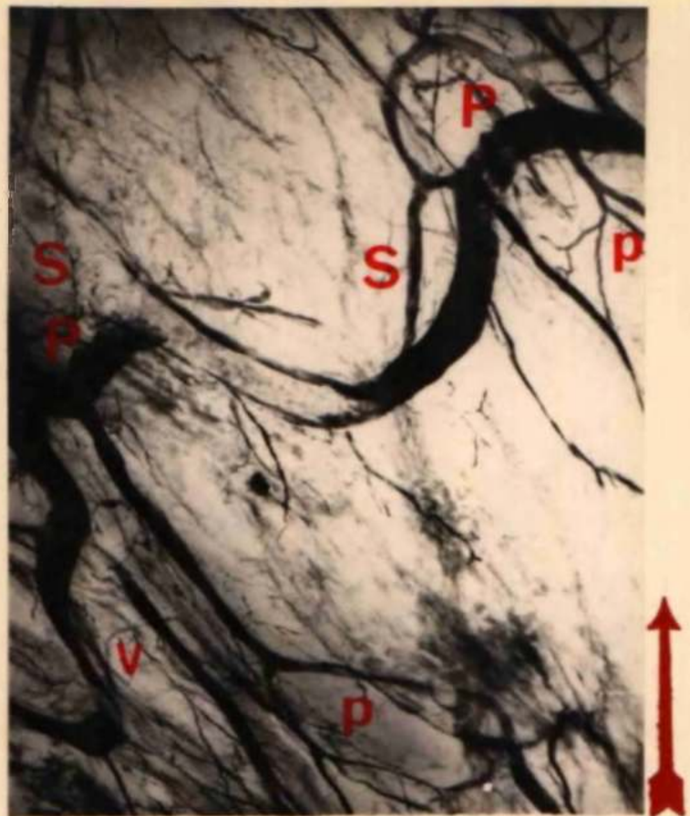

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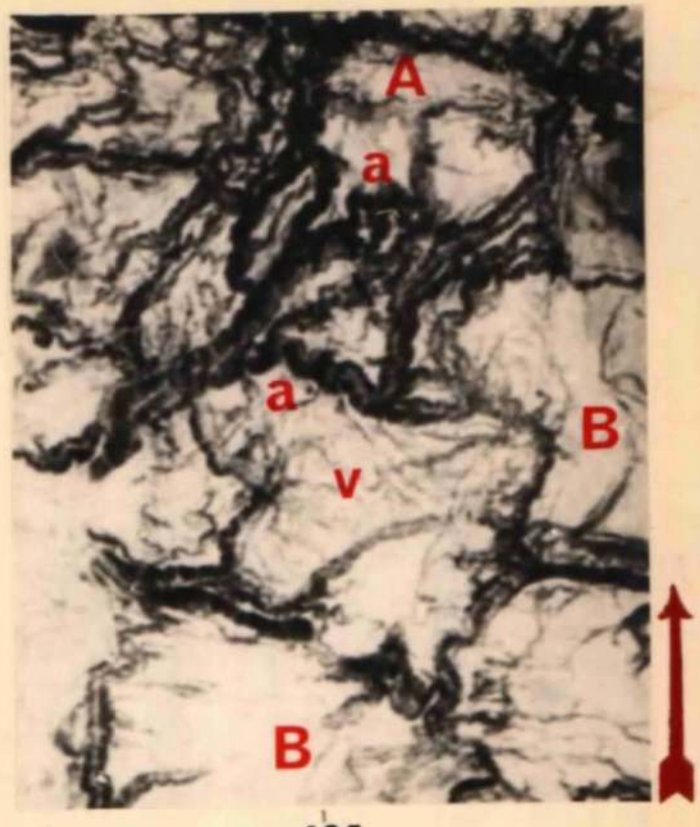

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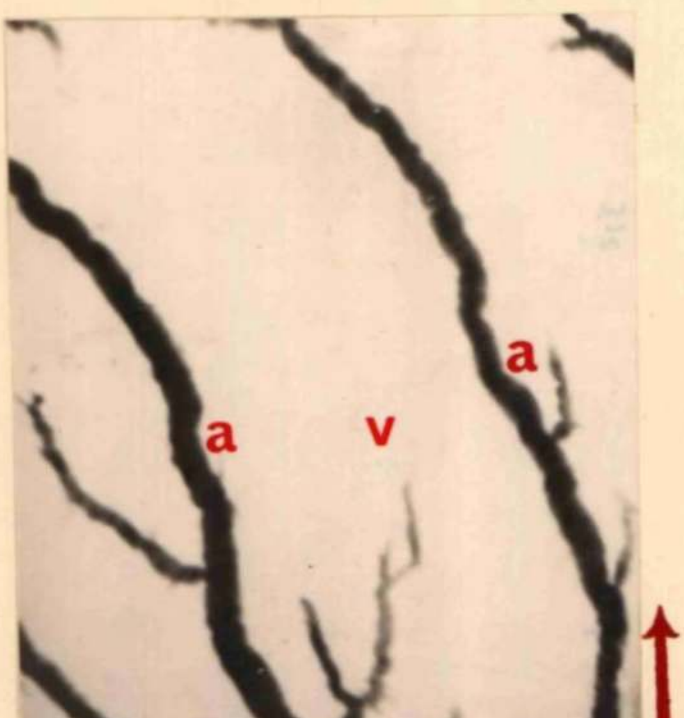

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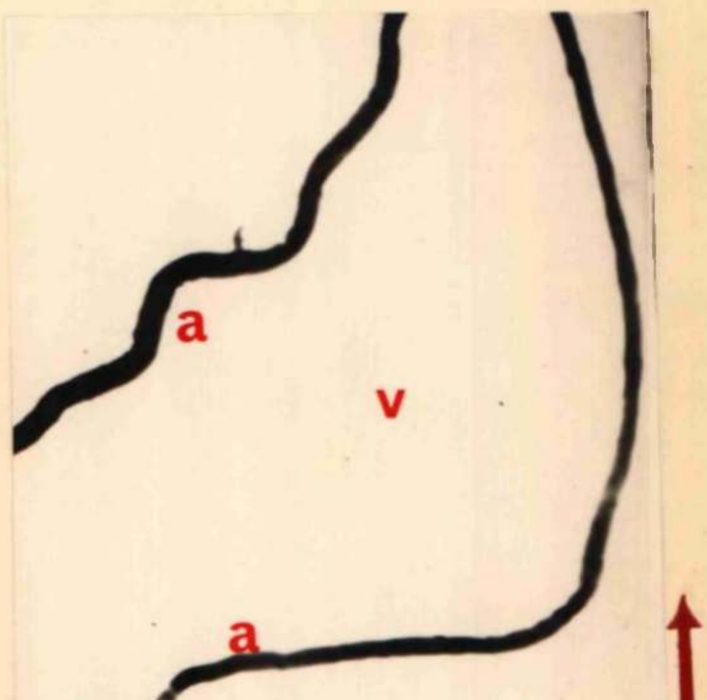

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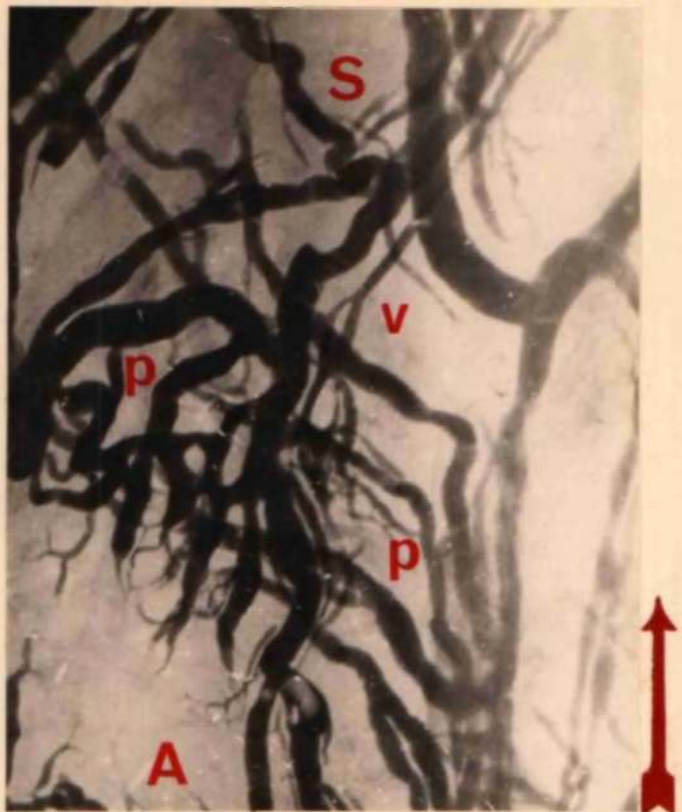

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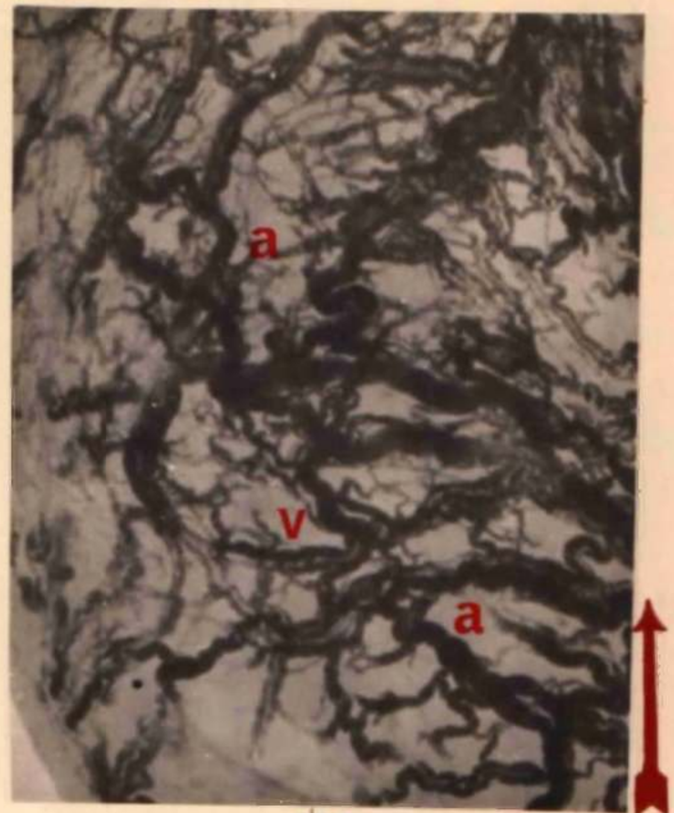

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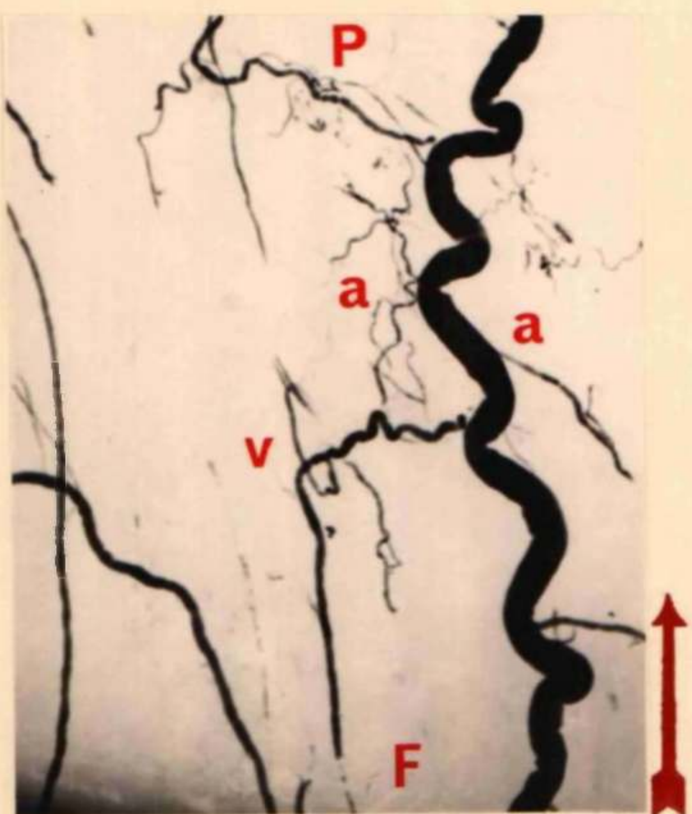

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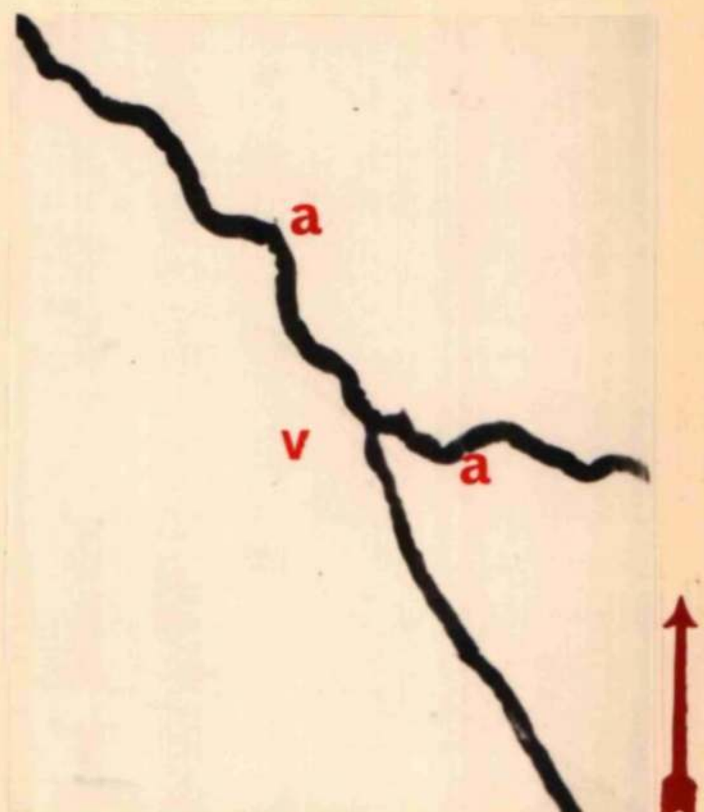

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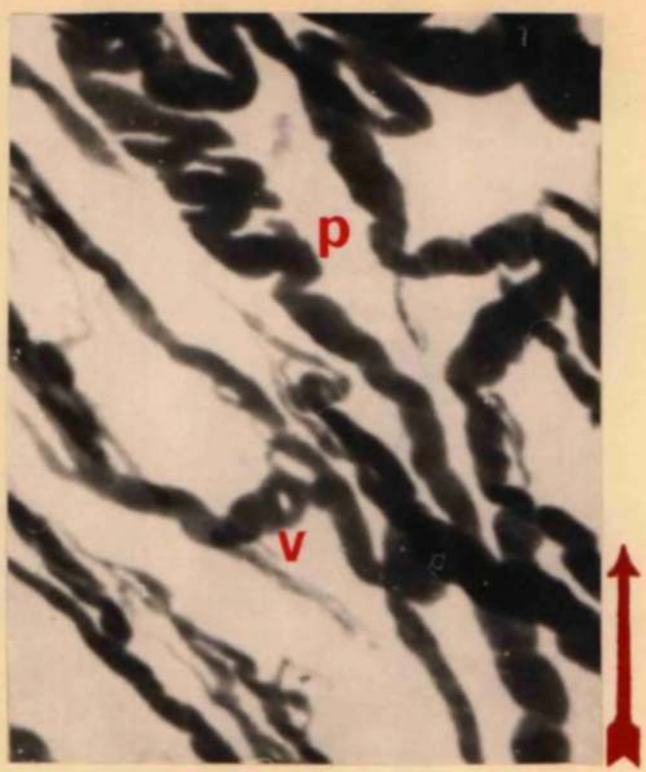

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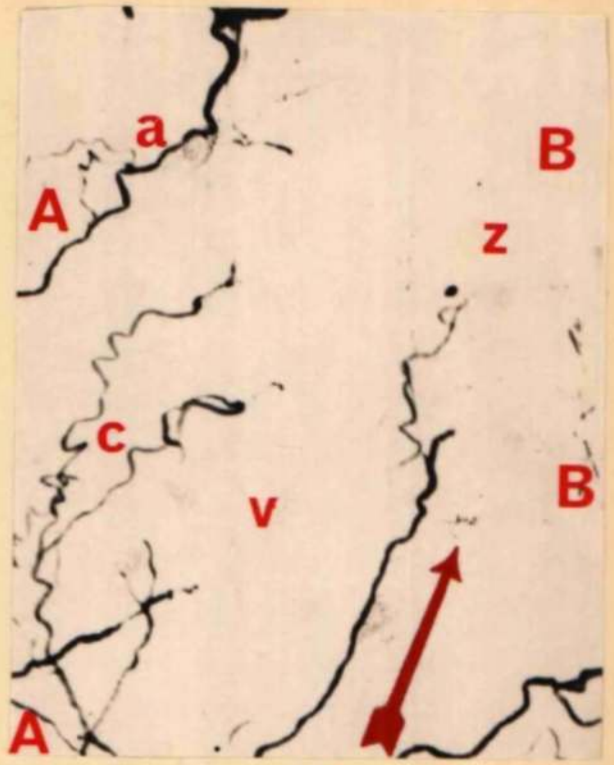

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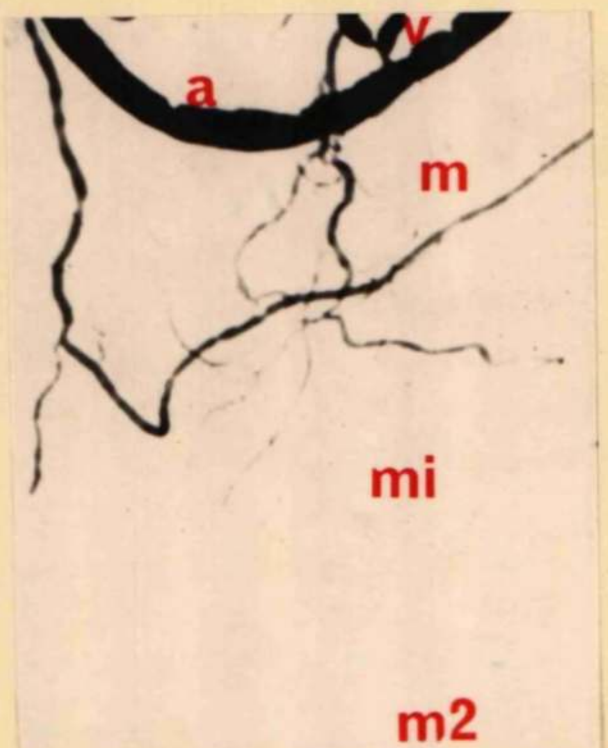

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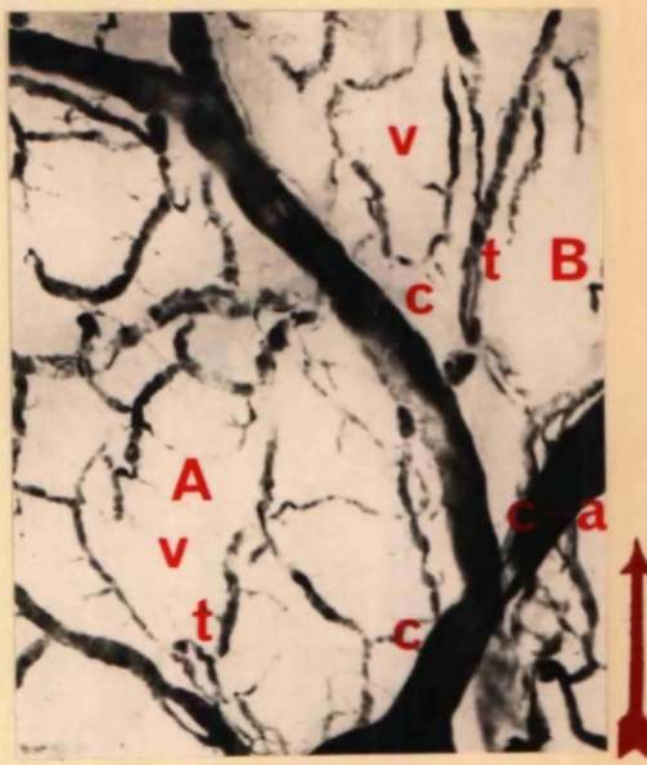

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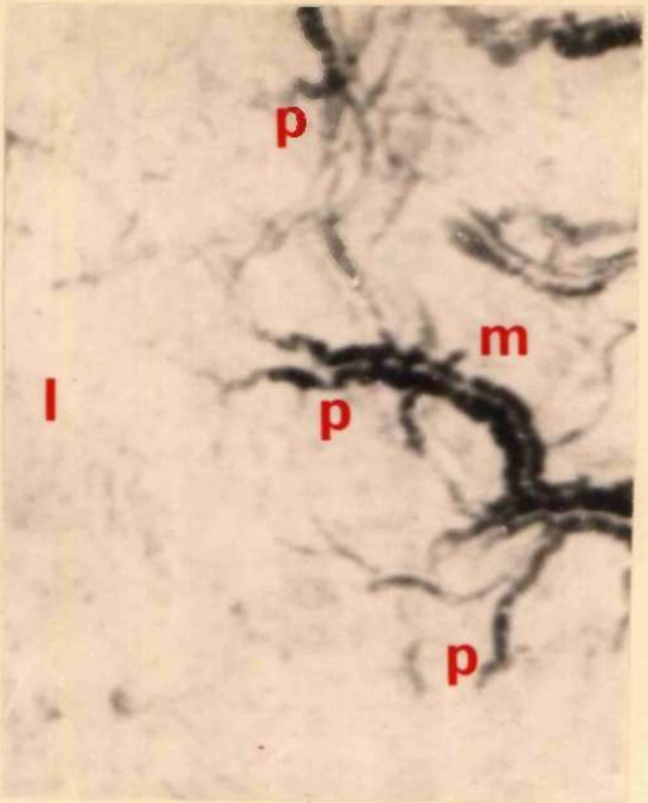

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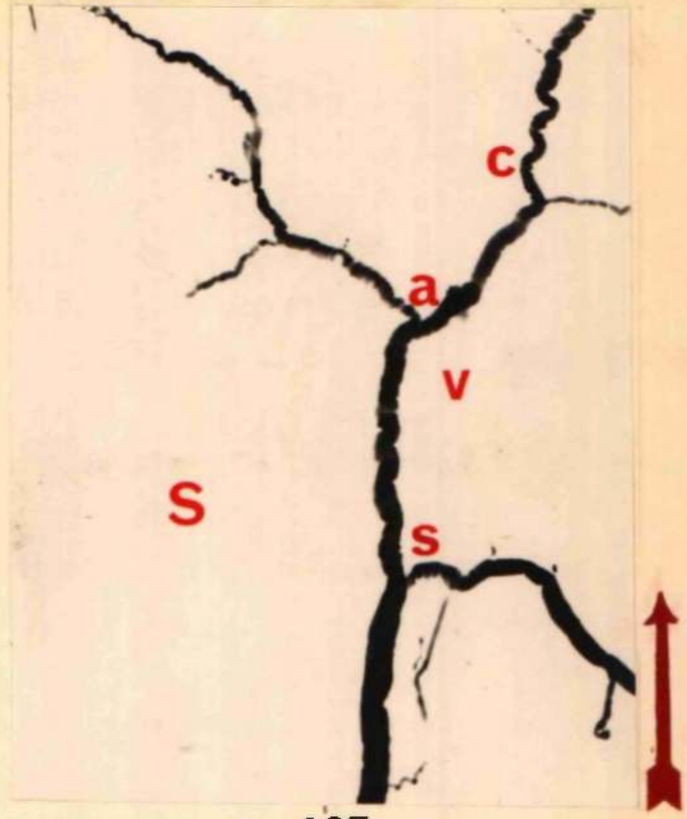

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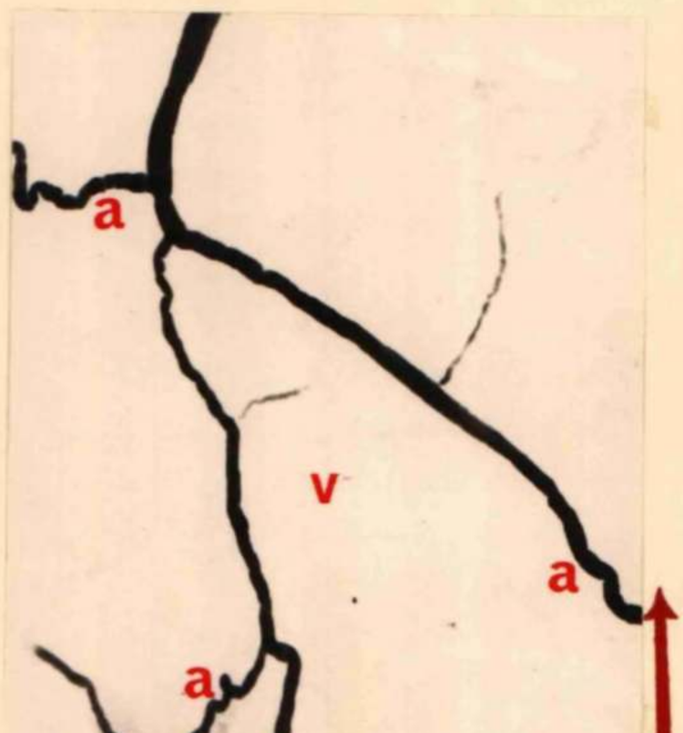

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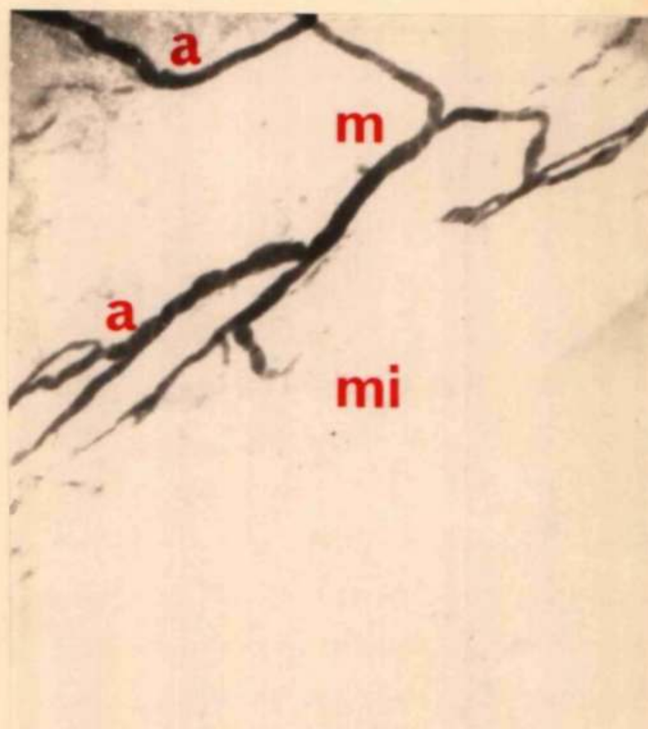

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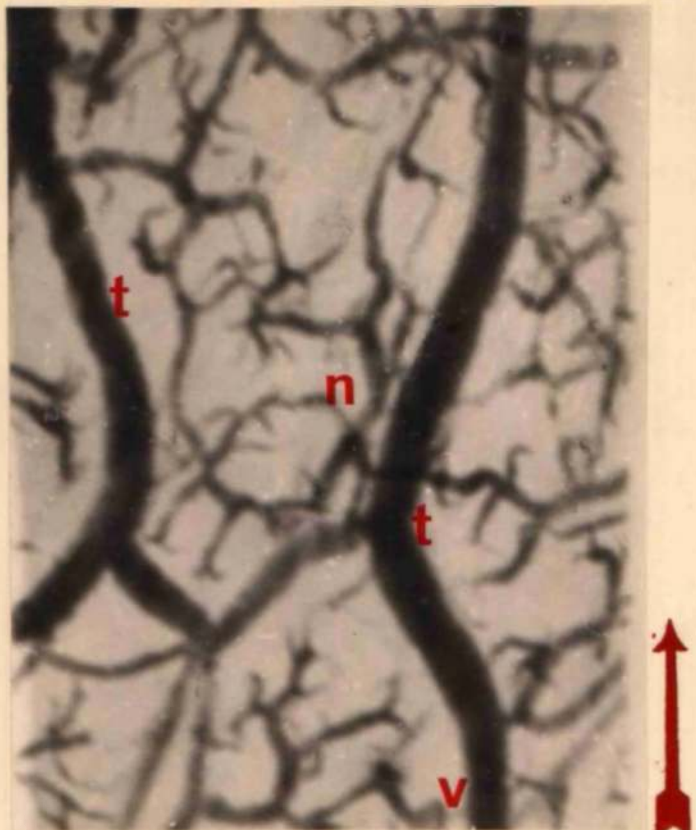

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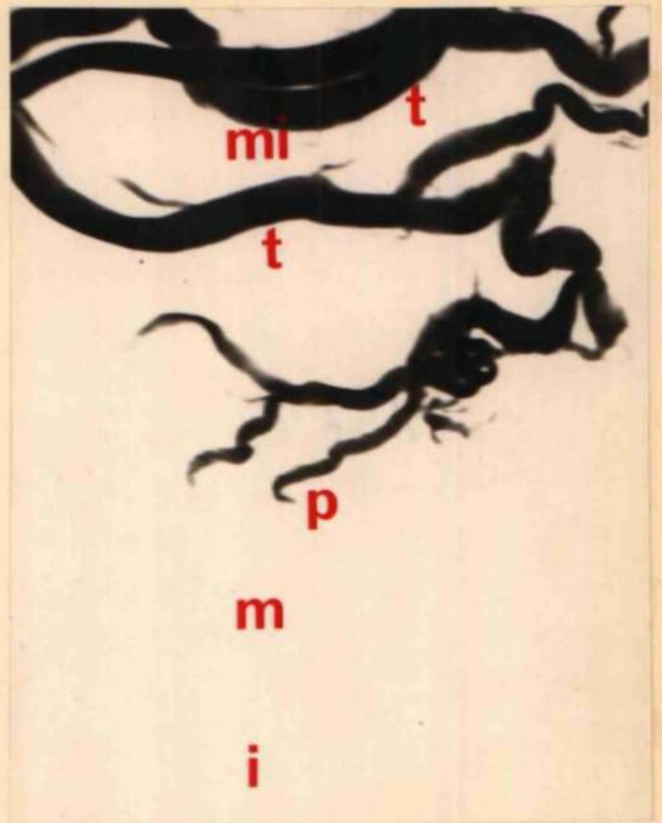

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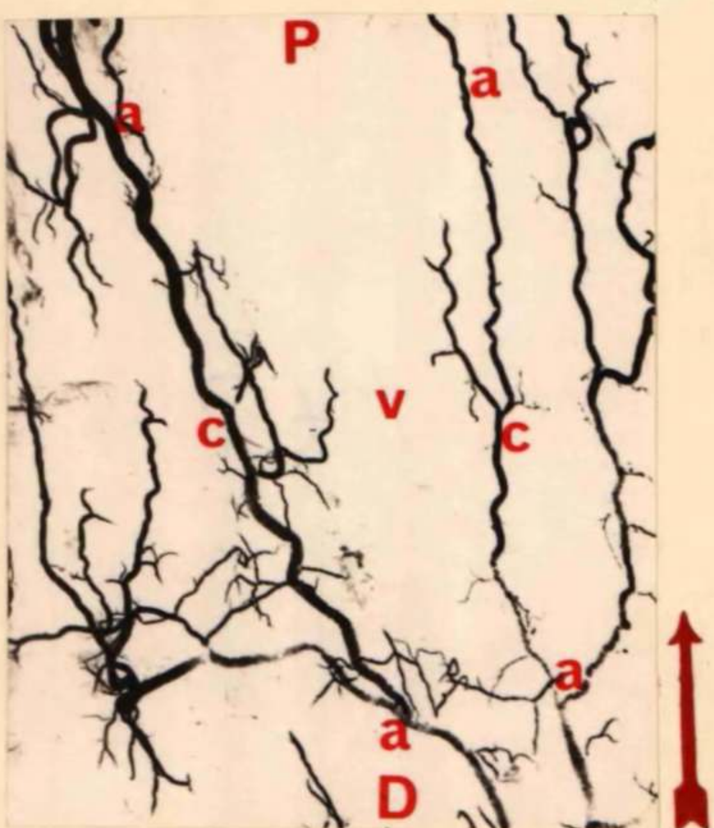

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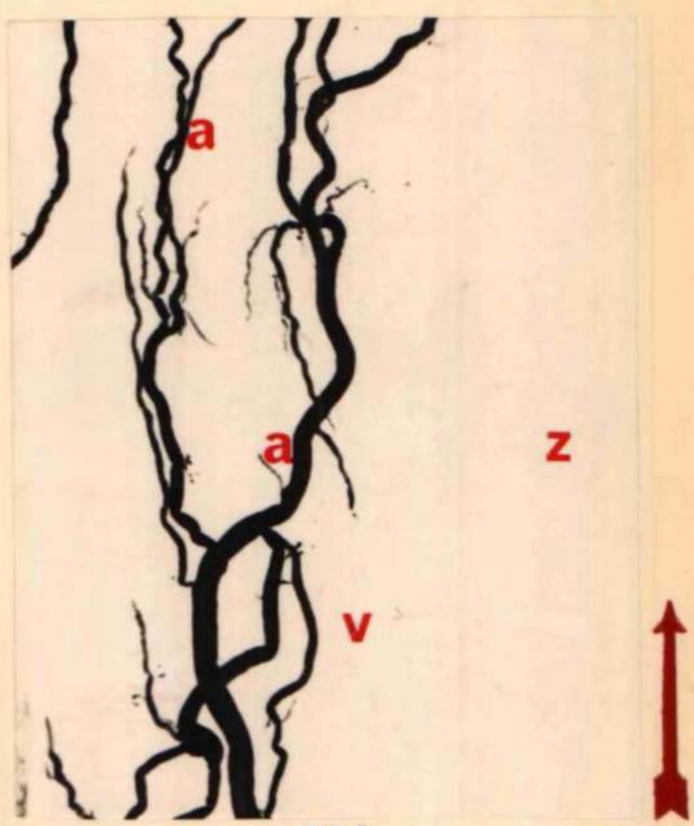

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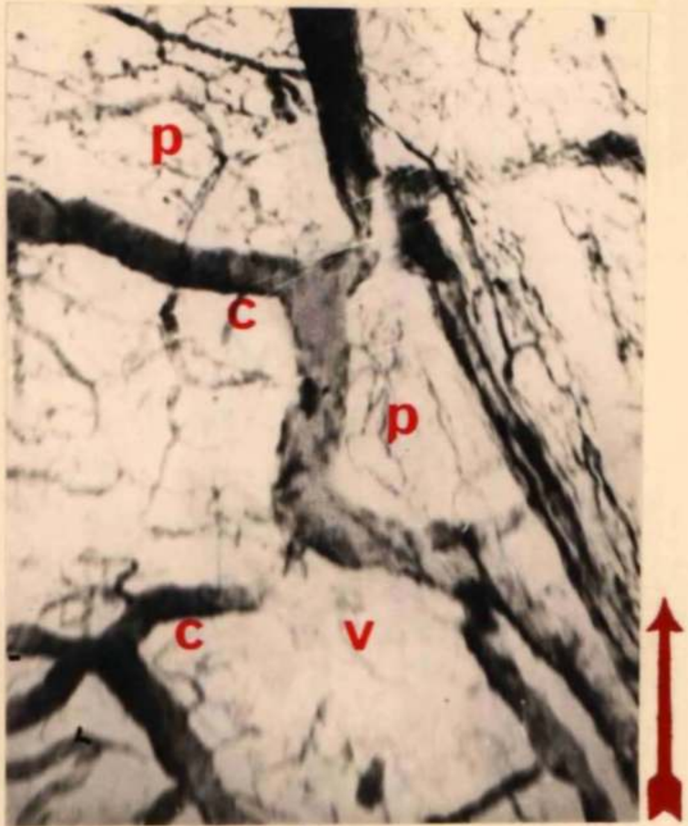

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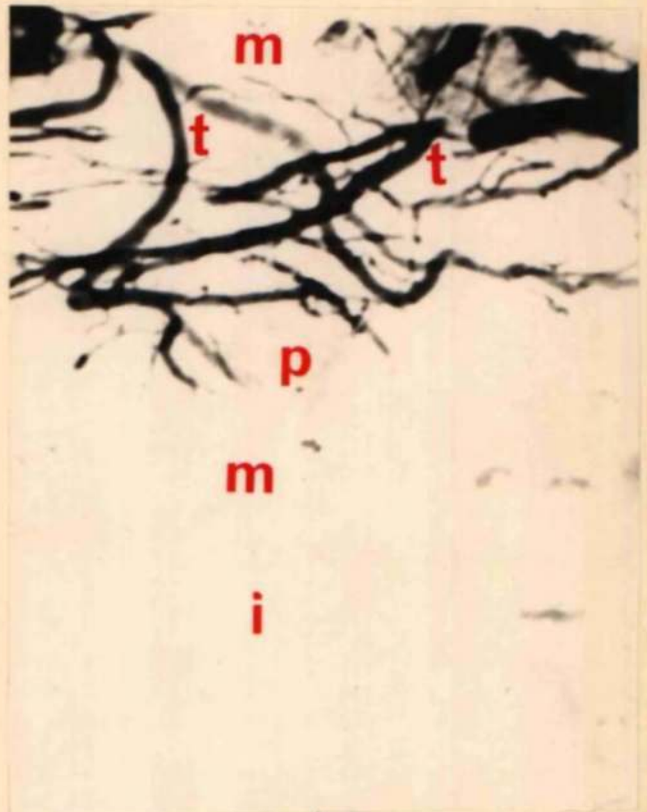

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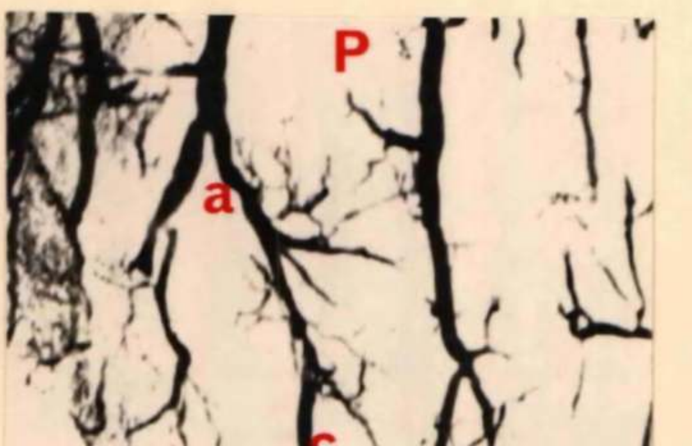

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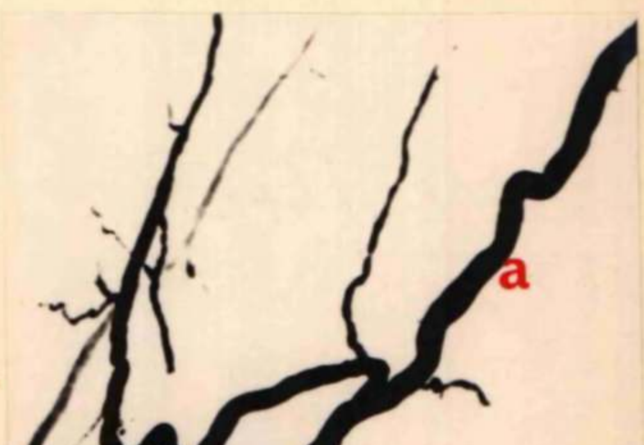

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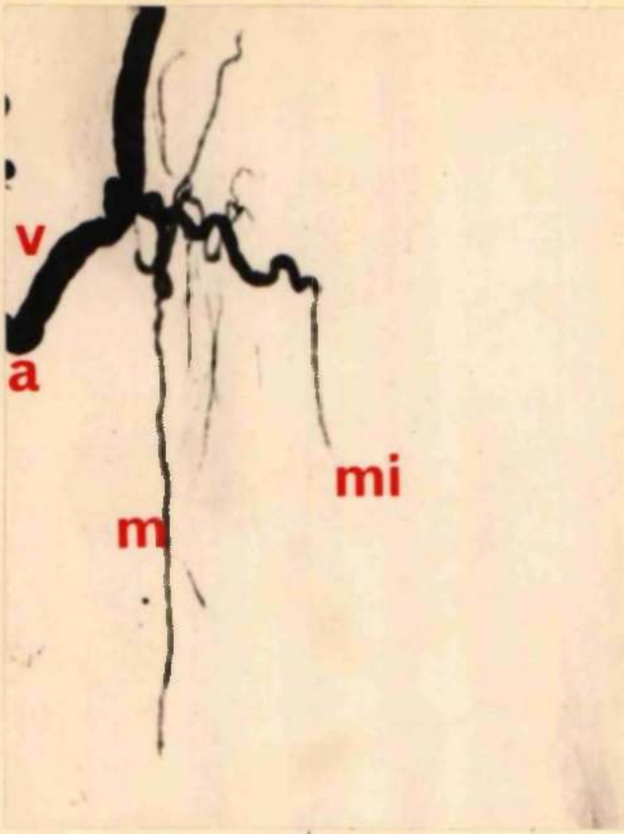

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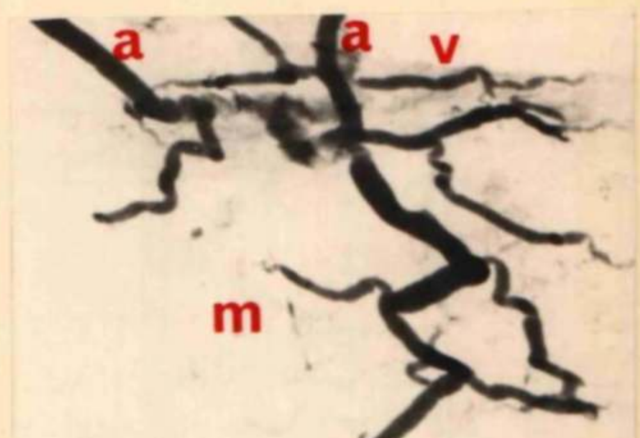

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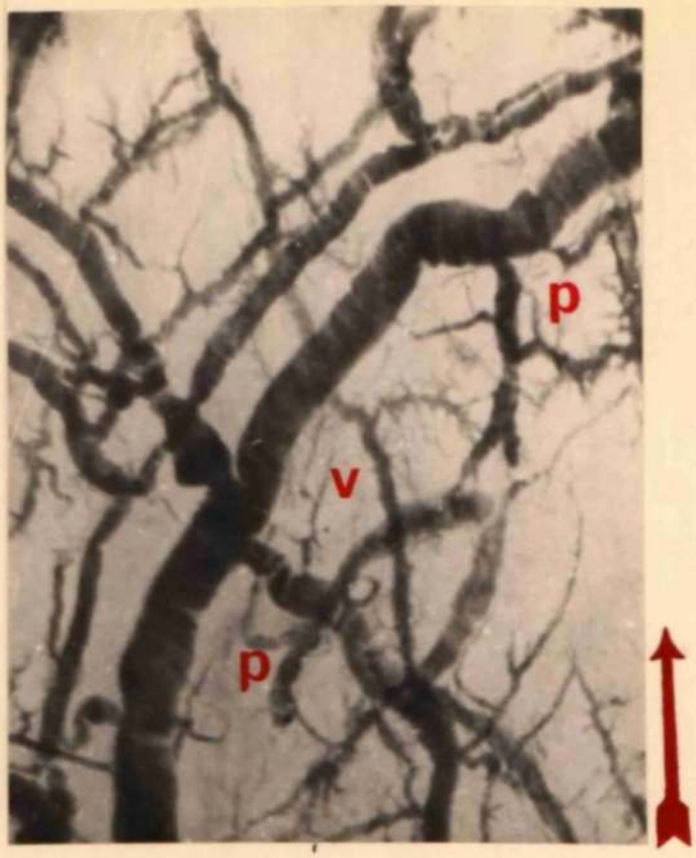

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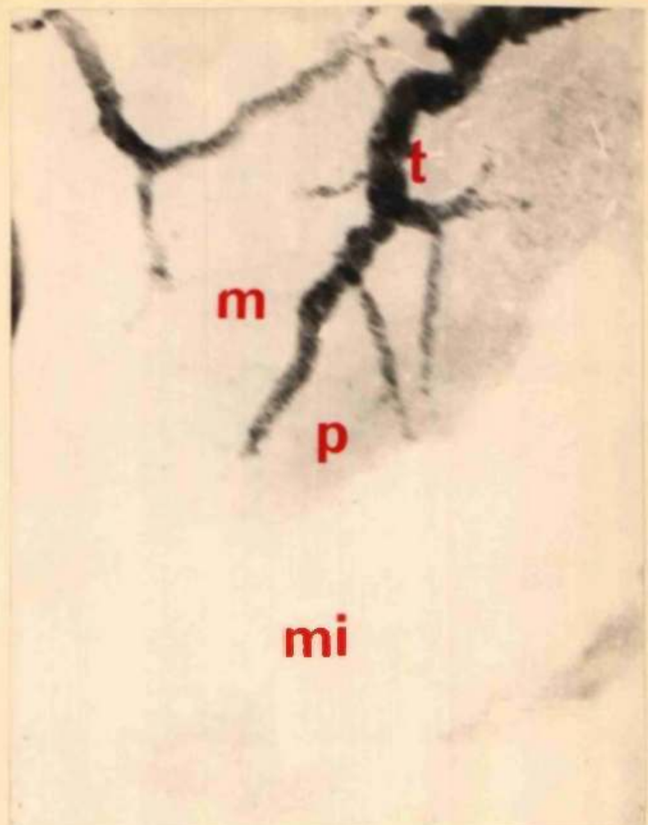

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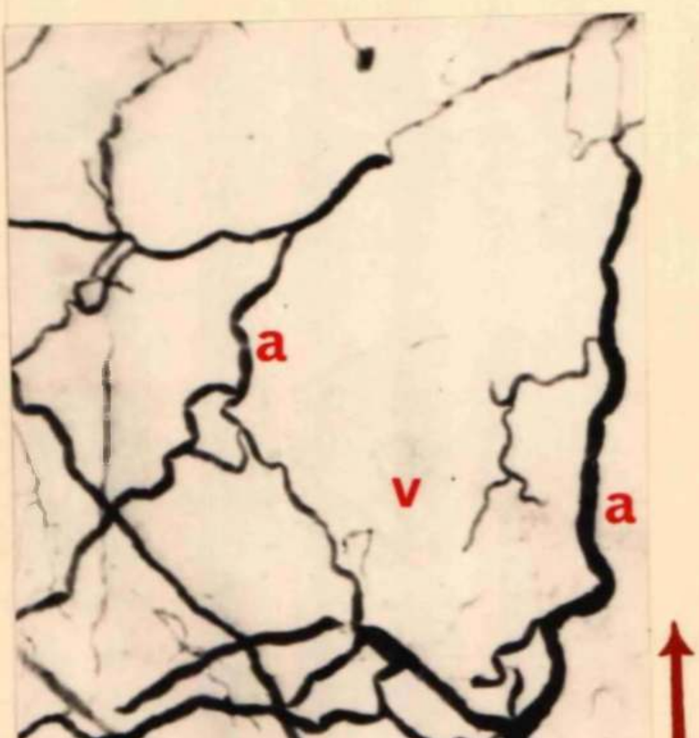

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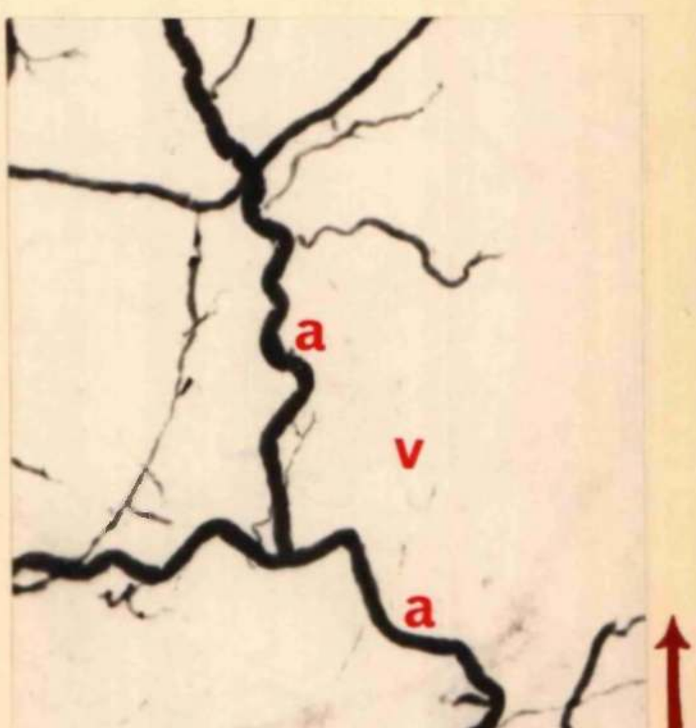

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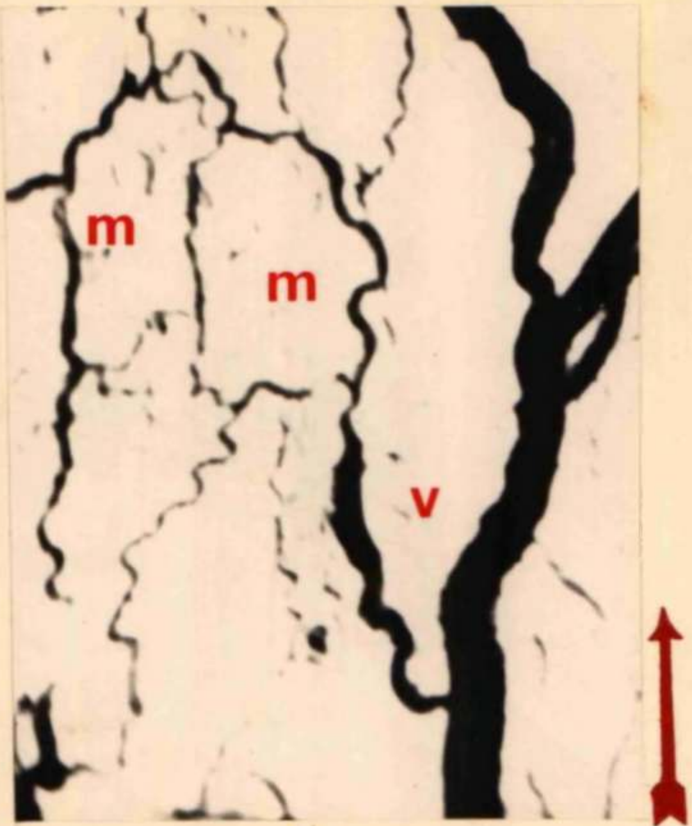

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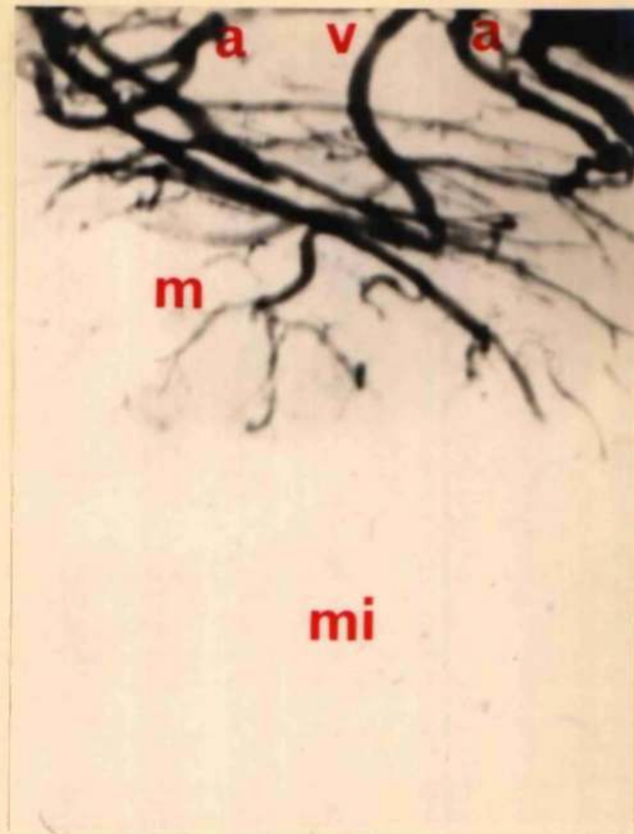

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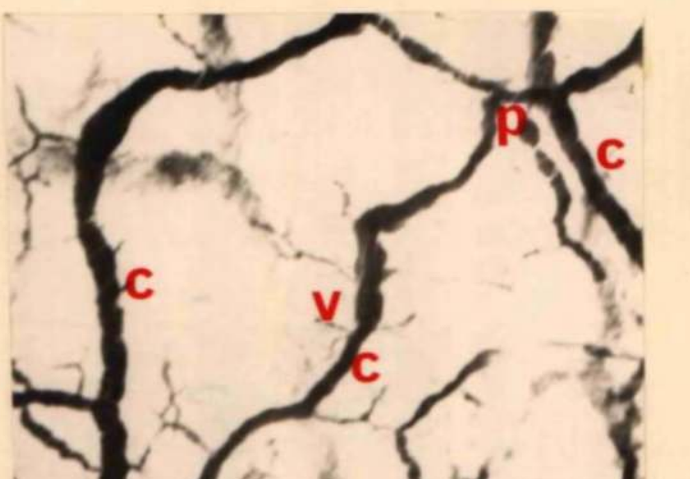

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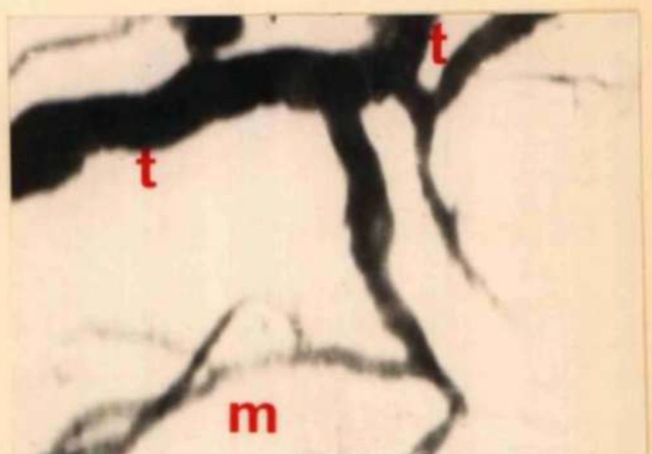

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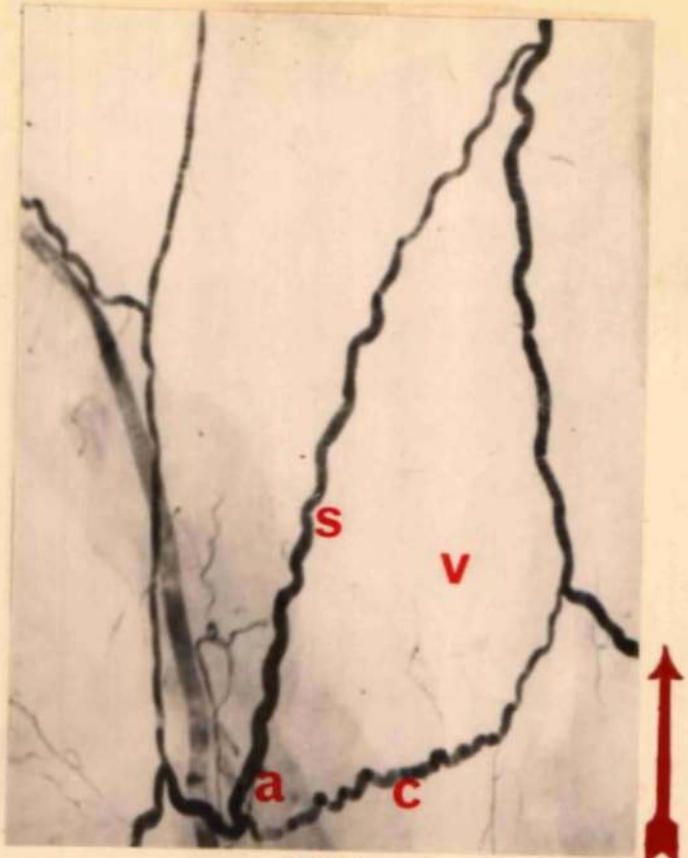

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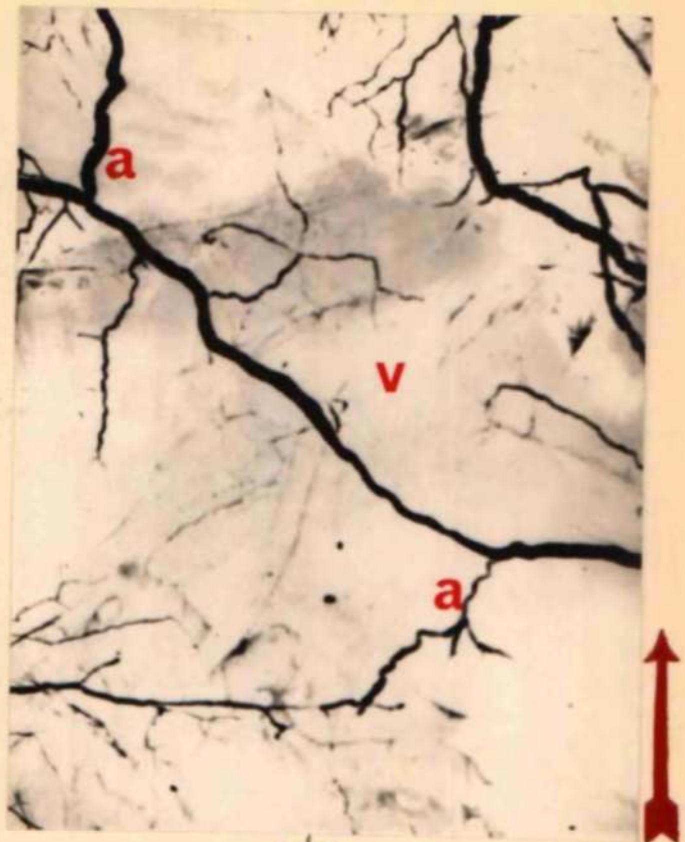

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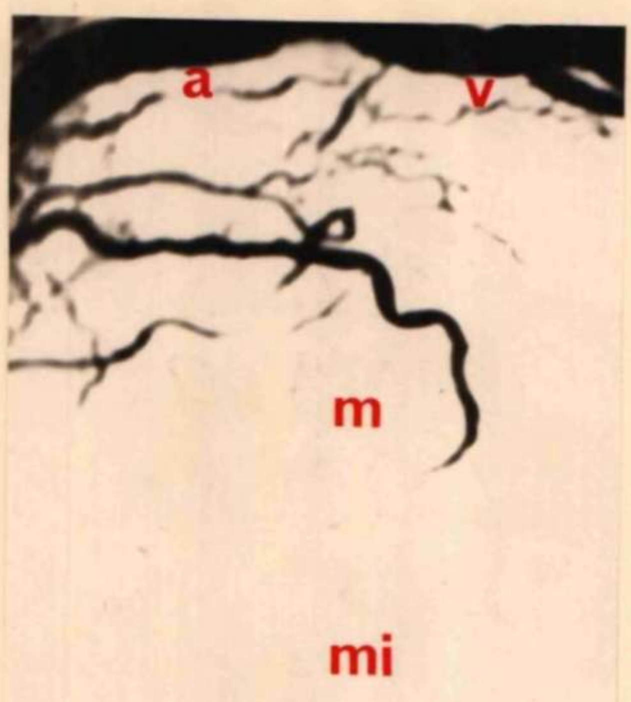

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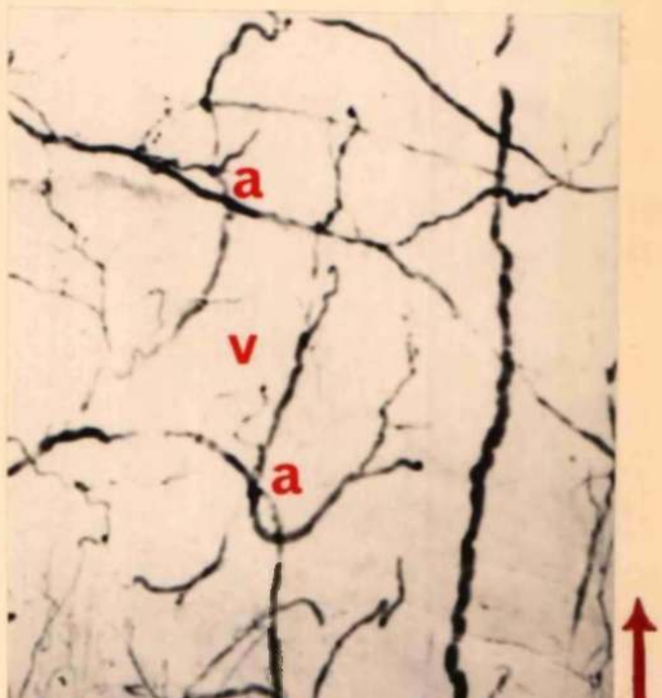

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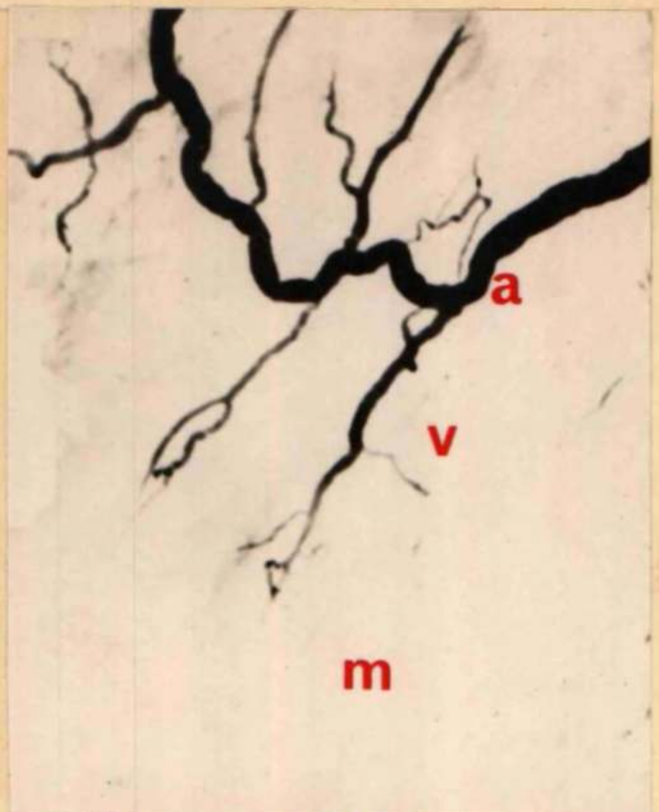

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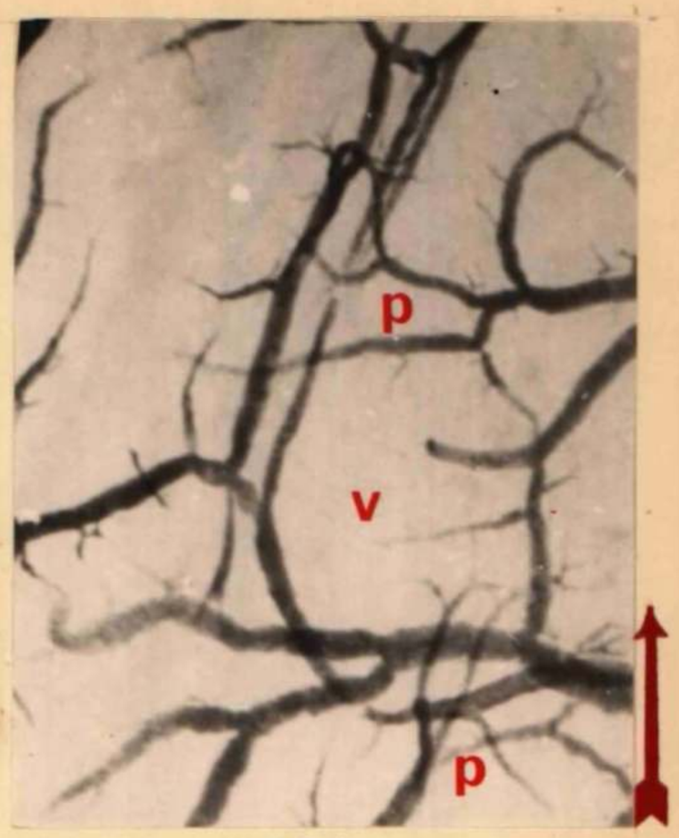

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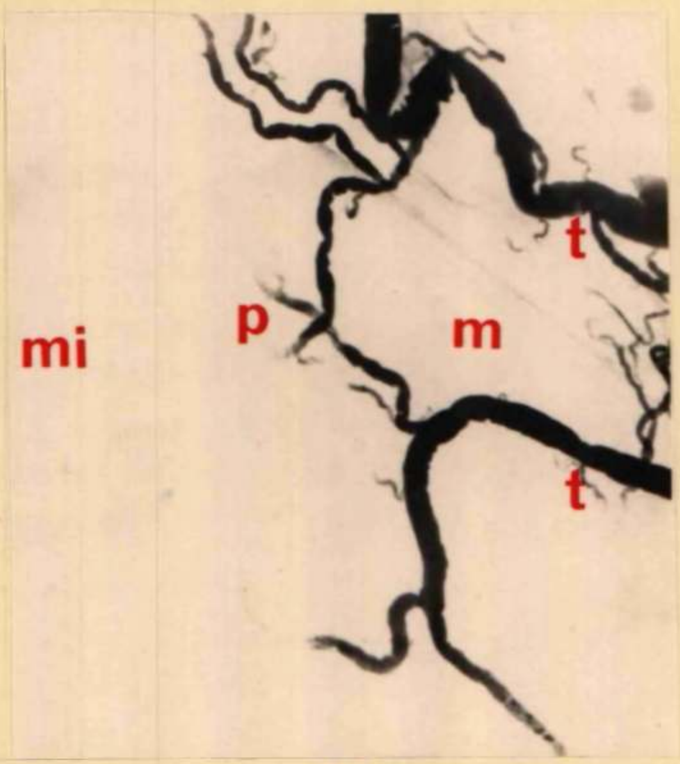

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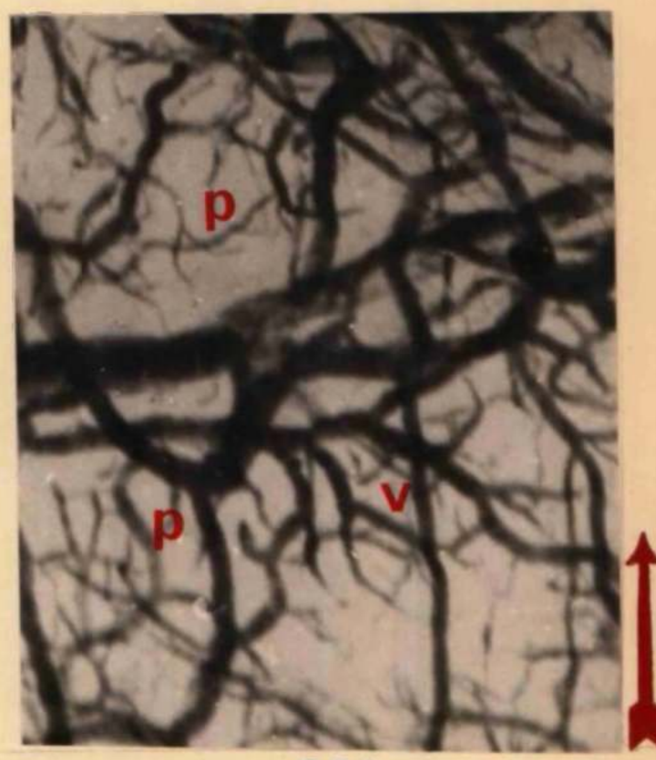

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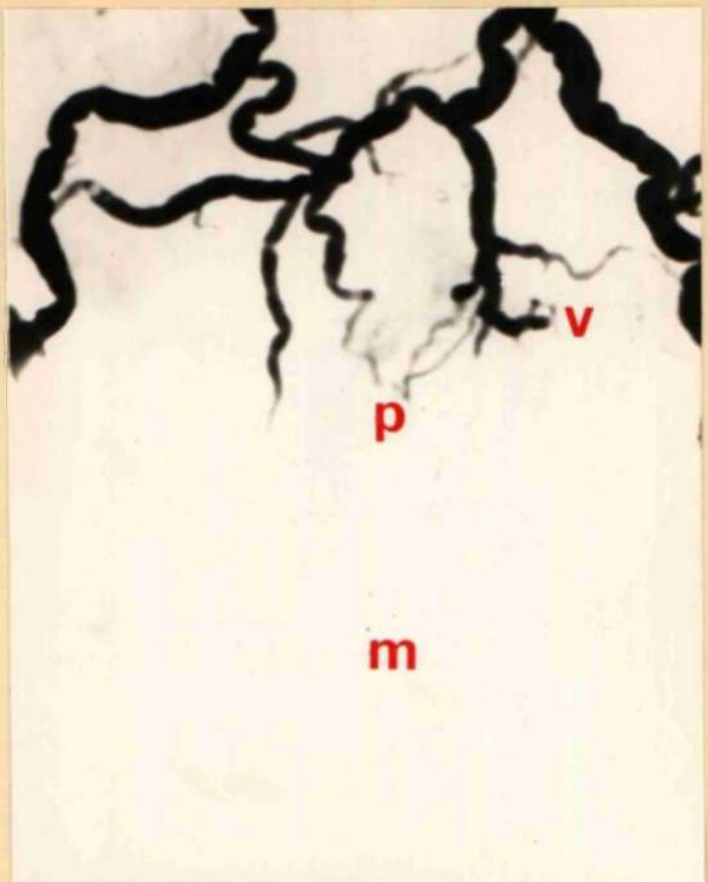

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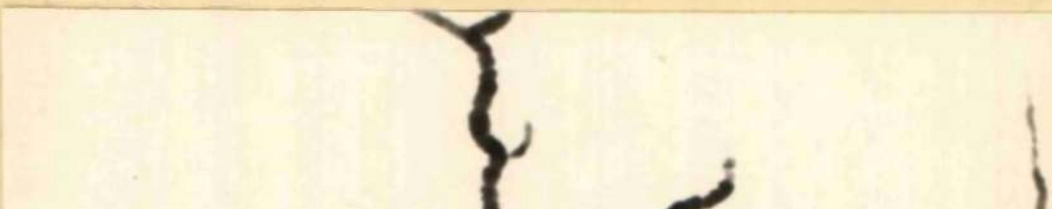

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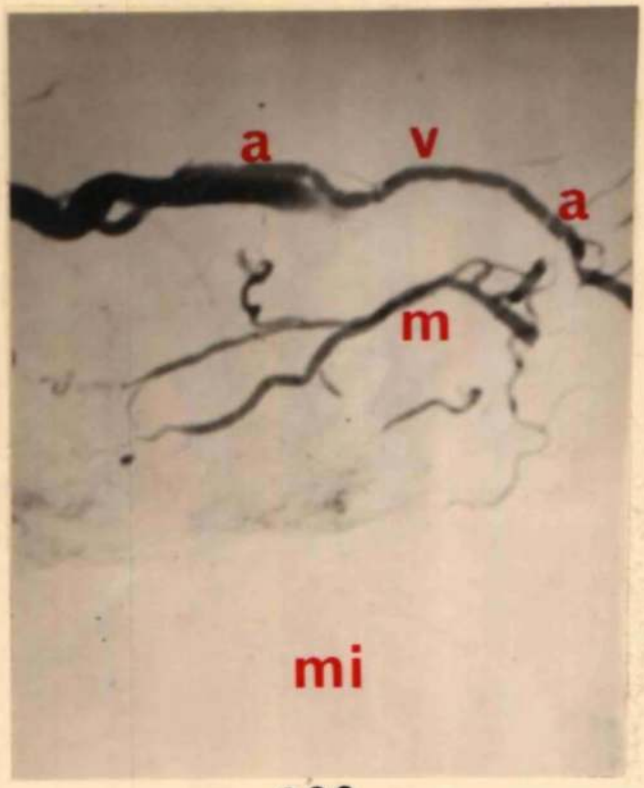

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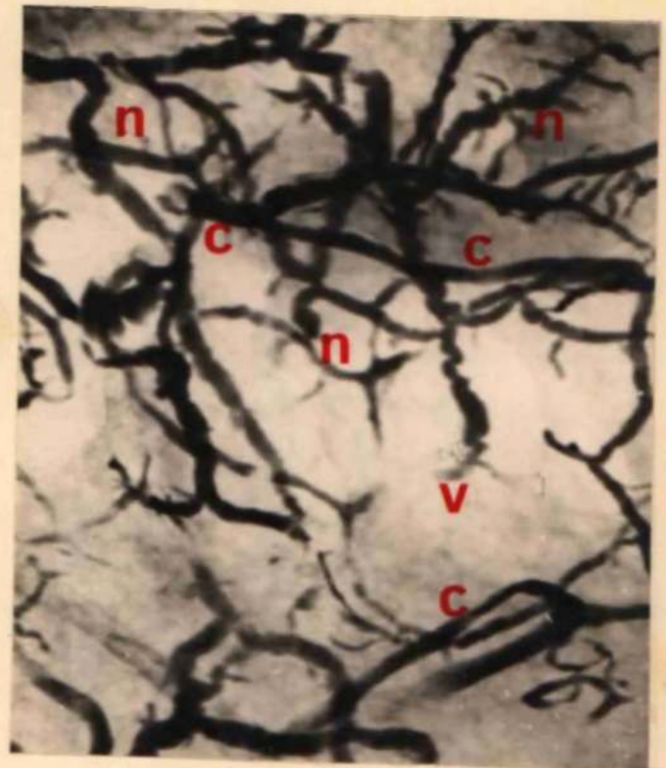

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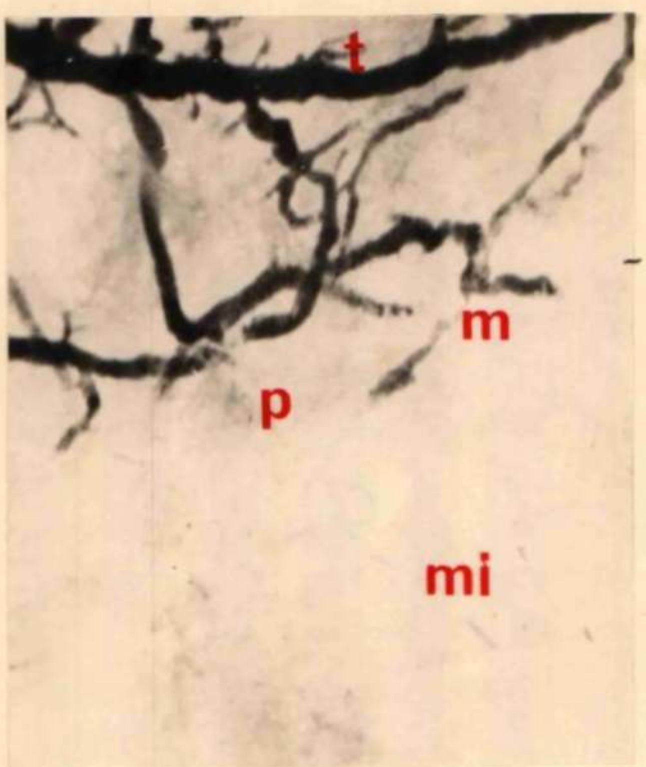

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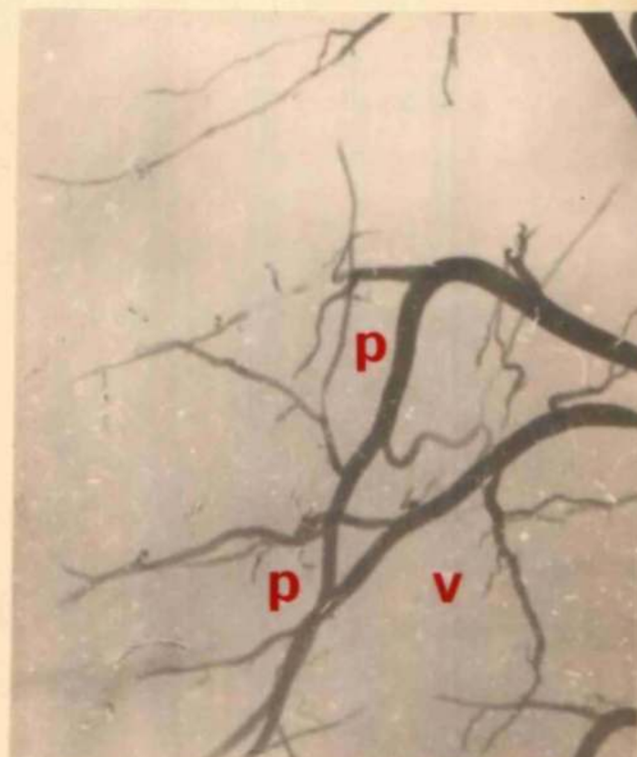

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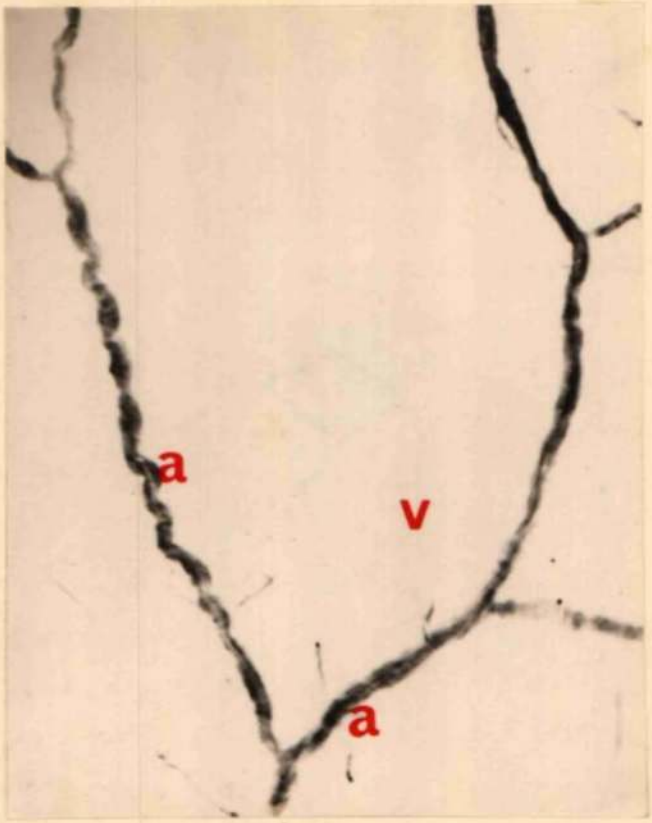

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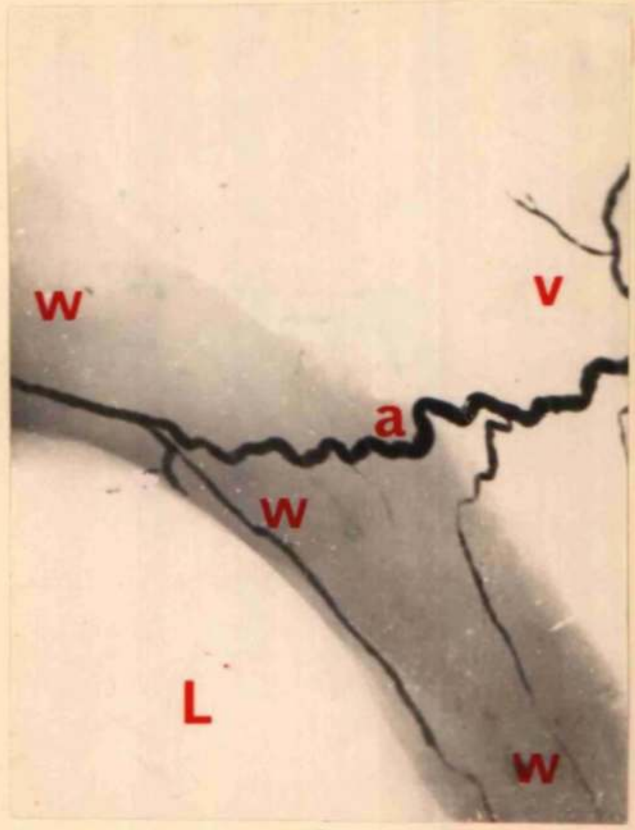

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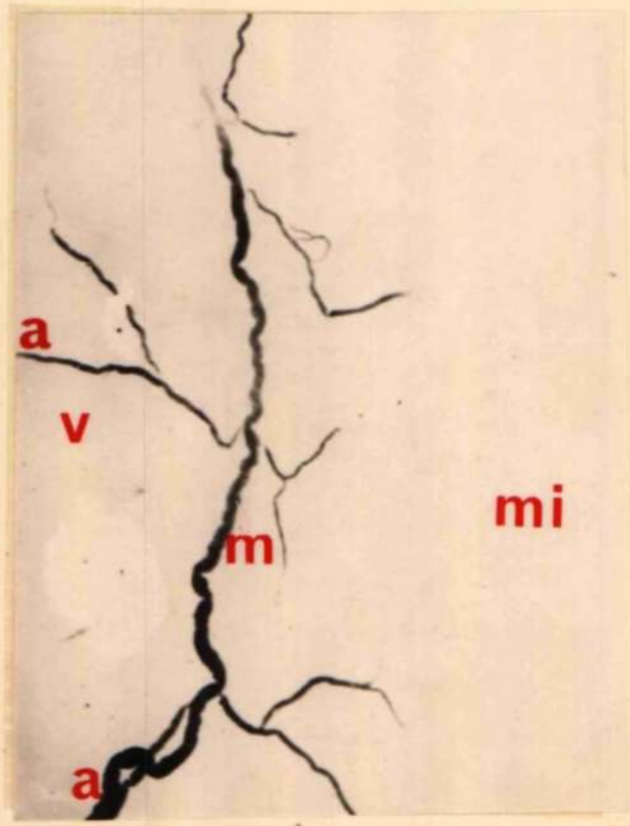

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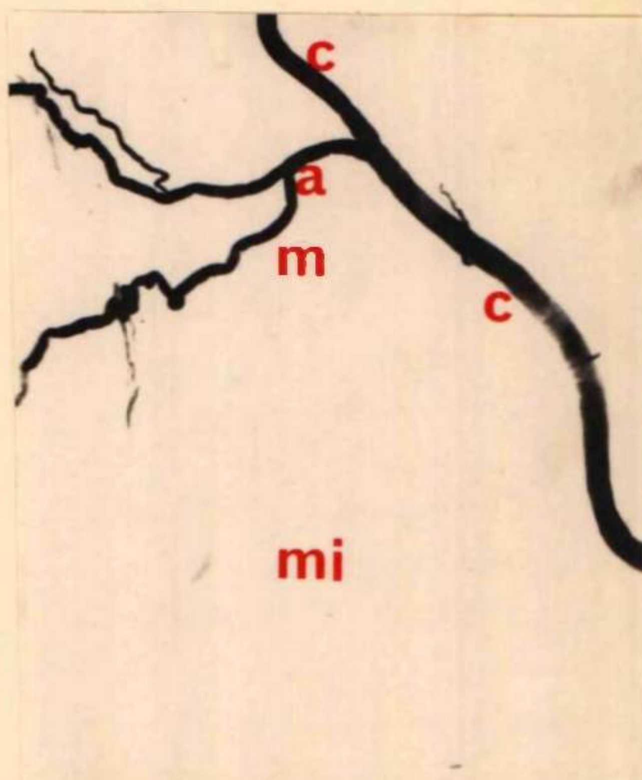

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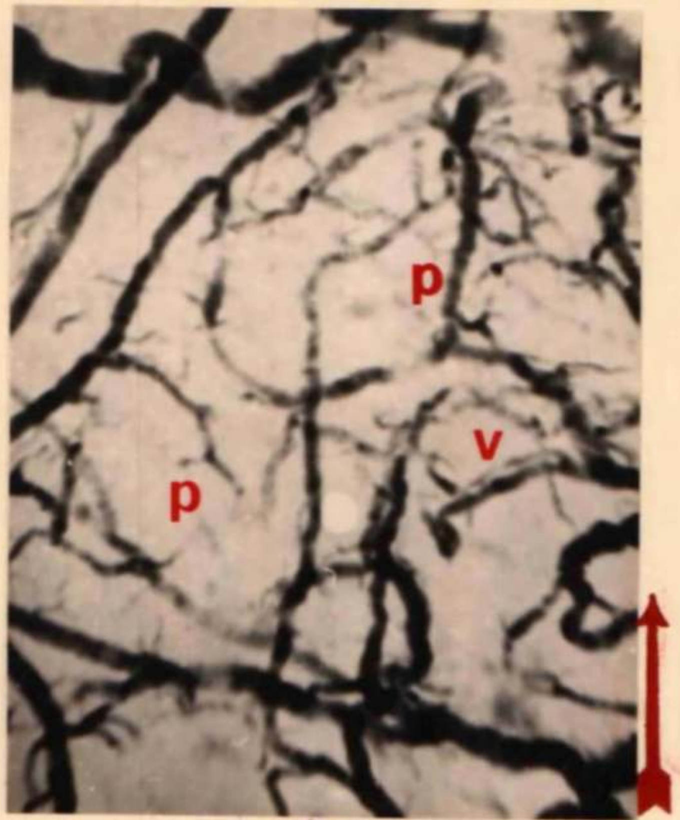

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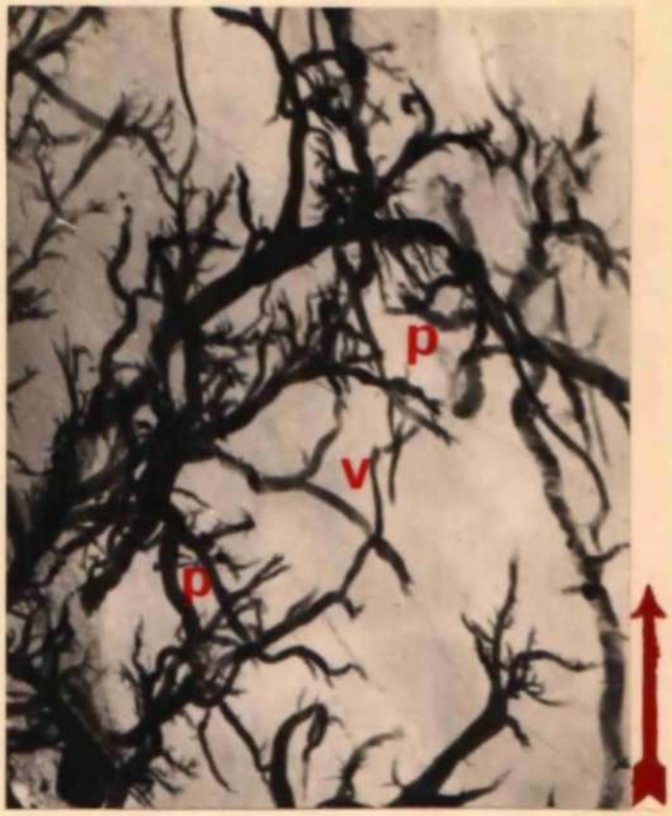

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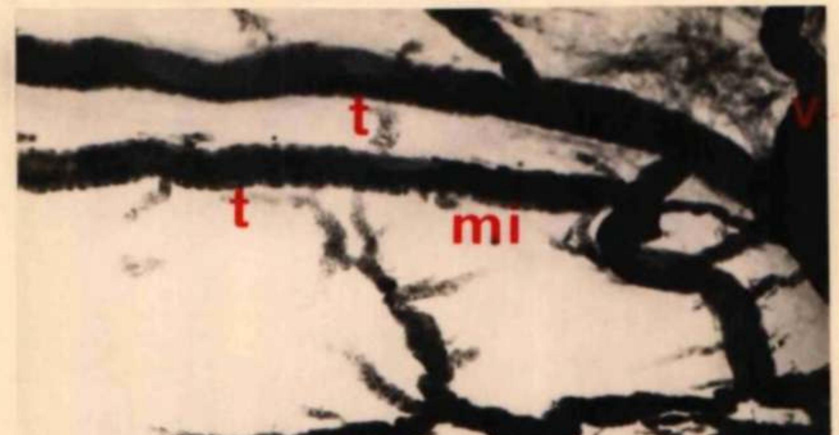

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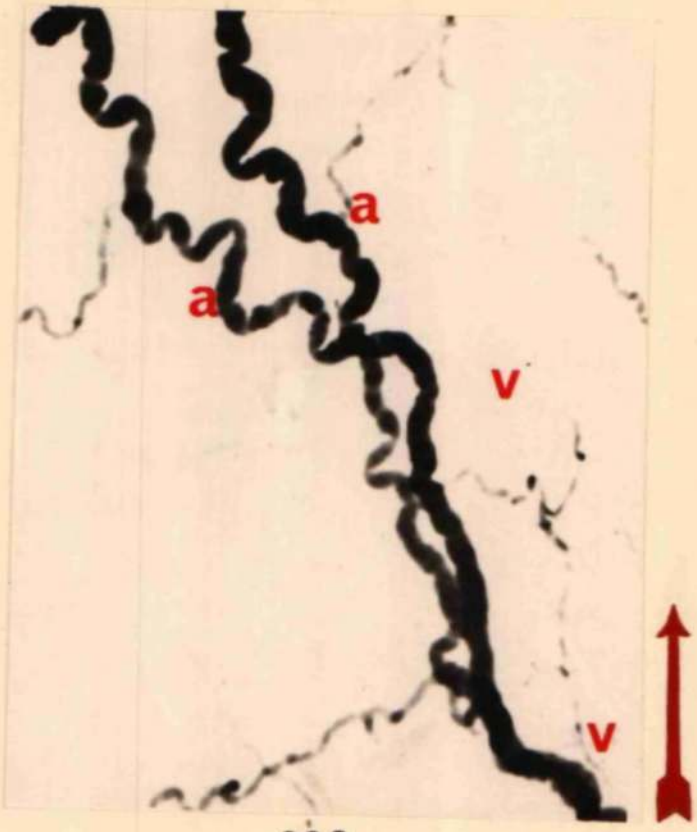

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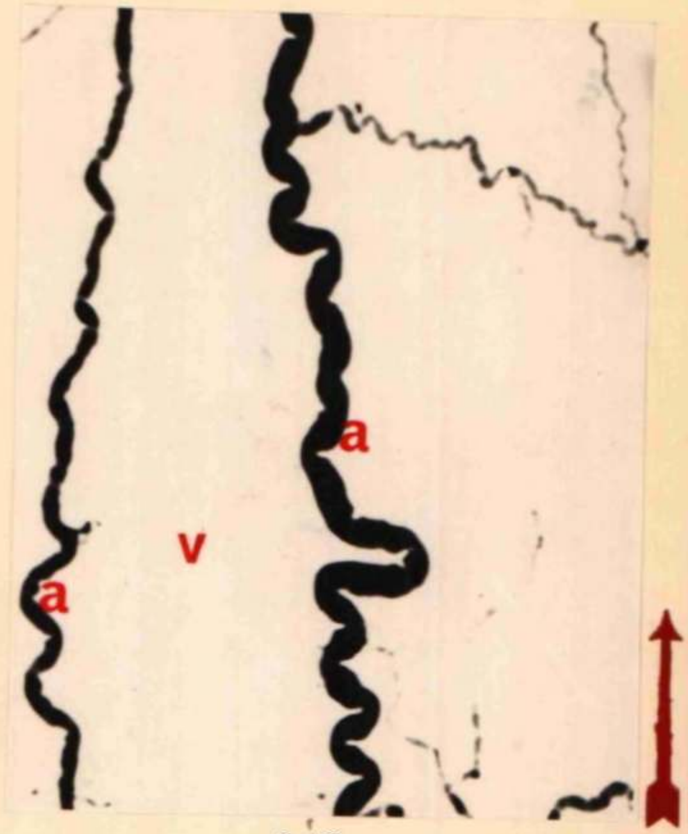

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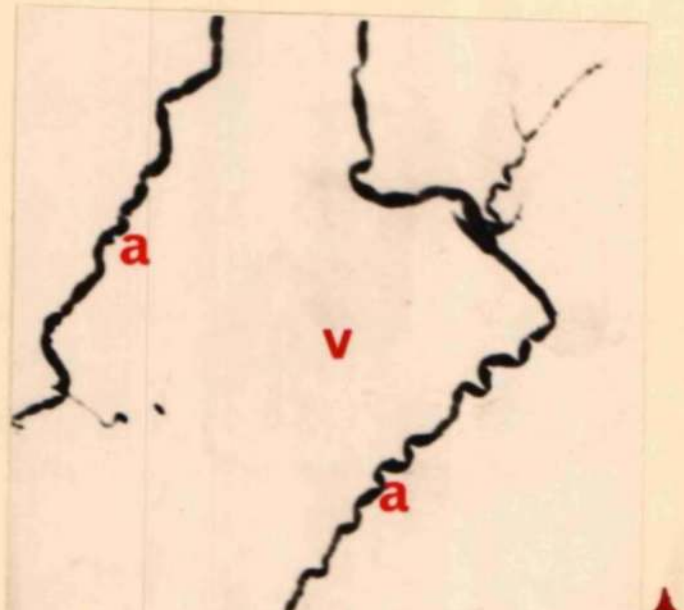

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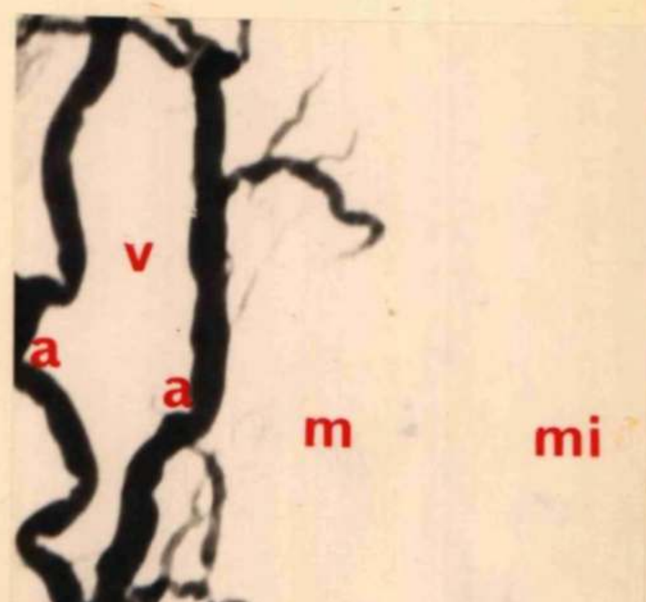

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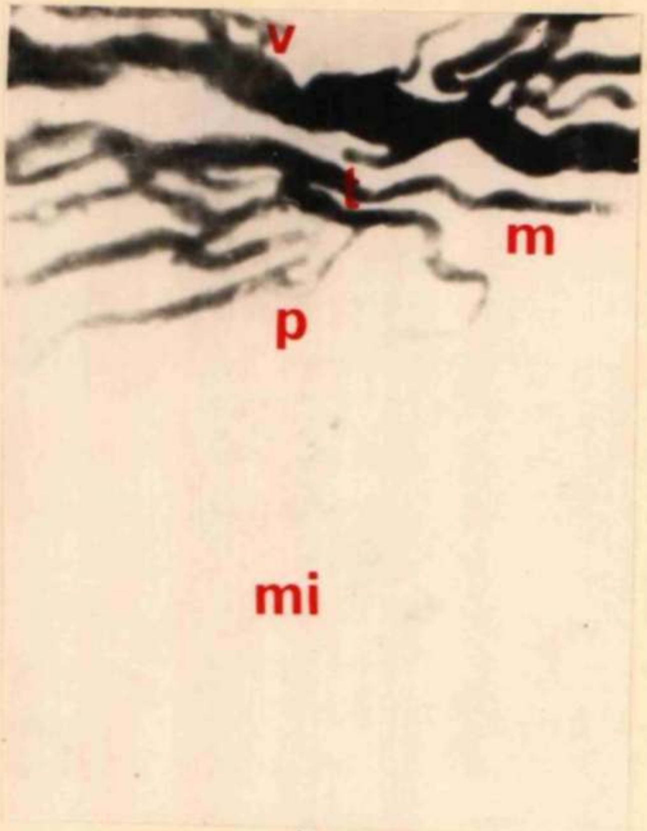

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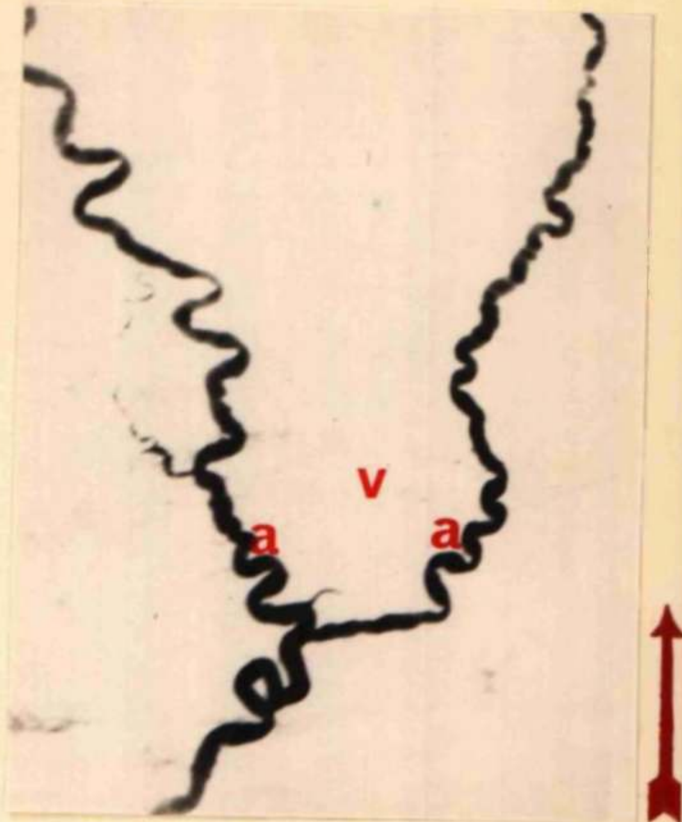

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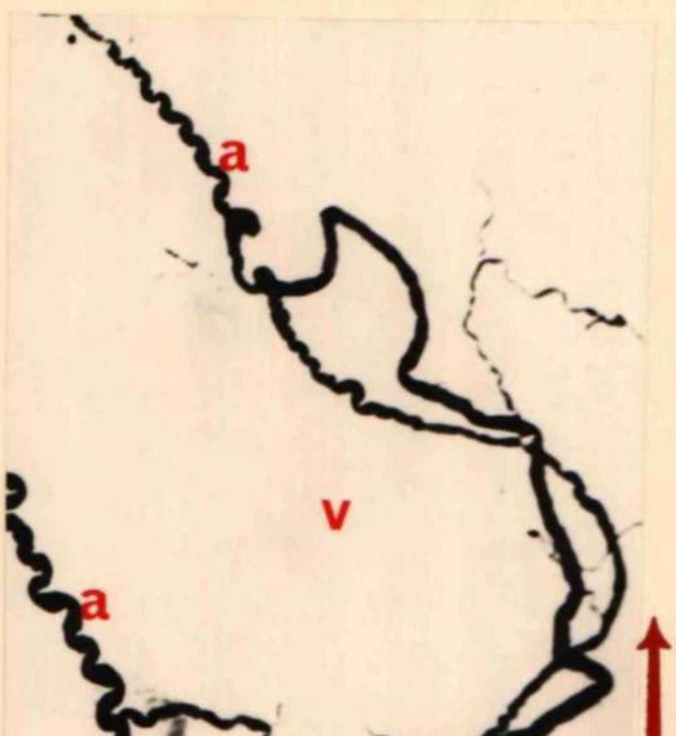

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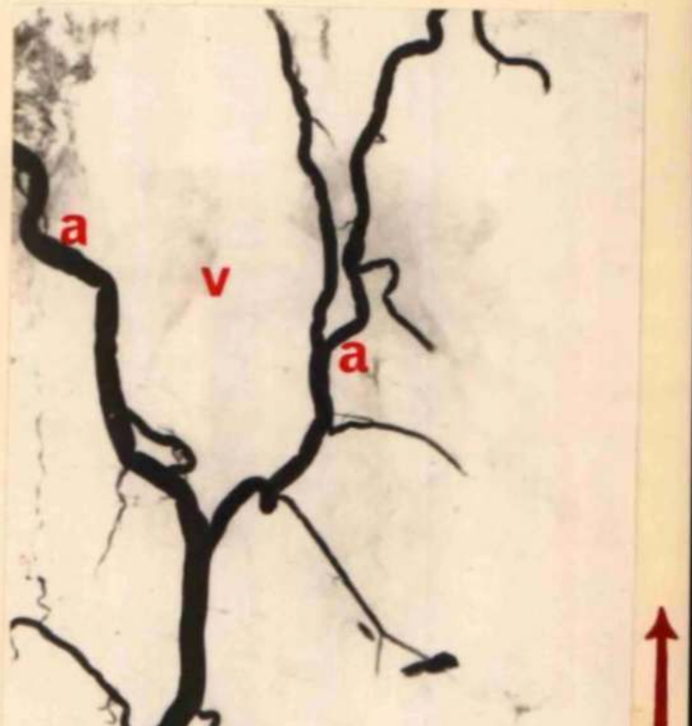

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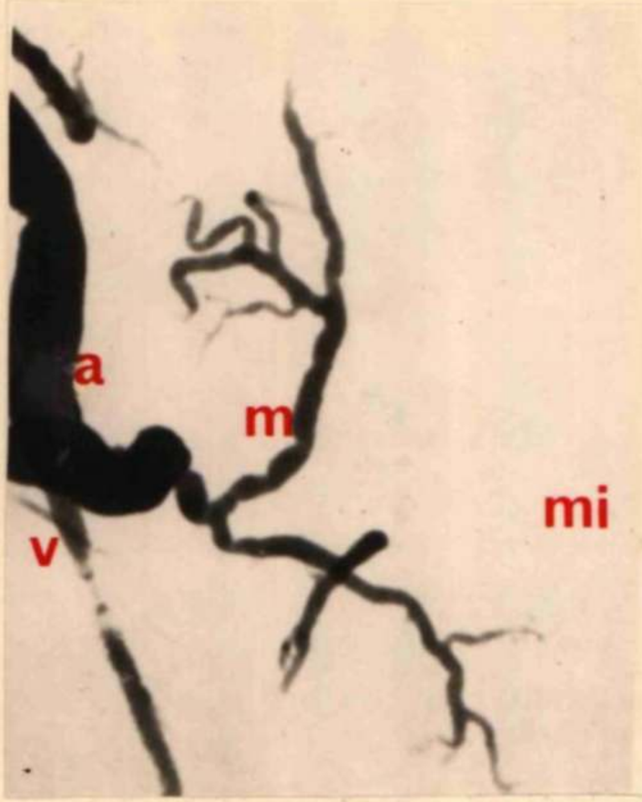

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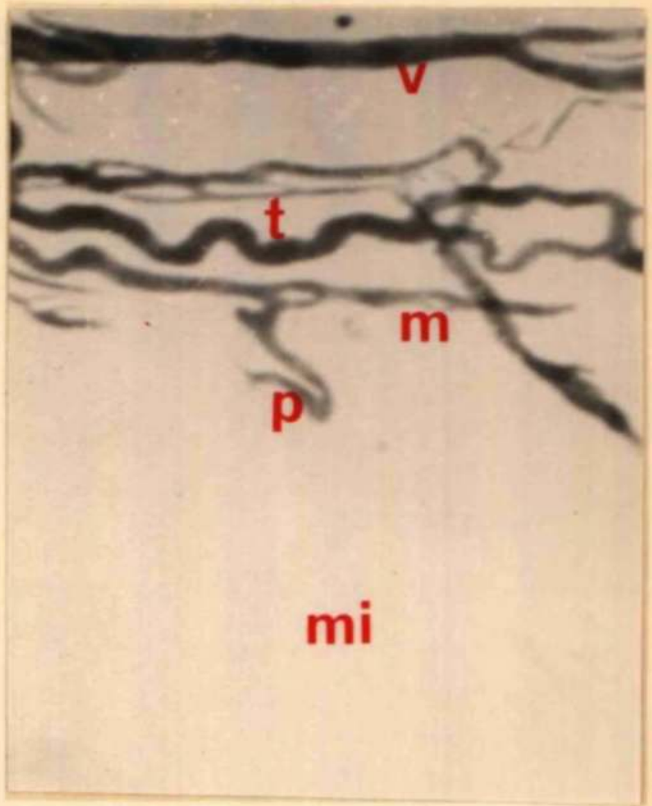

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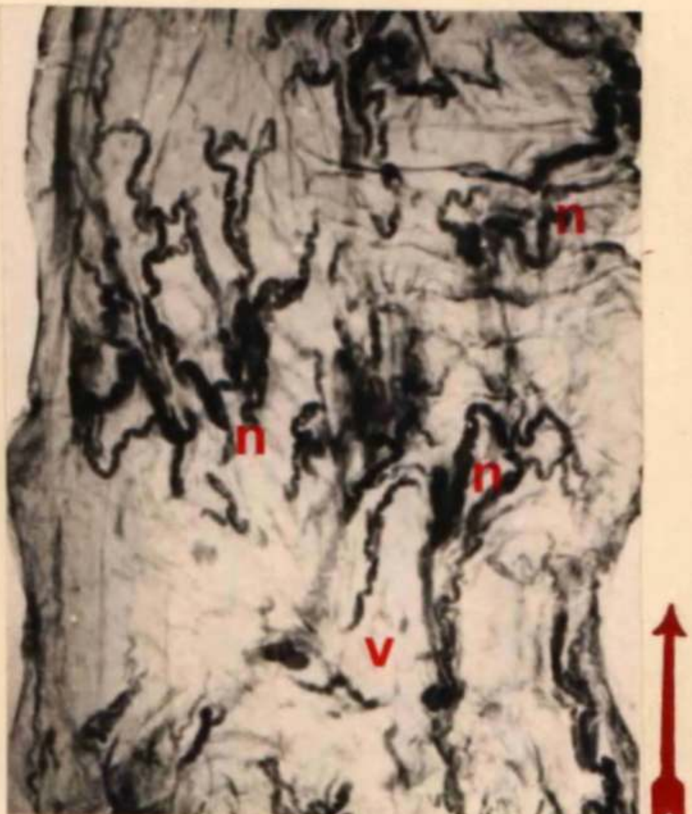

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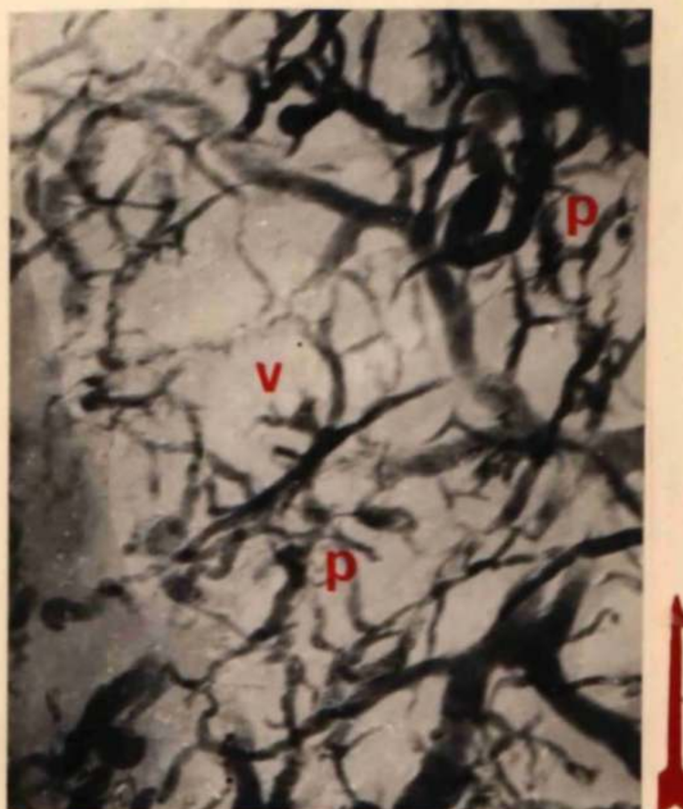

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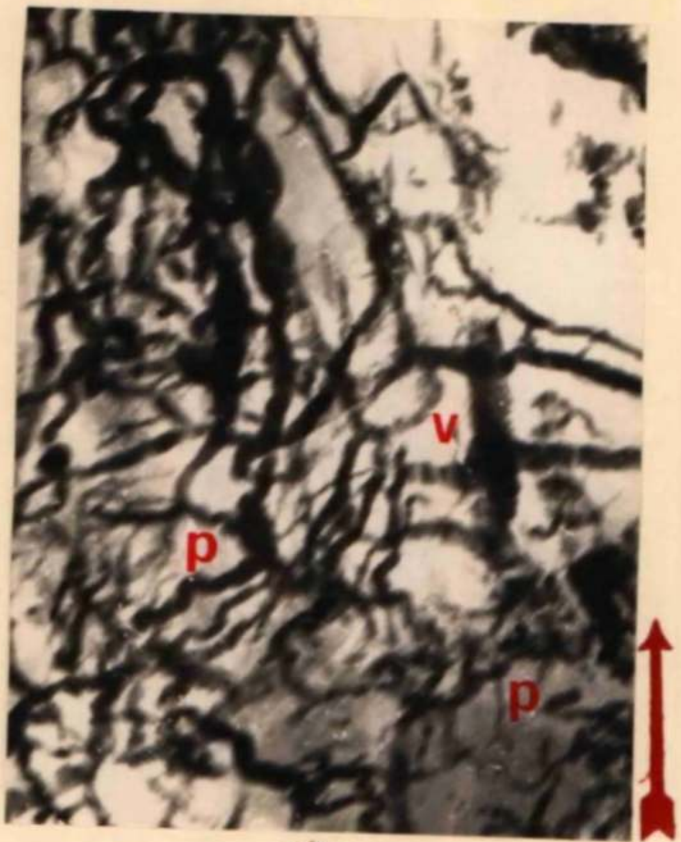

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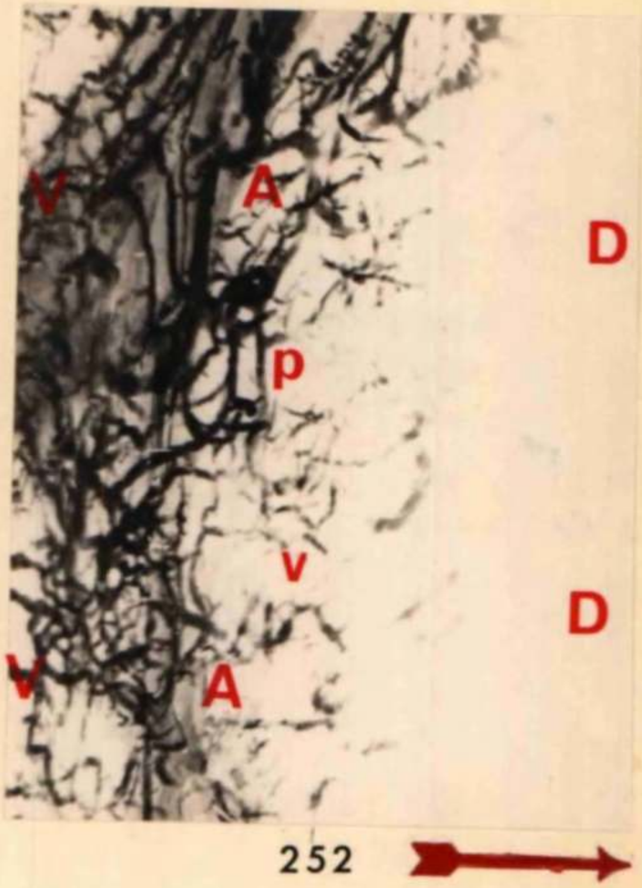

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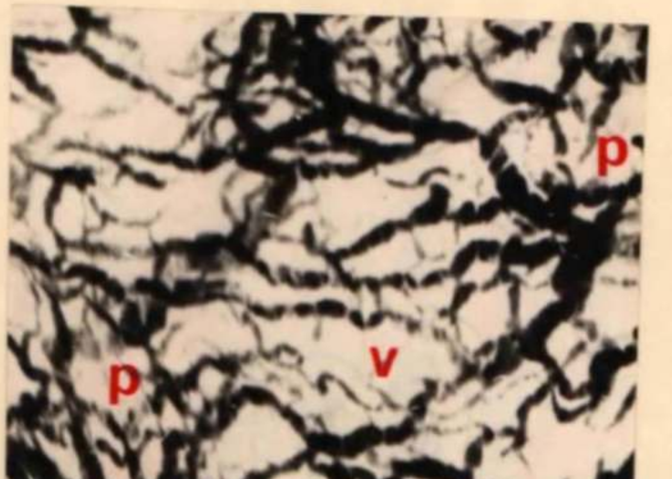

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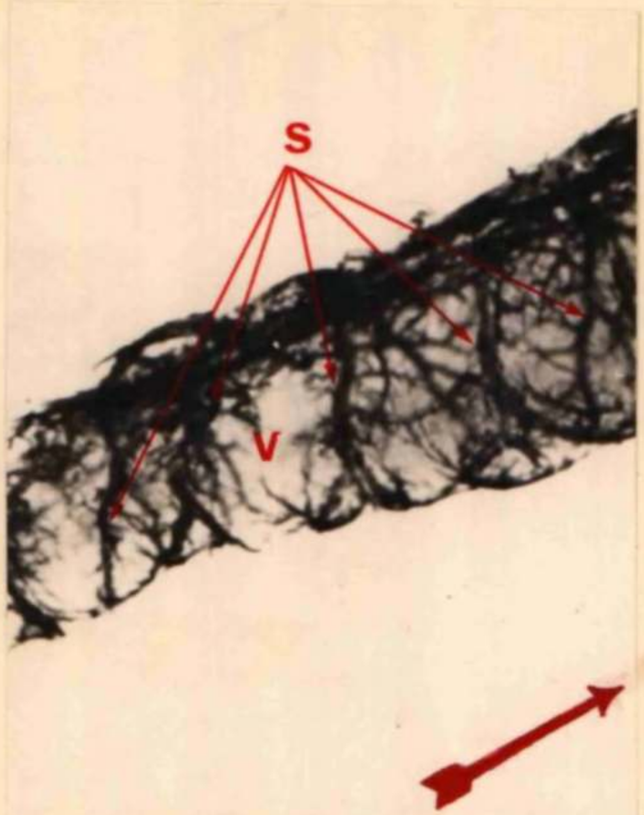

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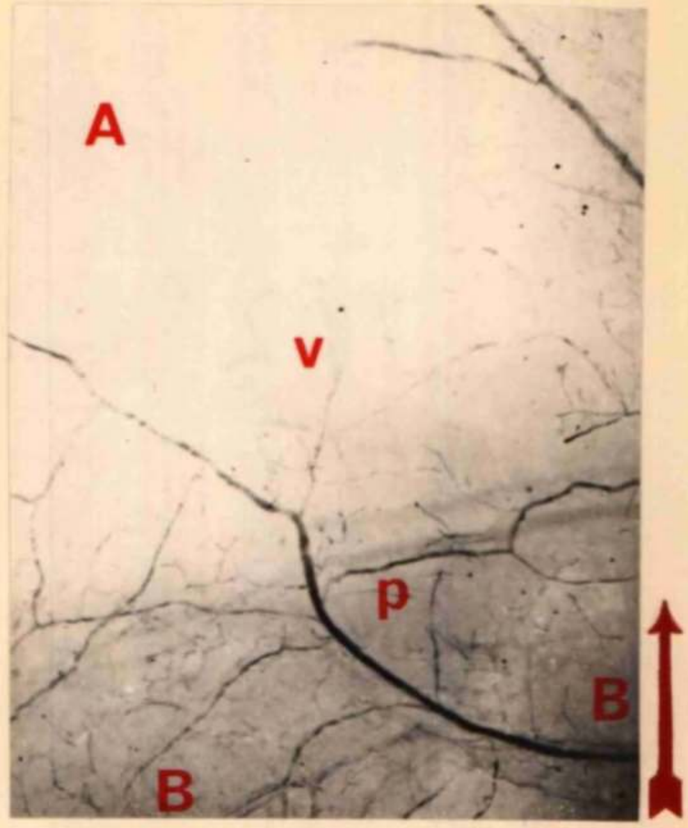

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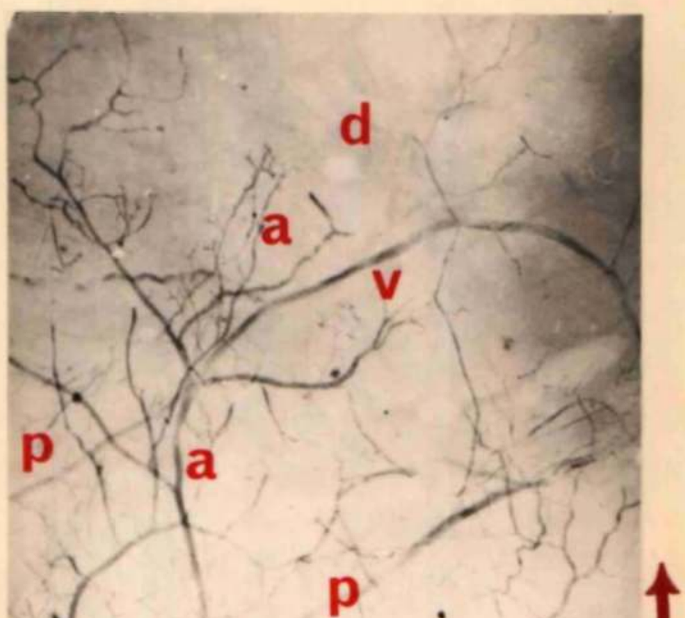

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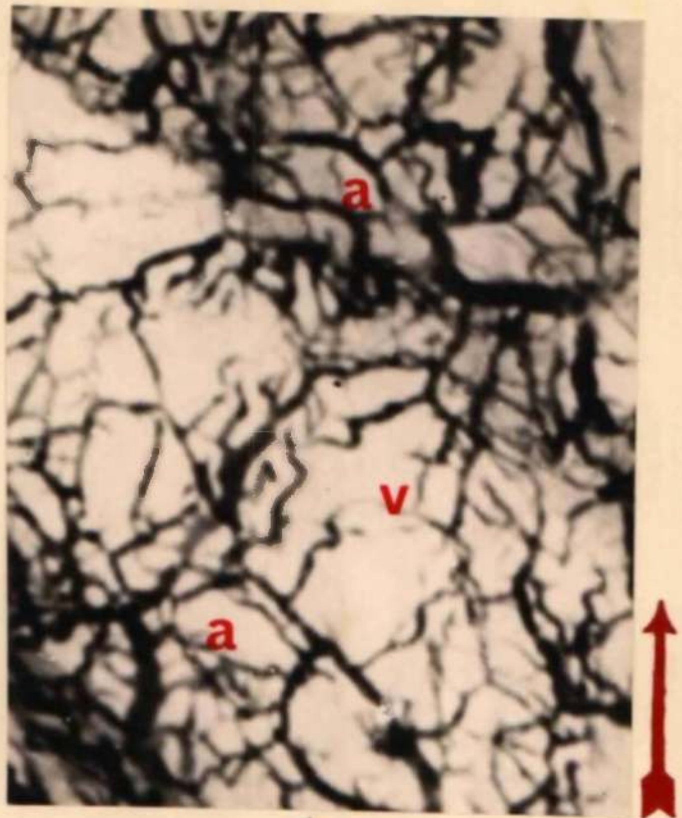

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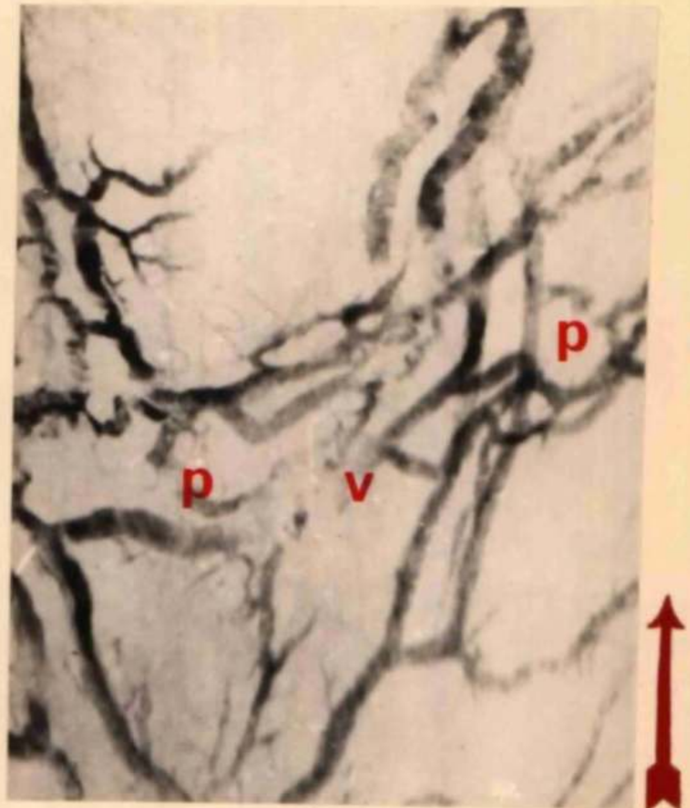

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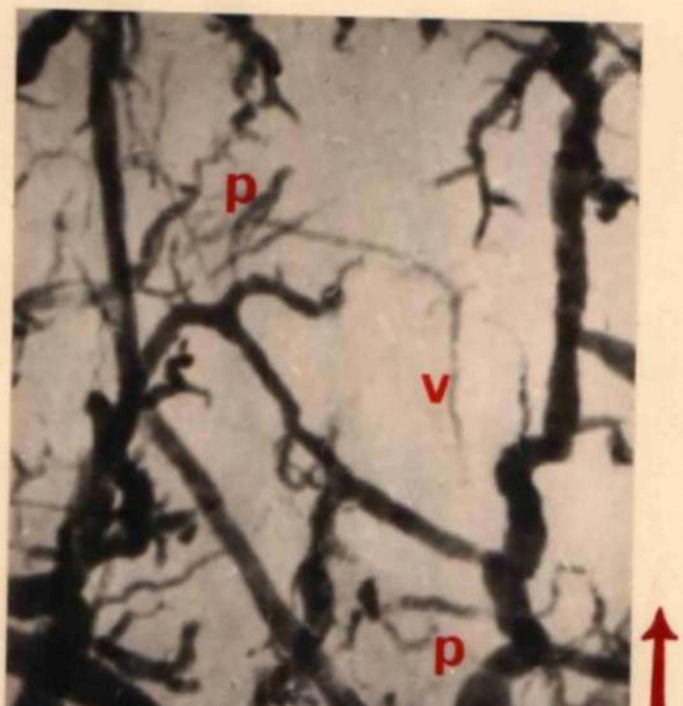

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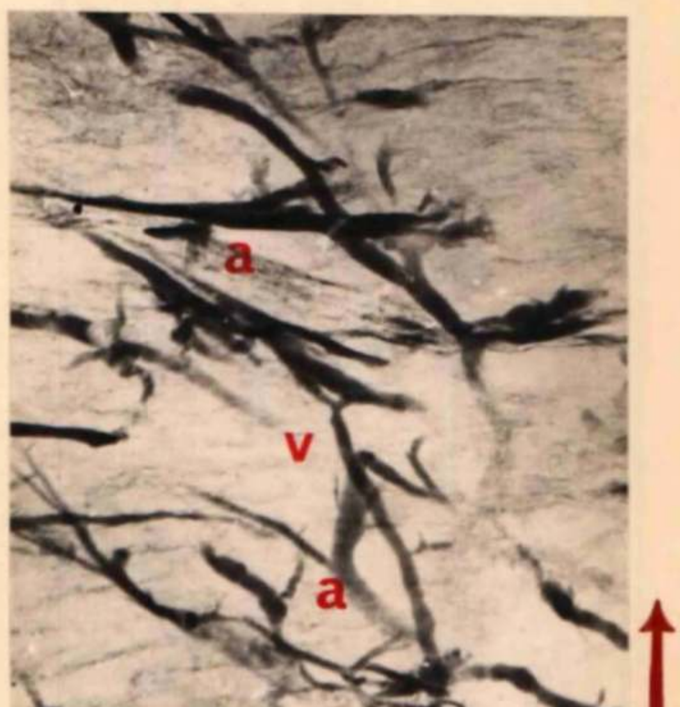

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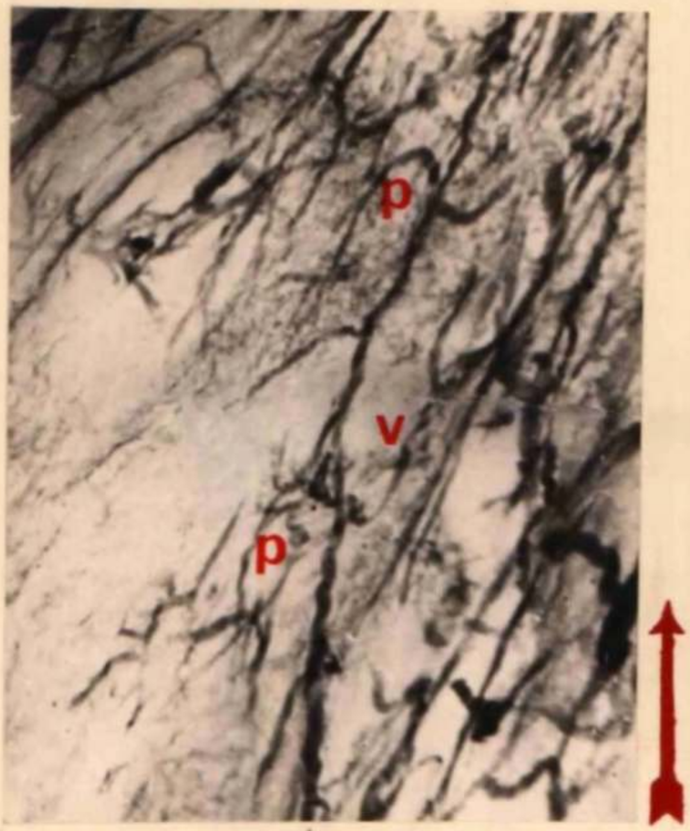

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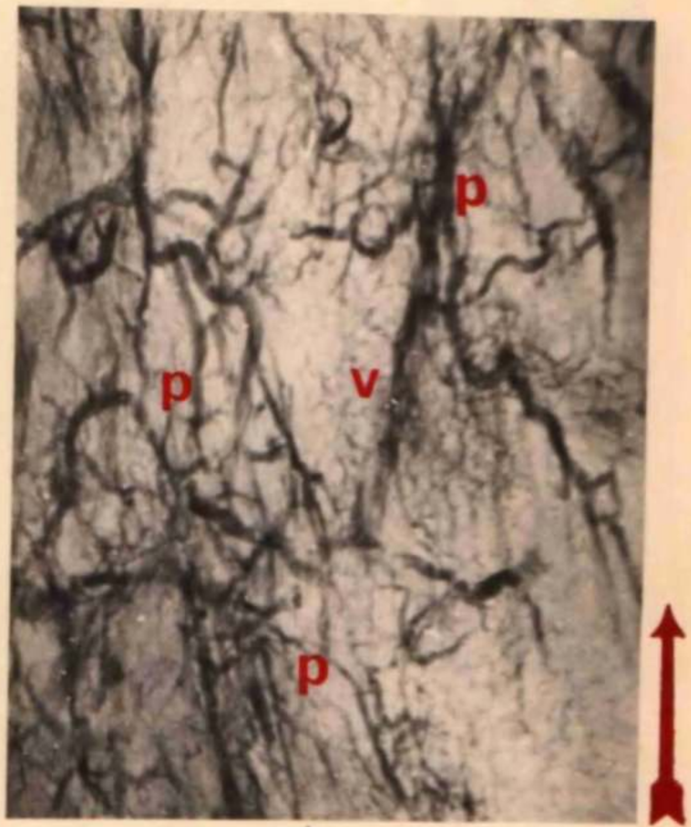

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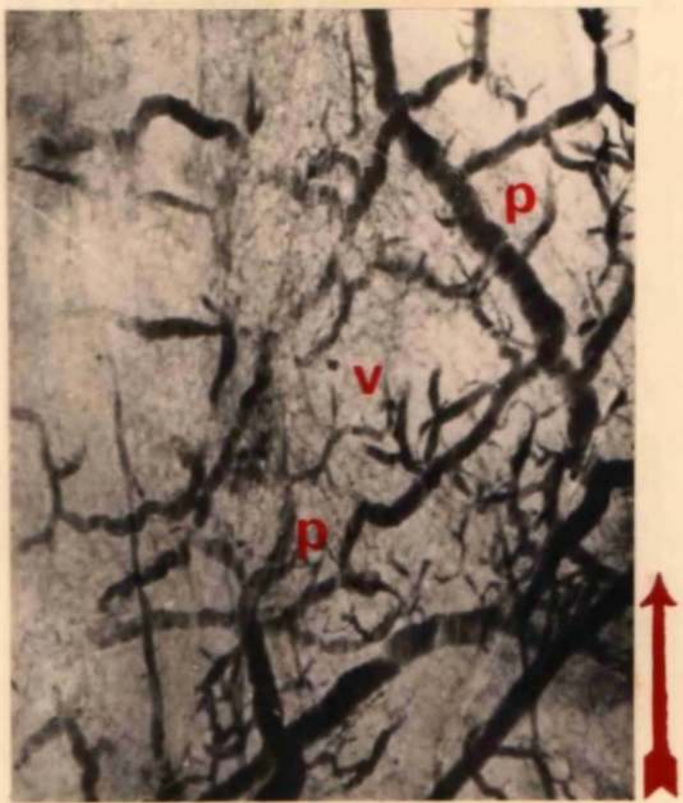

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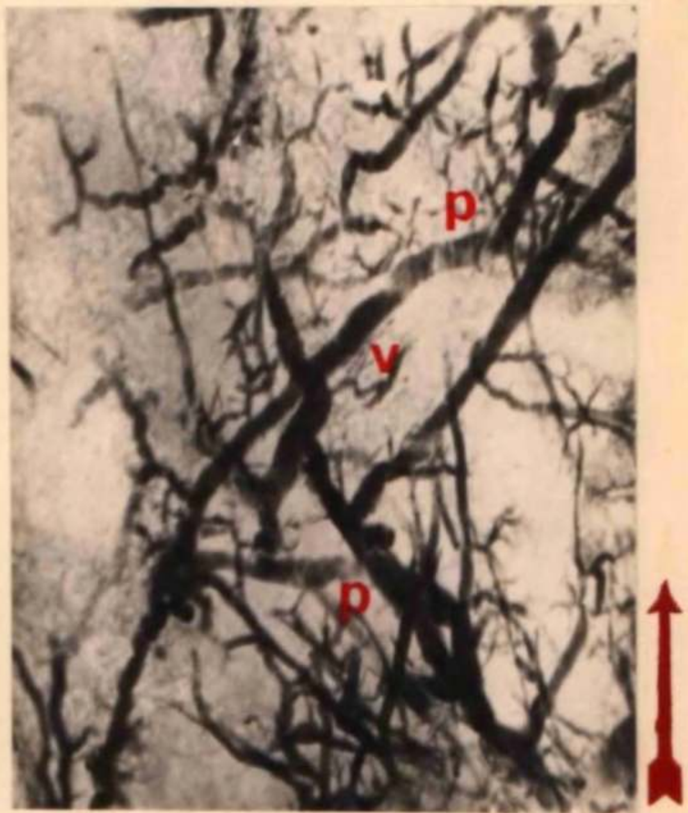

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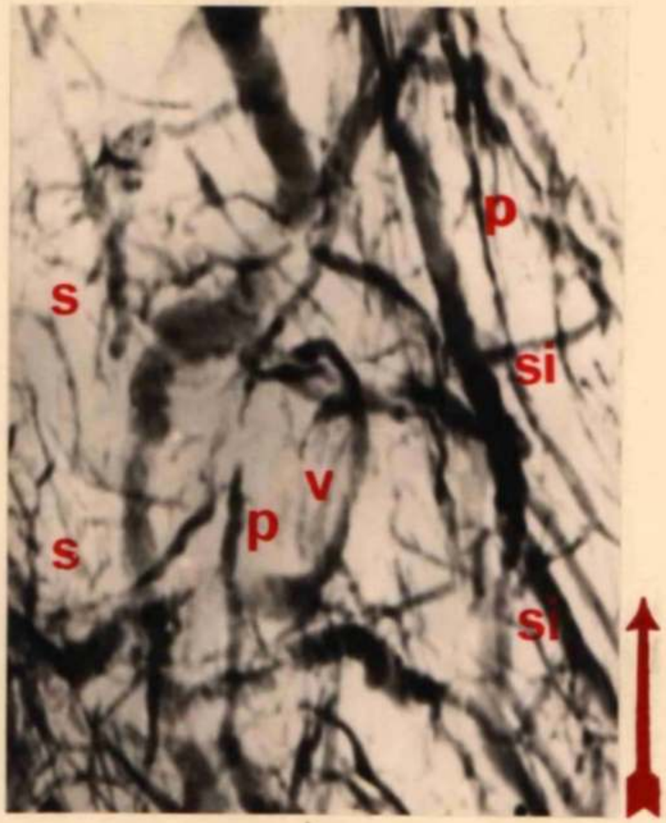

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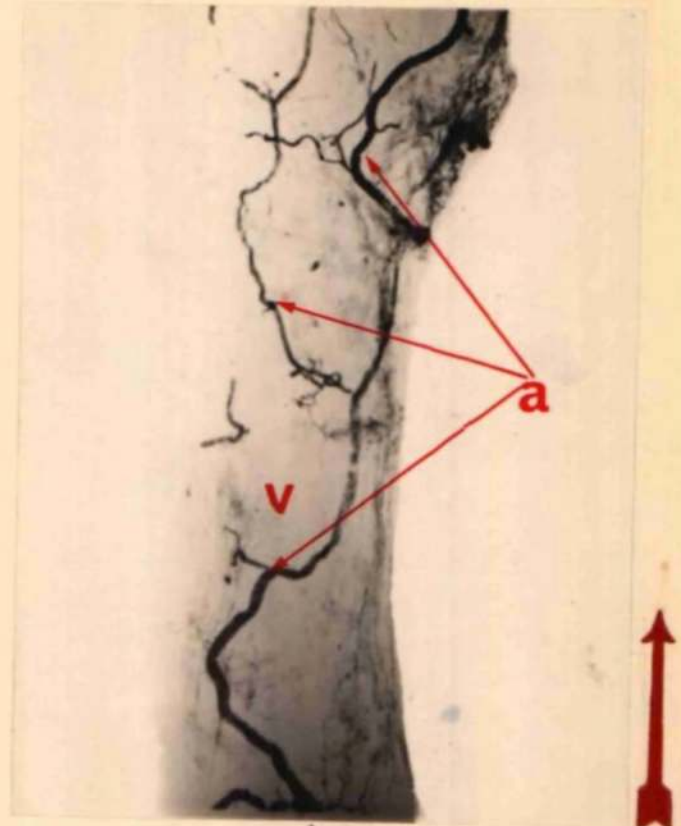

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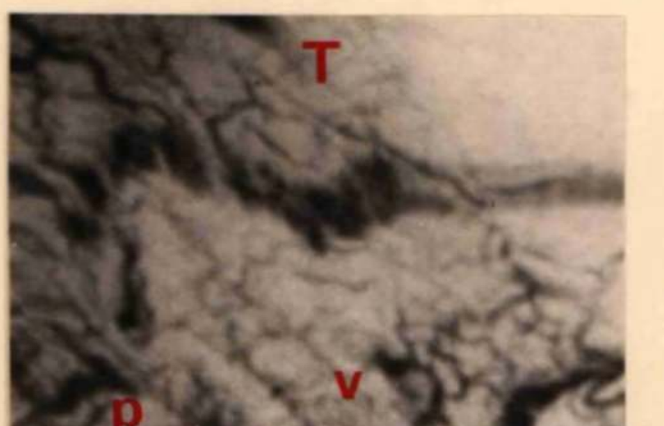

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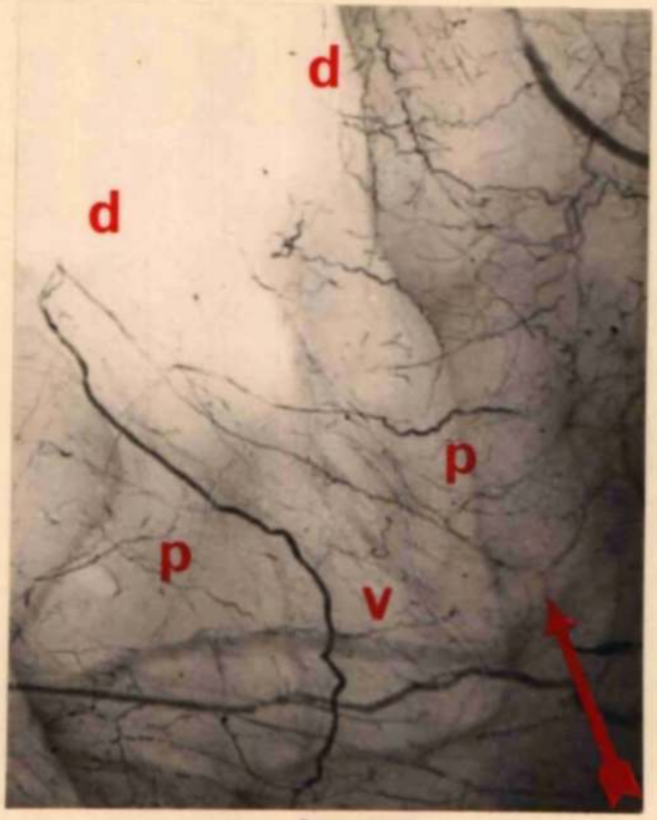

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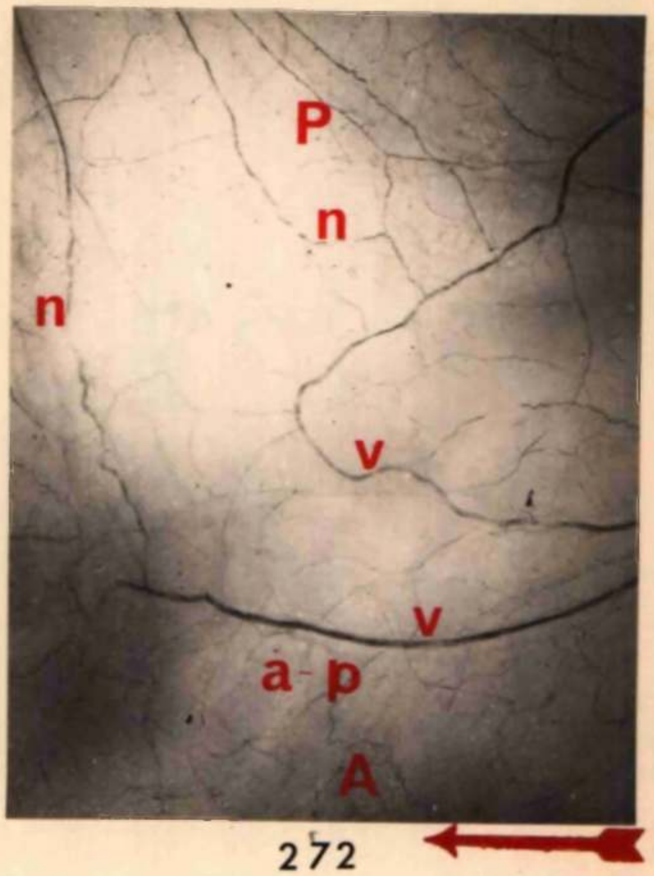

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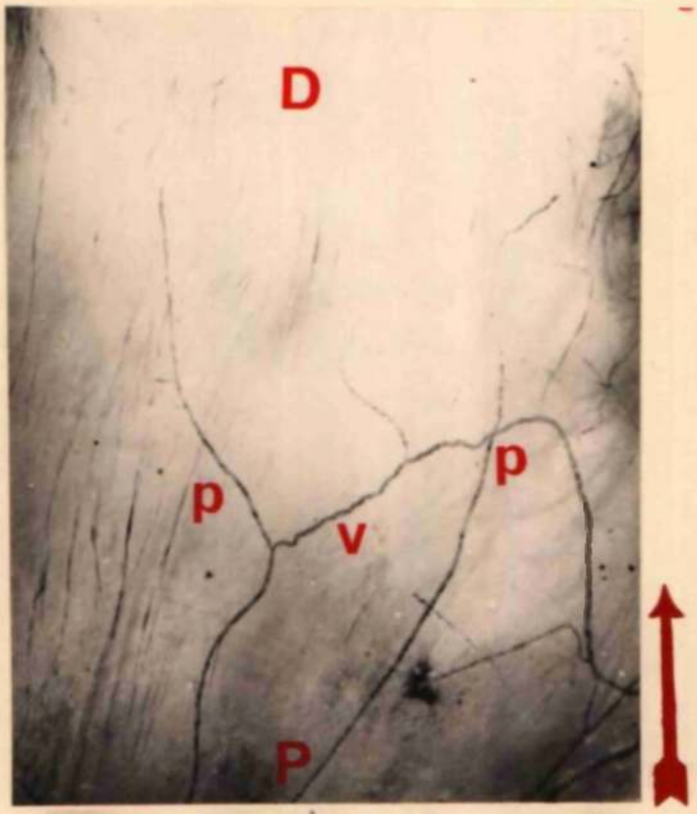

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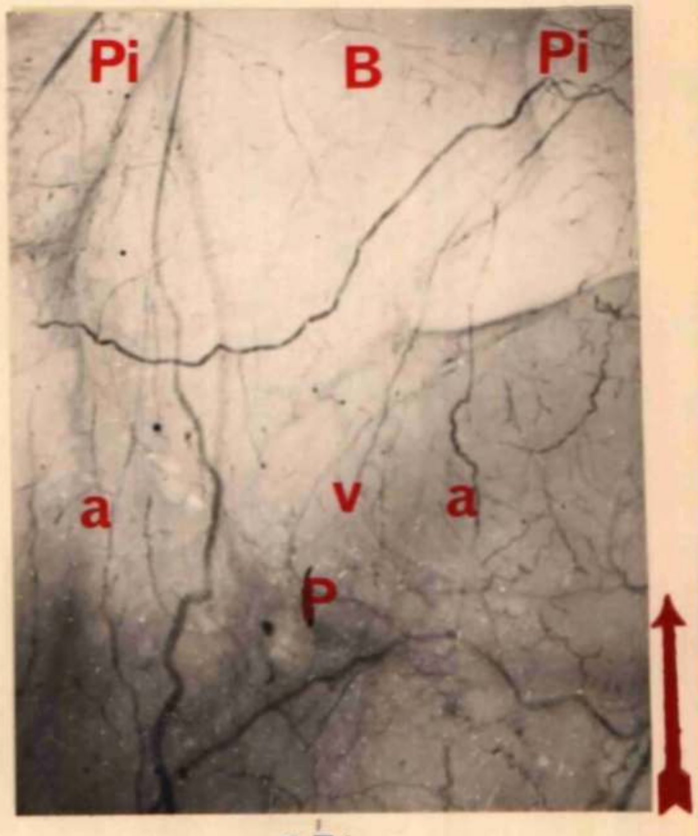

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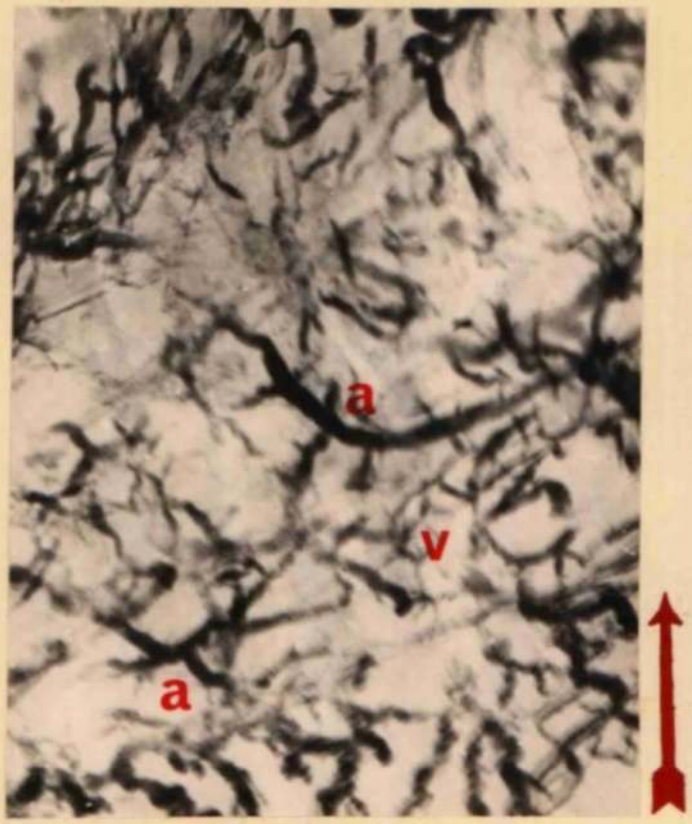

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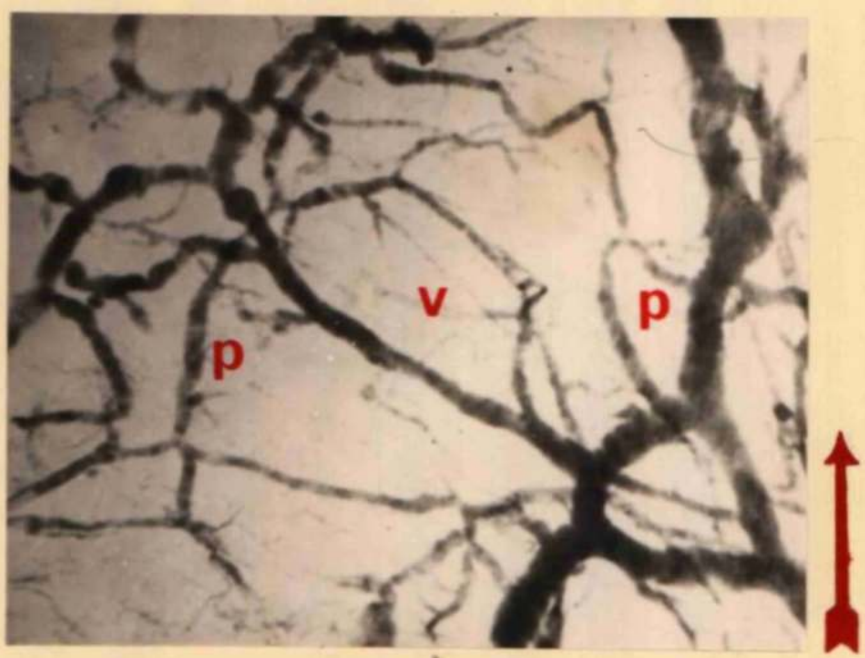

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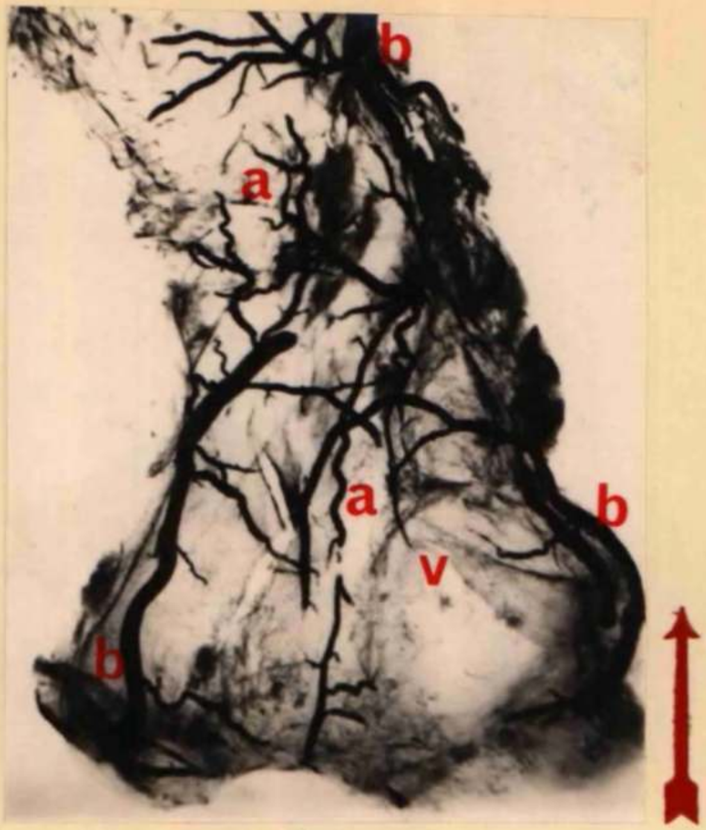

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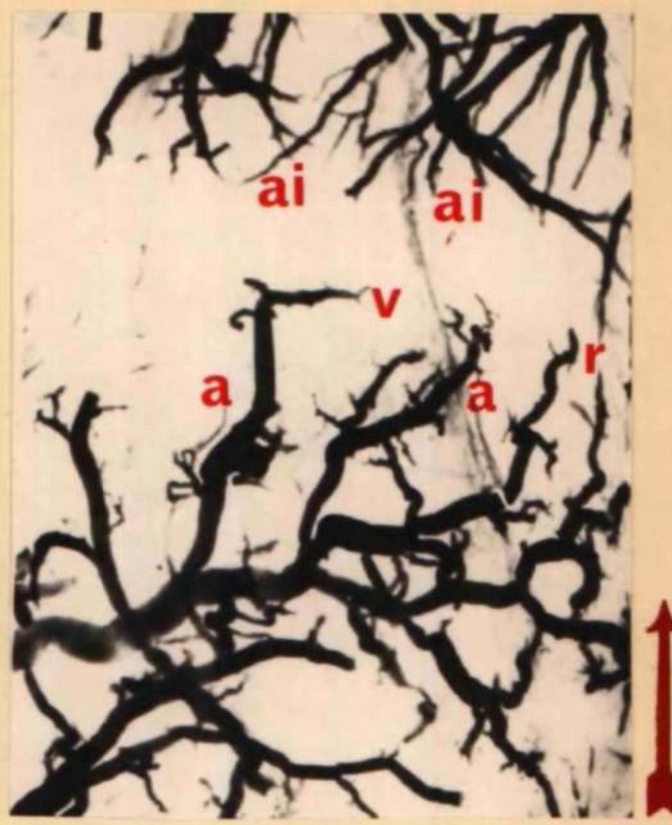

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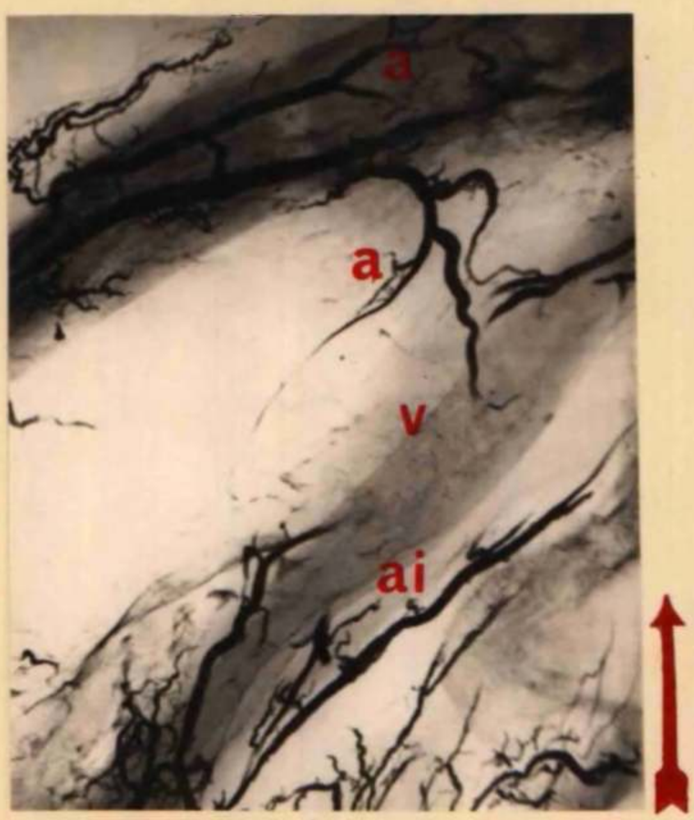

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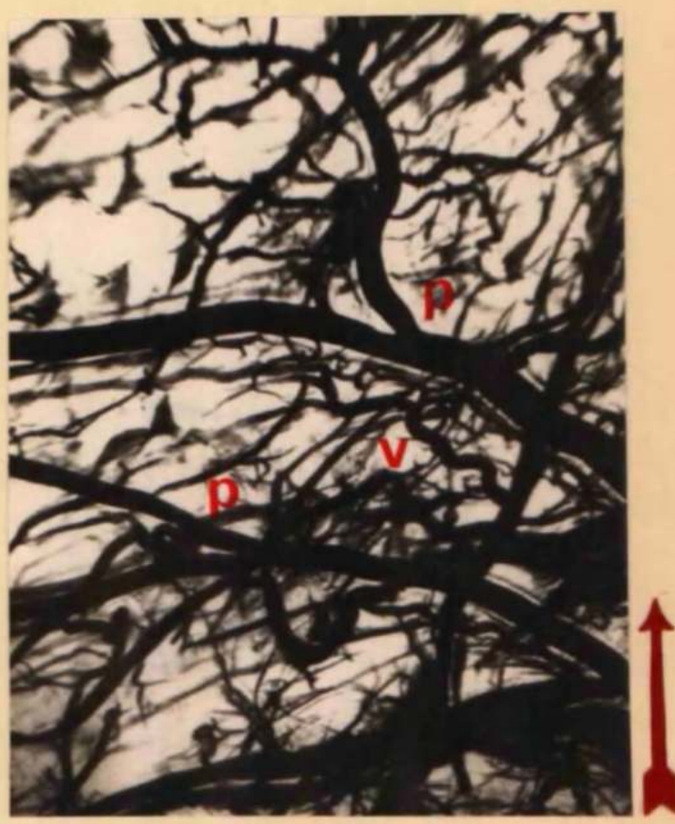

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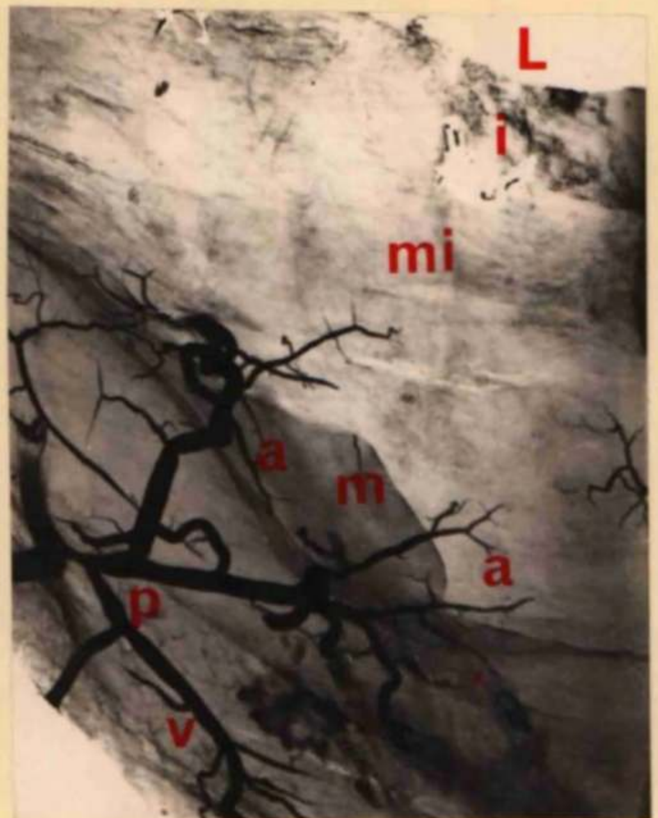

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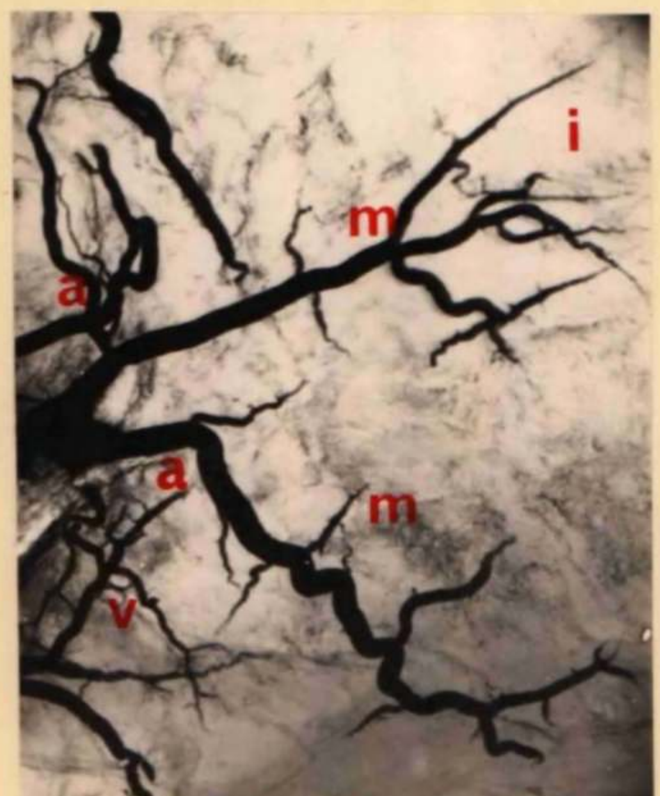

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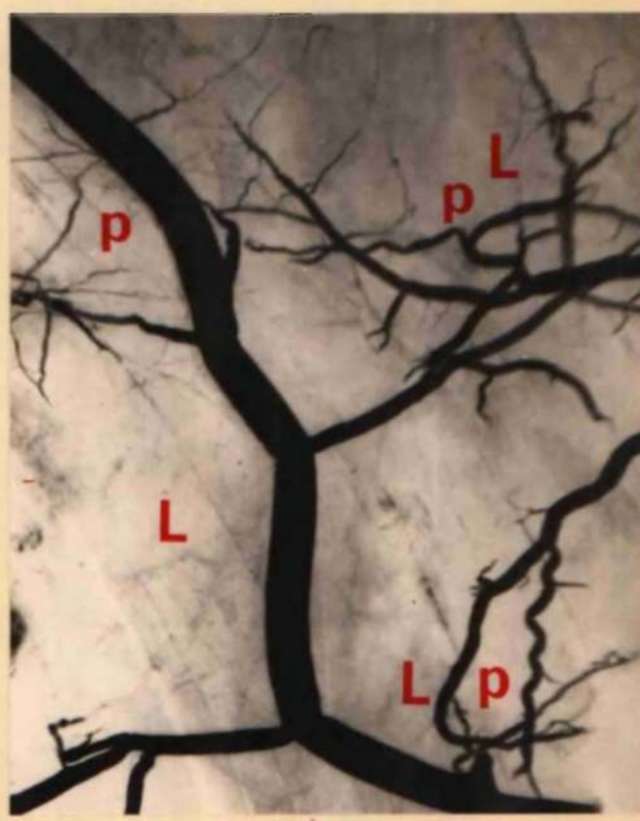

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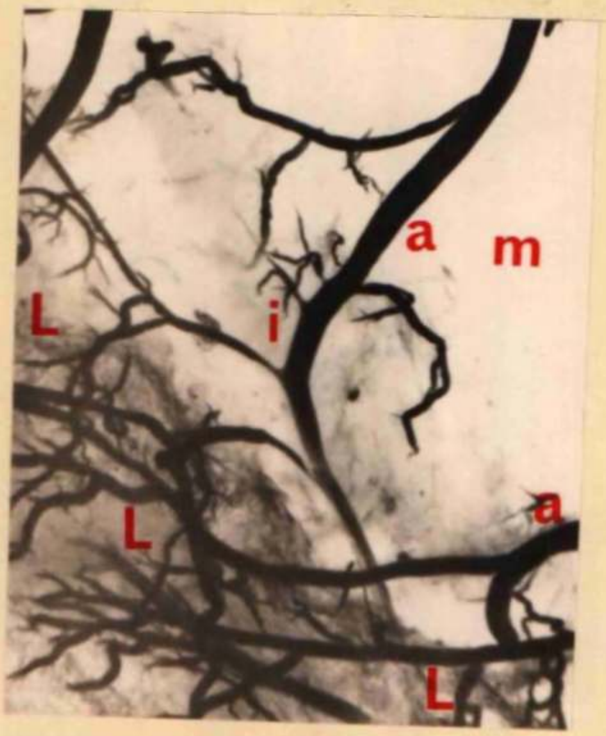

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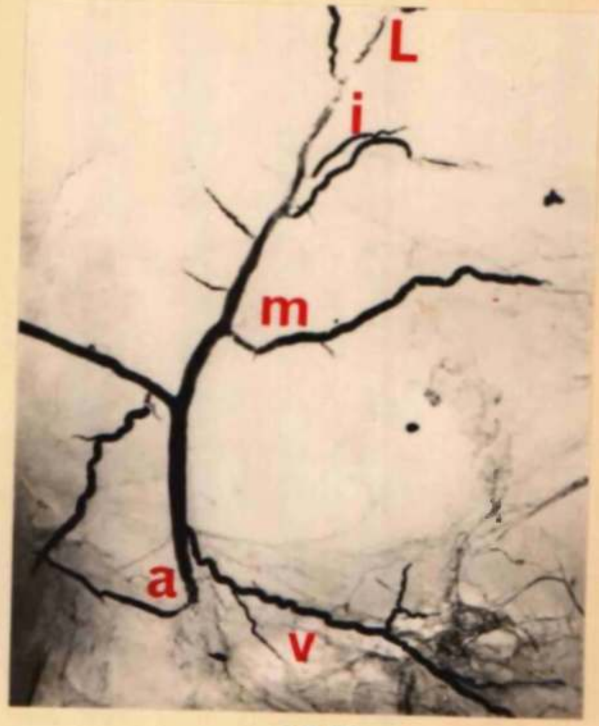

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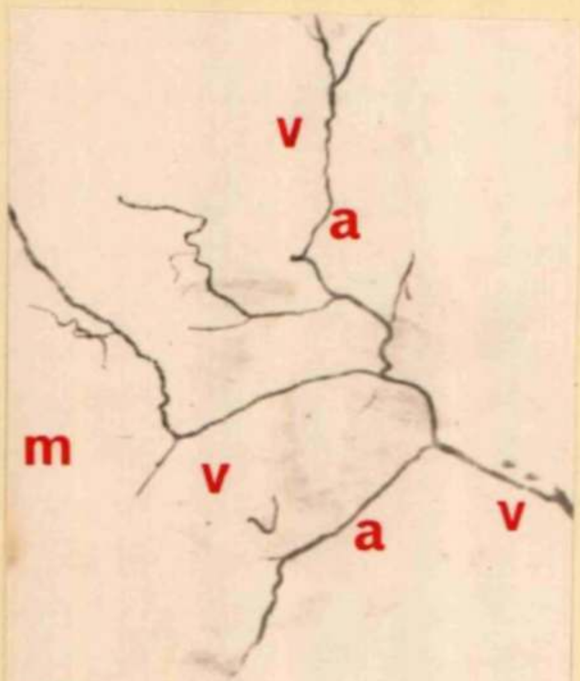

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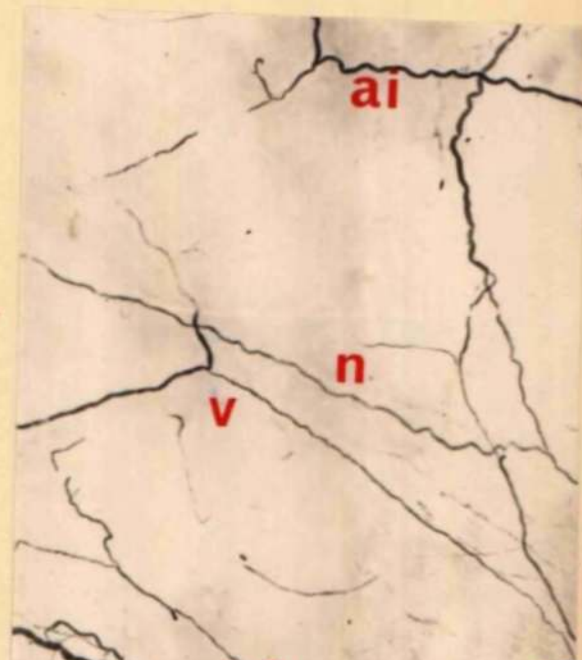

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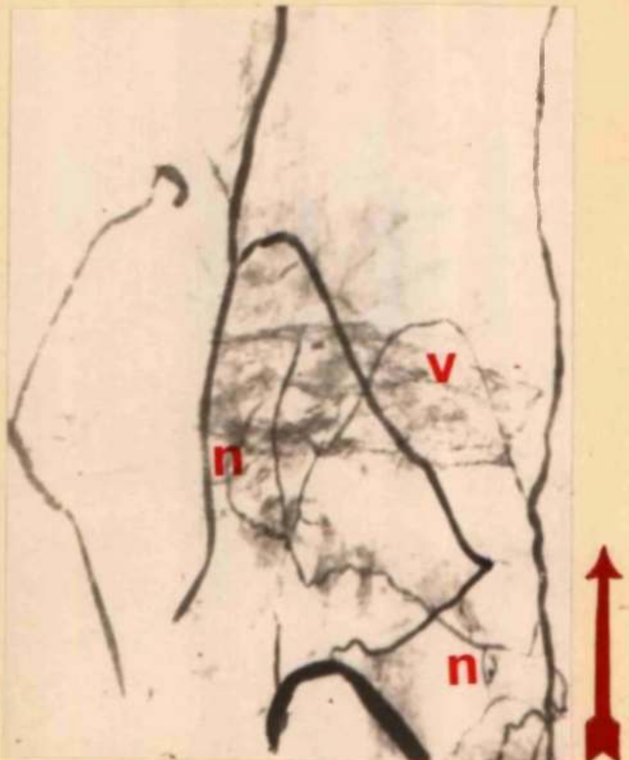

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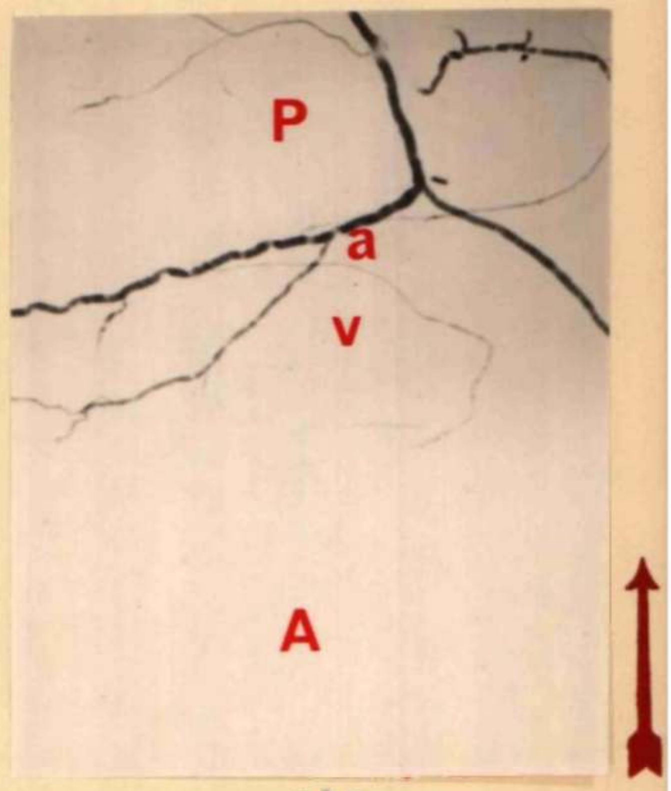

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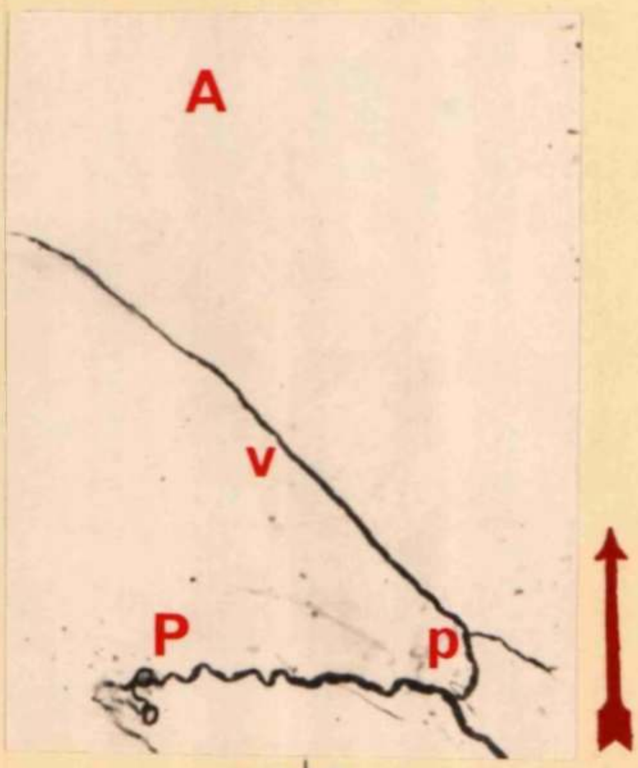

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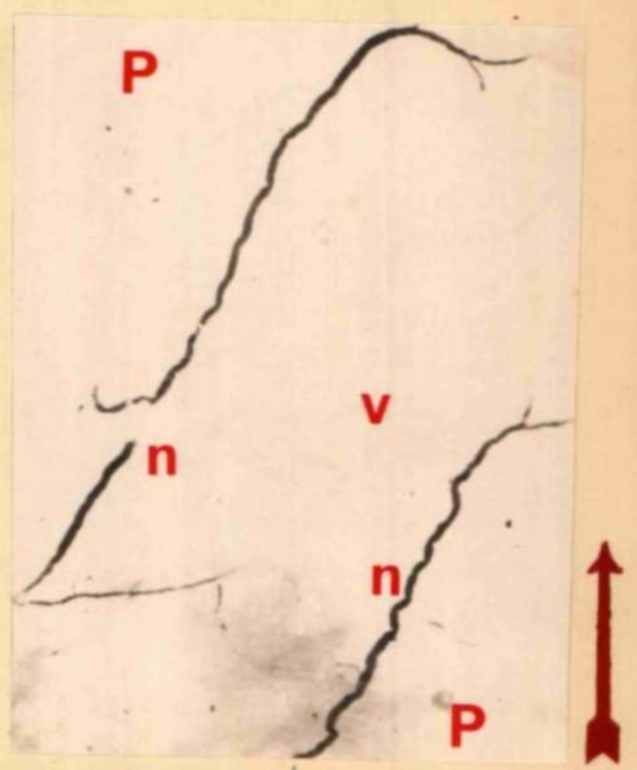

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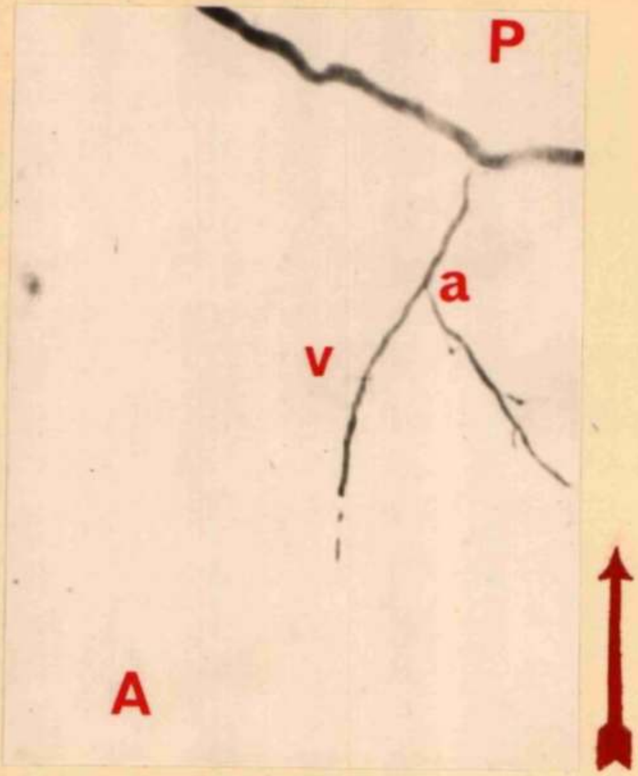

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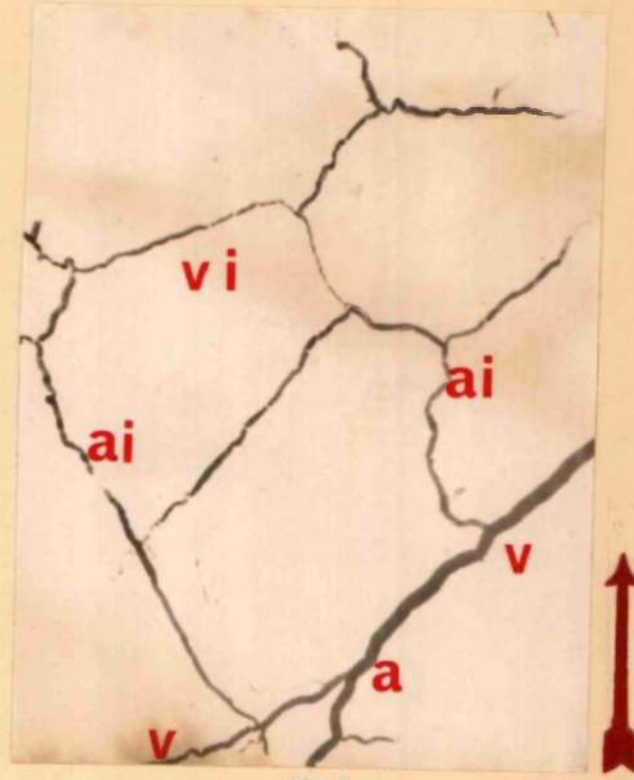

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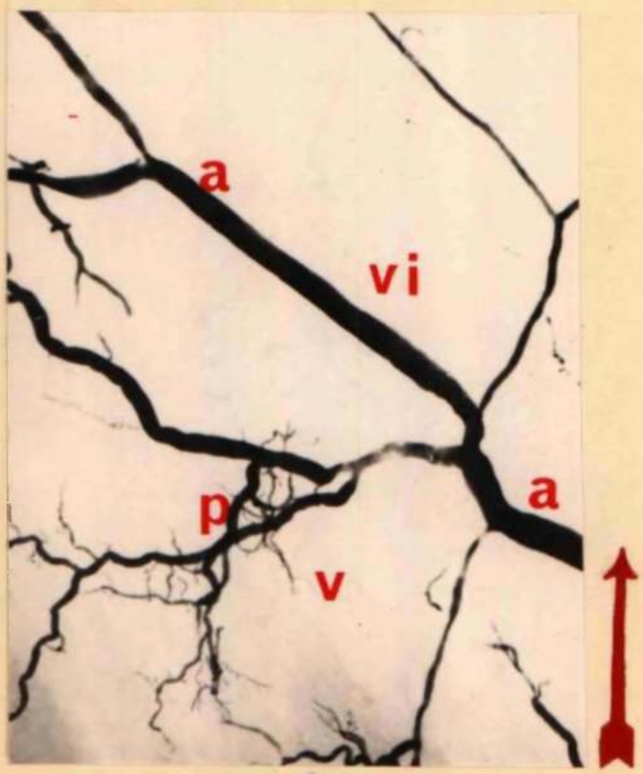

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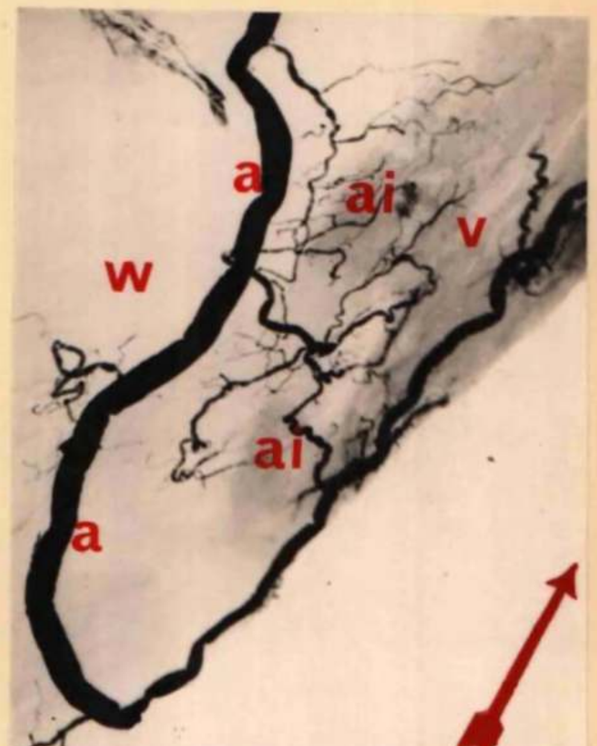

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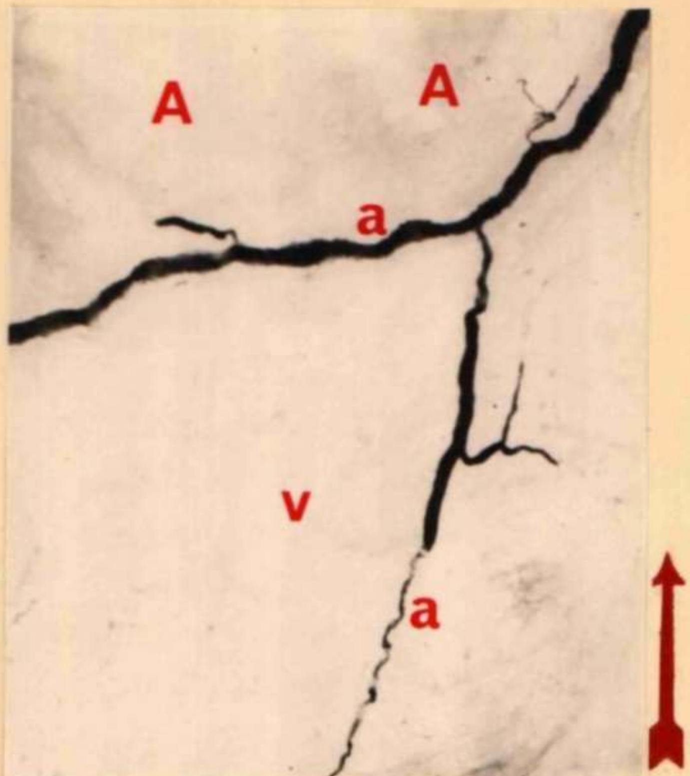

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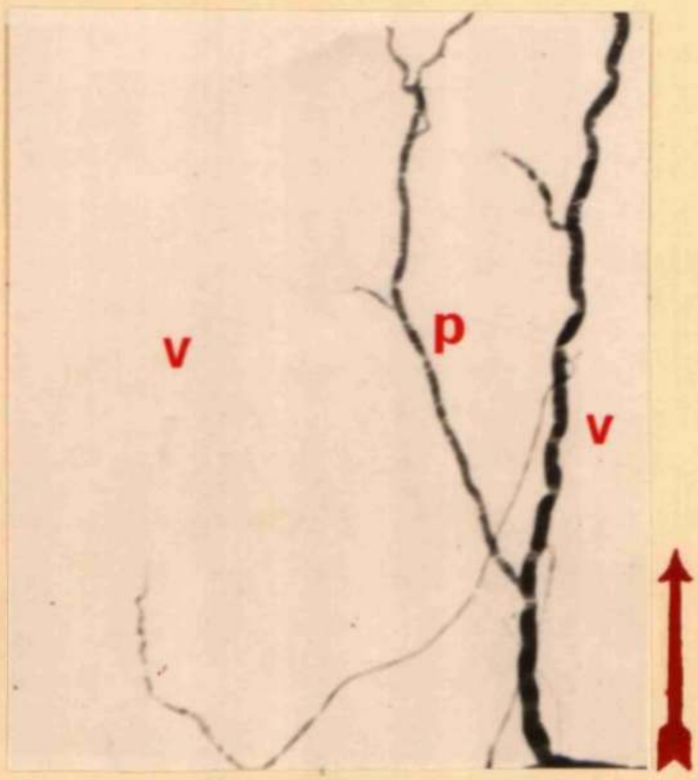

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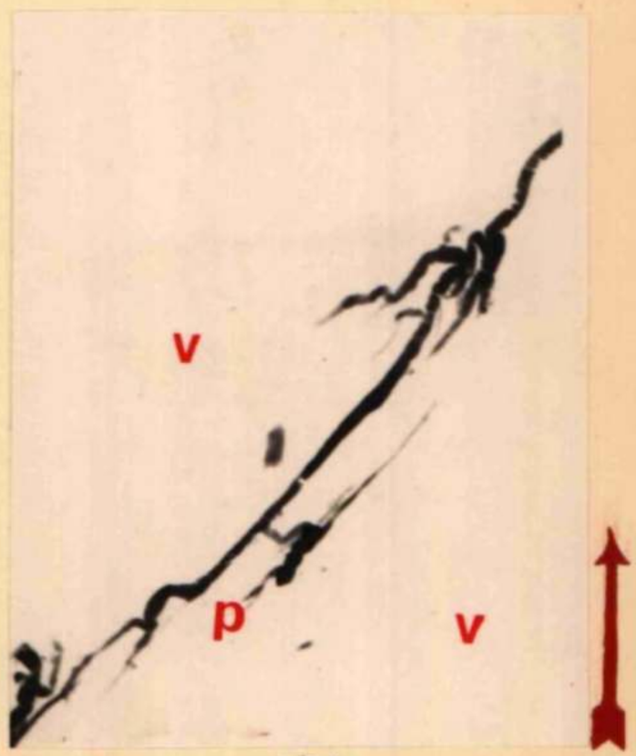

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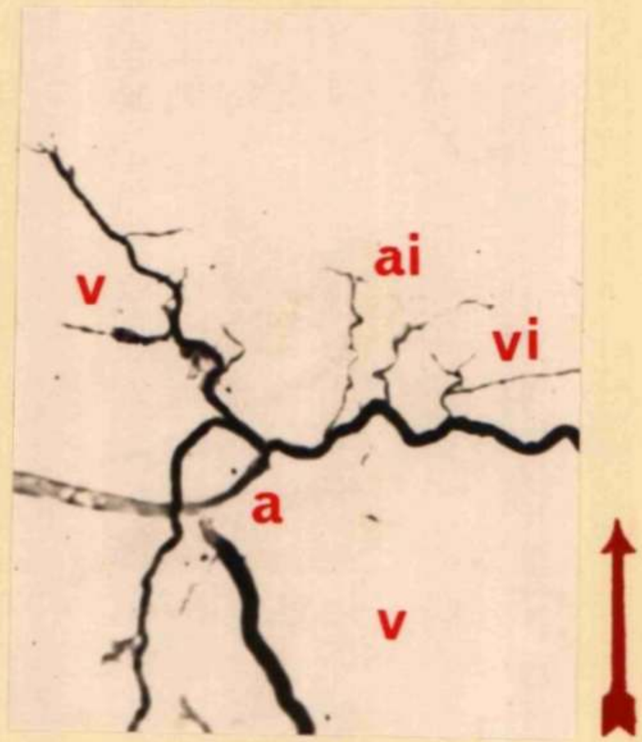

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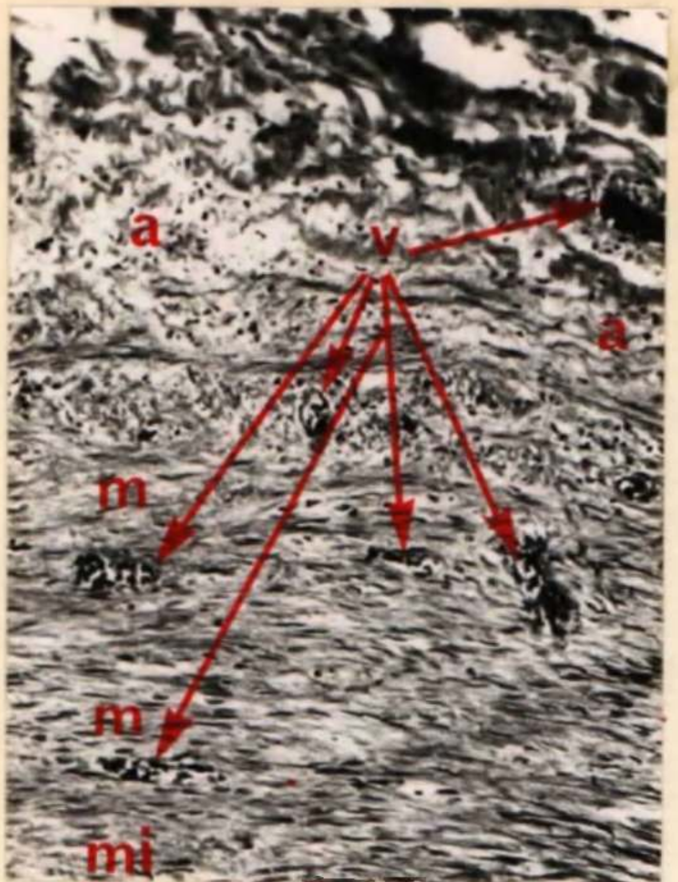

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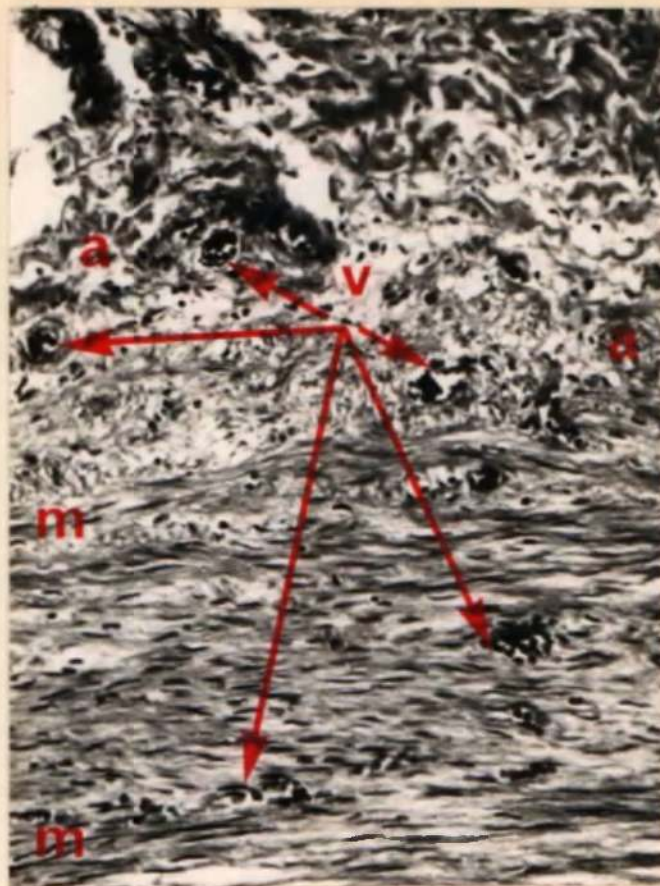

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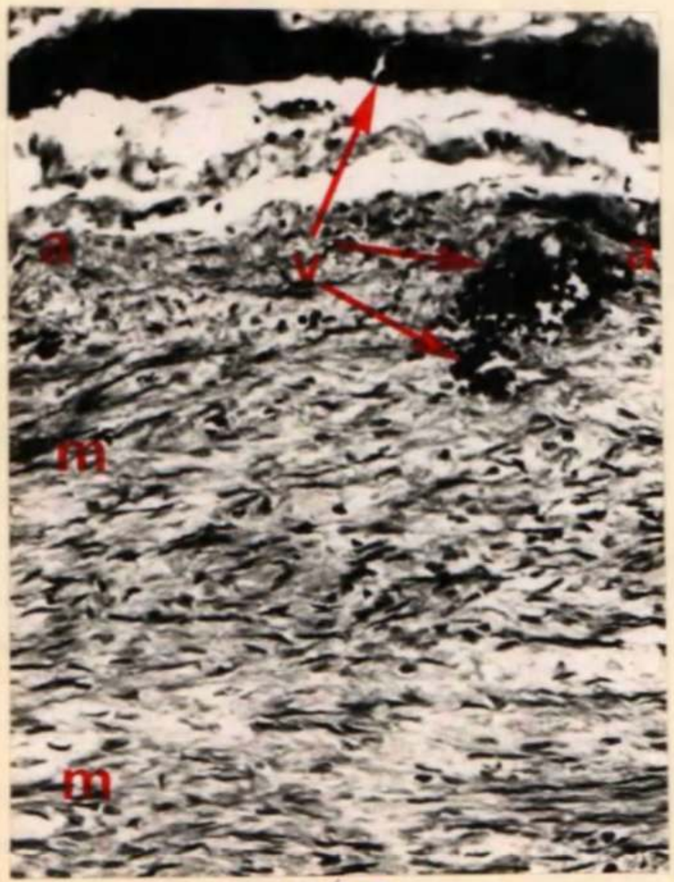

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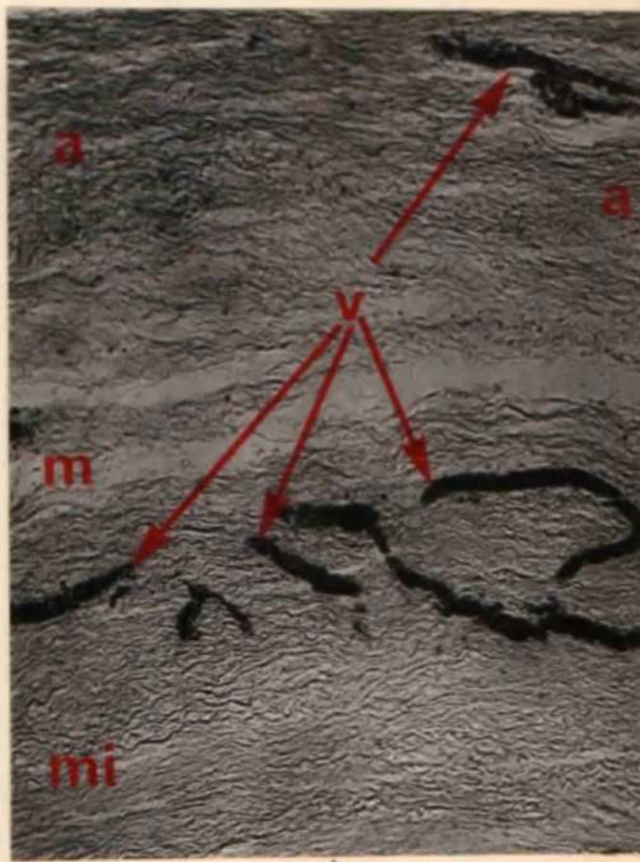

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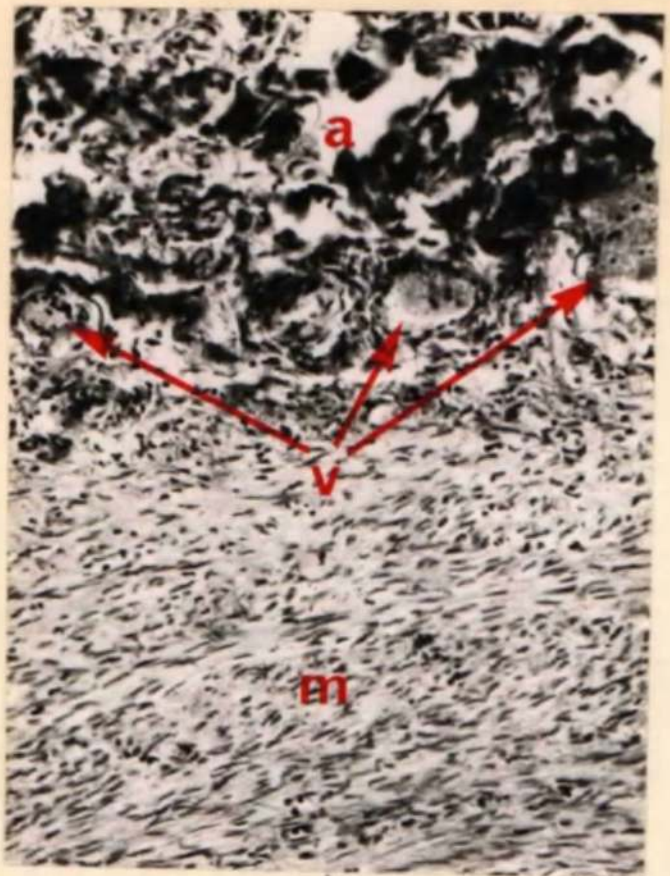

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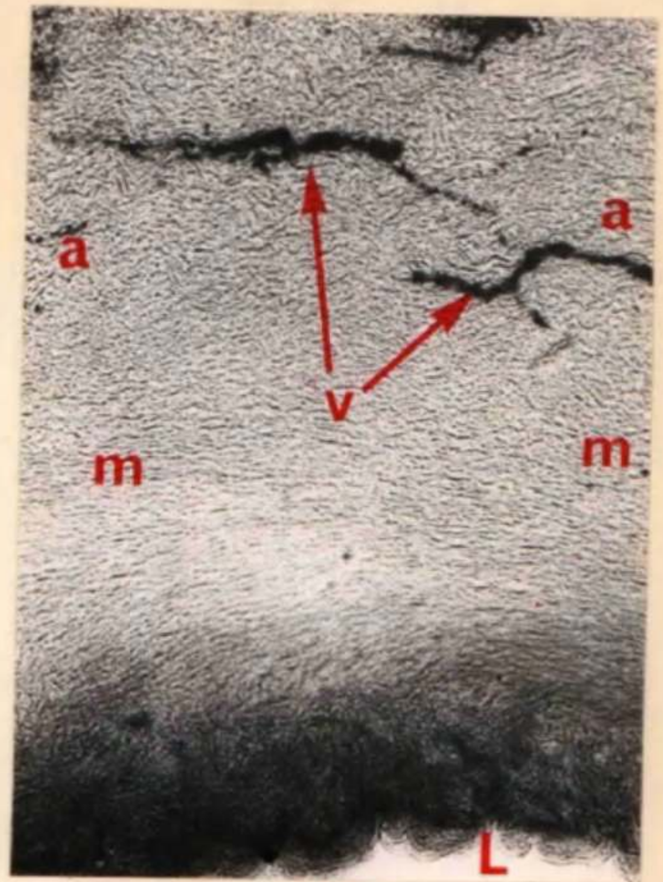

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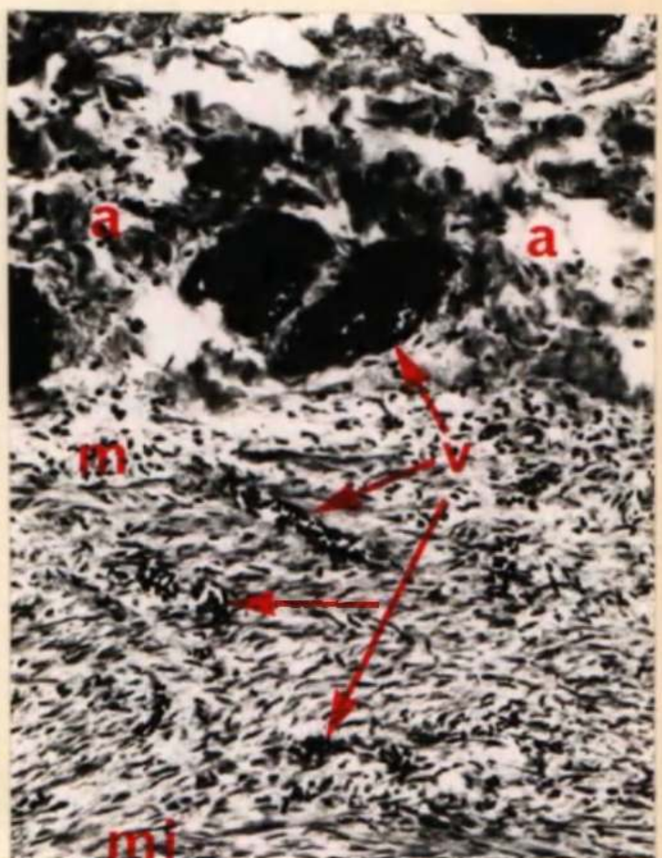

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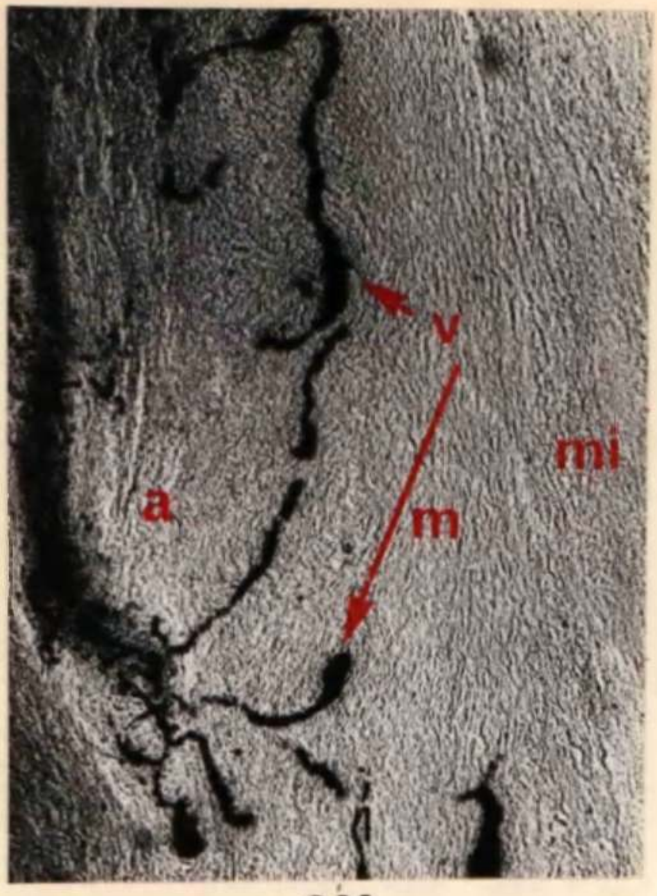

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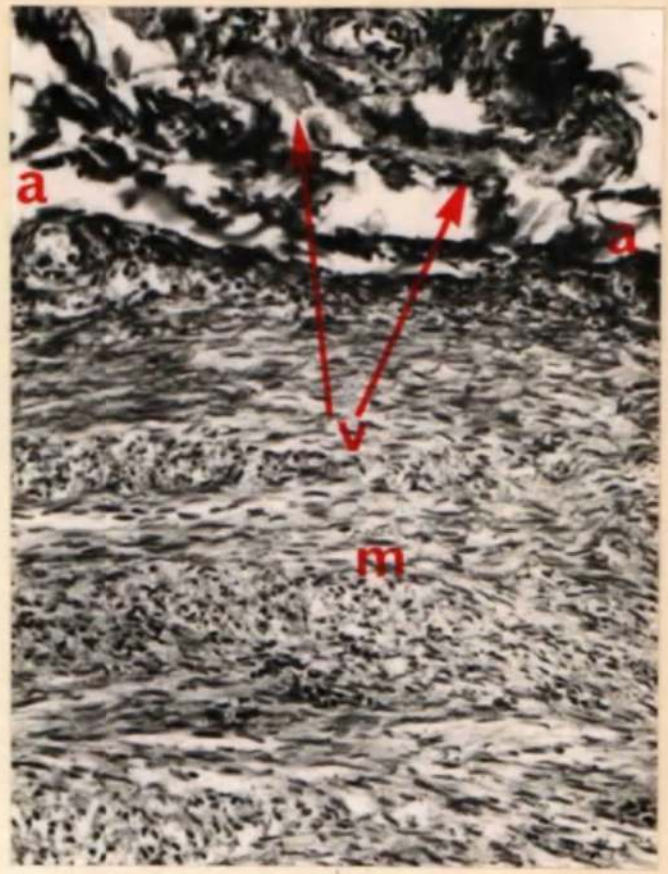

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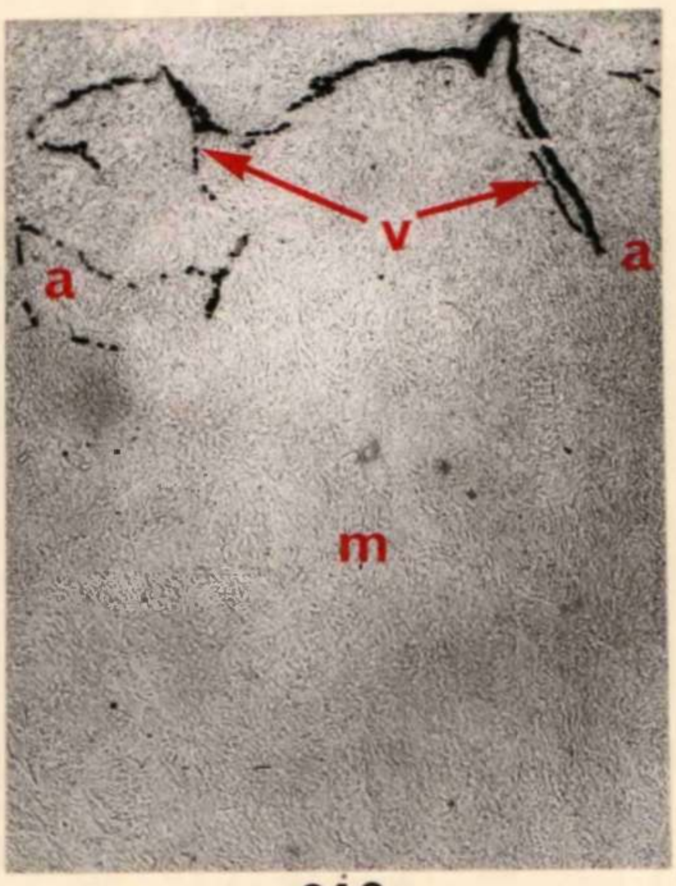

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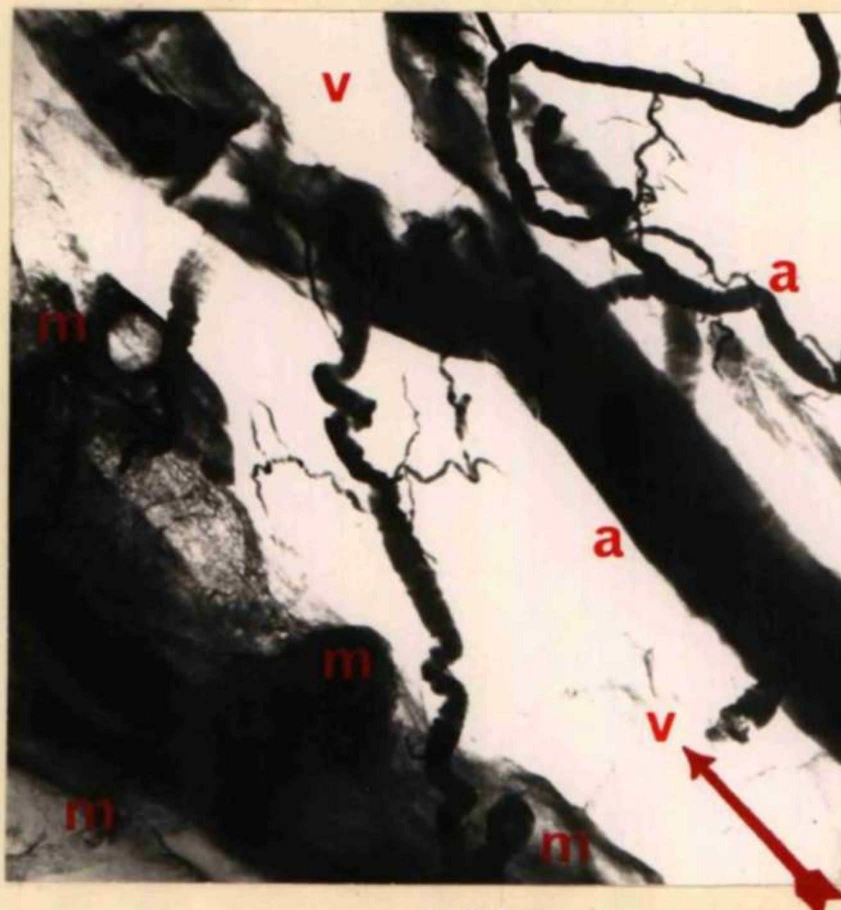
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EXPLANATION OF PLATES

All micrographs are of full thickness arterial wall, except where indicated. The long axis of the arterial wall in full thickness micrographs is denoted by the arrow at the side or base of the projection micrograph.

Fig. 1. Micrograph of ascending aorta showing arteriole (a) originating from the right coronary ostium (o) to distribute branches (b) to the adventitia (v). Lumen of coronary ostium (l). x 20.

Fig. 2. Micrograph of base of ascending aorta (A) and apex of left ventricle (V) showing terminal branch of left coronary artery (b) distributing arterioles (a) to the adventitia (v). x 20.

Fig. 3. Micrograph of ascending aorta. Note longitudinal coiled arterioles (a) supplying the adventitia (v). x 20.

Fig. 4. Micrograph of ascending aorta showing cross anastomosis (a-s) between the arterioles (a) in the adventitia (v). x 20.

Fig. 5. Micrograph of 1mm. transverse section of the ascending aorta. Note arteriole (a) penetrating the adventitia (v) to divide and supply the outer two thirds of the media (m1). Inner third of the media (m2) avascular. x 15.

Fig. 6. Micrograph of convex side of the ascending aorta. Note adventitial arterioles (a) and increased coiling (c). x 20.

Fig. 7. Micrograph of the aortic-ventricular junction (j) showing coiled arterioles (a1) originating from terminal branches of the left coronary artery (b), and arborising with arterioles from the left coronary ostium (a2) in the adventitia (v). Aorta (A): left ventricle (V). x 20.

Fig. 8. Micrograph of 1mm. longitudinal section of the ascending aorta. Note arteriole (a) penetrating adventitia (v) to divide and supply the outer two thirds of the media (m1). Inner third of the media (m2) avascular. x 20.

Fig. 9. Micrograph of ascending aorta showing venous tributaries (t) draining into longitudinal veins (l) in the adventitia (v). Cross anastomotic vein (c). x 30.

Fig.10. Micrograph of 1mm. longitudinal section of the ascending aorta. Note origin of venous plexus (p) in the inner third of the media (mi) draining through the outer two thirds of the media (m2) to the adventitial veins (v). Intima (i) is avascular. x 50.

Fig.11. Micrograph of arch of aorta. Note arteriole (a) originating from the ostium of the brachio-cephalic trunk (o) to distribute coiled branches (b) to the adventitia (v) of the summit of the aortic arch(s). x 30.

Fig.12. Micrograph of the side of the aortic arch. Note sinuous arterioles (a) in adventitia (v) arising from terminal branch of the bronchial artery (b). x 20.

Fig. 13. Micrograph of 1mm. transverse section of the aortic arch. Note arterioles (a) penetrating the adventitia (v) to divide and supply the outer two thirds of the media (m1). Inner third of the media (m2) avascular. x 25.

Fig. 14. Micrograph of the summit of the aortic arch(s) showing the adventitial venous network (v) draining into venous channel (c) on side of the aortic arch (a). x 40.

Fig. 15. Micrograph of the side of the aortic arch. Note adventitial venous network (v) draining into tributaries of the bronchial veins (t). x 40.

Fig. 16. Micrograph of 1mm. longitudinal section of the aortic arch. Note the origin of the venous plexus (p) in the inner third of the media (m) draining into tributary (t) of the adventitial veins. Intima (i) avascular. x 100.

Fig. 17. Micrograph of the thoracic aorta. Note arteriole (a) originating from intercostal artery (i) to be distributed to the adventitia (v). x 20.

Fig. 18. Micrograph of the thoracic aorta showing longitudinal arteriolar plexus (p) in adventitia (v). Proximal arterioles (a1): distal arterioles (a2); anastomoses of two sets of arterioles (a-s). x 15.

Fig. 19. Micrograph of 1mm. transverse section of the thoracic aorta. Note arterioles (a) penetrating the outer two thirds of the media (m1). Inner third of the media (m2) avascular. x 20.

Fig. 20. Micrograph of the thoracic aorta. Note circumferential veins (c) in the adventitia (v) receiving tributaries (t). x 40.

Fig. 21. Micrograph of 1mm. longitudinal section of the thoracic aorta. Note origin of venous plexus (p) in the inner third of the media (mi) draining into adventitial tributaries (t) in the outer two thirds of the media (m2). Intima (i) avascular. Lumen (L). Capillary-venule bed (c-v). x 50.

Fig. 22. Micrograph of abdominal aorta showing arteriole (a) originating from lumbar artery (l) to supply adventitia (v). x 25.

Fig. 23. Micrograph of abdominal aorta showing sinuous arteriole (a) in the adventitia (v) of the anterior aspect of the aorta. x 30.

Fig. 24. Micrograph of the aortic bifurcation. Note arteriolar plexus (p) in adventitia (v). Arterioles from lumbar arteries (ai); arterioles from inferior mesenteric artery (a2). x 25.

Fig. 25. Micrograph of abdominal aorta, aged 65 years, showing coiled arteriole (a) originating from ostium of coeliac axis (o) to divide and distribute branches (b) to adventitia (v). x 20.

Fig. 26. Micrograph of aortic bifurcation. Note arterioles (a) in the adventitia (v) of the aorta (A) and common iliac artery (B). x 25.

Fig. 27. Micrograph of 1mm. transverse section of the abdominal aorta showing arterioles (a) penetrating the outer two thirds of the media (m1). Inner third of the media (m2) avascular. x 25.

Fig. 28. Micrograph of abdominal aorta. Note circumferential veins (c) in adventitia (v) receiving tributaries (t). Compare fig. 20. x 40.

Fig. 29. Micrograph of 1mm. longitudinal section of the abdominal aorta. Note origin of venous plexus (p) in the inner third of the media (m1) draining into tributaries (t) of the adventitial veins in the outer two thirds of the media (m2). Intima (i) avascular. x 60.

Fig. 30. Micrograph of right common iliac artery showing sinuous arterioles (a) in the adventitia (v). x 30.

Fig. 31. Micrograph of 1mm. transverse section of the left common iliac artery showing arterioles (a) penetrating the adventitia (v) to divide and supply the outer third of the media (m). Middle third of the media (m_1) is avascular. x 30.

Fig. 32. Micrograph of the left common iliac artery. Note adventitial venous network (v) receiving tributaries (t). x 40.

Fig. 33. Micrograph of 1mm. longitudinal section of the right common iliac artery. Note origin of venous vasa (v) in the middle third of the media (m1) draining into tributaries (t) of the adventitial veins. Inner third of the media (m2) avascular. x 100.

Fig. 34. Micrograph of 1mm. transverse section of the ascending aorta. Note arteriole (a1) originating from the intimal stoma (s), traversing the intima (i) to arborise in the media (m) with branches of the adventitial arterioles (a2). Lumen of the aorta (L). x 15.

Fig. 35. Micrograph of the thoracic aorta showing the adventitial veins (v) on the dorsal aspect draining into circumferential vein (c). Note avascular area (A). x 40.

Fig. 36. Micrograph of thoracic aorta showing poorly vascularized area on the dorsal aspect. Note longitudinal adventitial arterioles (a) and avascular area (A). x 50.

Fig. 36a. Micrograph of the proximal end of the aortic arch. Note the arterioles (a) from the summit of the aortic arch (A) and the arterioles (ai) from the ascending aorta (B) in the adventitia (v). Avascular area (c). x 40.

Fig. 36b. Micrograph of the distal end of the aortic arch(A). Note the arterioles (a) from the summit of the aortic arch and the arterioles (ai) from the thoracic aorta (T) in the adventitia (v). Avascular area (c). x 25.

Fig. 36c. Micrograph of the junction of the thoracic aorta (T) and the abdominal aorta (B). Note the arterioles (a) from the thoracic aorta anastomosing (a-s) with the arterioles (ai) from the abdominal aorta. Adventitia (v). x 20.

Fig. 37. Micrograph of left coronary ostium (o) showing origin of arterioles (a) and their distribution to the adventitia (v) of the proximal 1cm. of the left coronary artery (c). x 20.

Fig. 38. Micrograph of proximal 1cm. of right coronary artery. Note longitudinal coiled arterioles (a) in adventitia (v). x 35.

Fig. 39. Micrograph of 1mm. longitudinal section of the left coronary artery, proximal 1cm. Note arteriole (a) penetrating adventitia (v) to divide and supply the outer third of the media (m1). Middle third of the media (m2) is avascular. x 40.

Fig. 40. Micrograph of right coronary artery showing indirect arterioles (ai) approaching the coronary wall (w) to divide and supply longitudinal arterioles (a2) to the adventitia (v). x 20.

Fig. 41. Micrograph of left coronary artery. Note the origin of direct arterioles (a1) from a collateral branch of the parent artery (c), and the longitudinal arterioles (a2) in the adventitia (v). x 25.

Fig. 42. Micrograph of 1mm. longitudinal section of the right coronary artery showing arteriole (a) penetrating the adventitia (v) to divide and supply the outer third of the media (m1). Middle third of the media (m2) avascular. x 50.

Fig. 43. Micrograph of 1mm. transverse section of the left coronary artery showing direct arteriole (a) originating from collateral branch of the coronary artery (c) to supply the outer third of the media (m1). Middle third of the media (m2), and intima (i) are avascular. Lumen (L). x 40.

Fig. 44. Micrograph of right coronary artery. Note venous plexus (p) in adventitia (v) draining into a tributary of the adjacent ventricular veins (t). x 30.

Fig. 45. Micrograph of 1mm. transverse section of left coronary artery showing the origin of the venous plexus (p) in the middle third of the media (m) draining into a tributary (t) of the adventitial veins (v). Inner third of media (mi) is avascular. Capillary-venule bed (c-v). x100.

Fig. 46. Micrograph of proximal 1cm. of the right coronary artery and ascending aorta. Note longitudinal aortic adventitial veins (vi) receiving adventitial veins (v2) from coronary artery. Aorta (A): coronary artery (B). x 60.

Fig. 47. Micrograph of 1mm. transverse section of left coronary artery aged 60 years, showing the arteriolar plexus (p) in the middle third of the media (mi). Inner third of the media (m2) avascular. x 50.

Fig. 48. Micrograph of right coronary artery showing coiled arterioles (a) in the adventitia (v). Specimen aged 65 years. x 20.

Fig. 49. Micrograph of the aortic-pulmonary groove (a-p), anterior aspect. Note arteriole (a) distributing branches (b) to the adventitia of the pulmonary trunk (v). x 45.

Fig. 50. Micrograph of the convex border of the pulmonary trunk showing longitudinal coiled arterioles (a) in the adventitia (v). x 30.

Fig. 51. Micrograph of the pulmonary trunk, anterior aspect. Note arteriolar networks (n) in the adventitia (v). x 25.

Fig. 52. Micrograph of the pulmonary bifurcation, anterior aspect (A). Note termination of arteriolar plexus (p1) from networks on anterior aspect of pulmonary trunk, and terminal arteriole (p2) extending onto anterior aspect from the dorsal side of the pulmonary trunk (D). x 30.

Fig. 53. Micrograph of the right pulmonary artery (P). Note the coiled arterioles (a) in the adventitia (v) and terminal arteriole (t) on pulmonary bifurcation (B). x 35.

Fig. 54. Micrograph of 1mm. longitudinal section of the pulmonary bifurcation. Note the arterioles (a) in the adventitia (v) penetrating and supplying the outer third of the media (m). Middle third of the media (mi) is avascular. x 40.

Fig. 55. Micrograph of the base of the pulmonary trunk. Note the coiled arterioles (a) in the adventitia (v) originating from a terminal branch of the right coronary artery (b). x 20.

Fig. 56. Micrograph of 1mm. transverse section of the base of the pulmonary trunk. Note the arterioles (a) in the adventitia (v) penetrating and supplying the outer third of the media (m). Middle third of the media (mi) is avascular. x 60.

Fig. 57. Micrograph of the pulmonary bifurcation, anterior aspect. Note the origin of the adventitial venous plexus (p) draining into longitudinal venous channels (c) in the adventitia (v). x 50.

Fig. 58. Micrograph of 1mm. longitudinal section of the pulmonary trunk. Note the origin of the venous plexus (p) in the middle third of the media (m) draining into tributaries (t) of the adventitial veins. Inner third of the media (mi) is avascular. Capillary-venule bed (c-v). x100.

Fig. 59. Micrograph of the anterior aspect of the aortic pulmonary groove (a-g). Note the adventitial vein (V) receiving tributaries (t) from the aortic adventitia (v), and tributaries (ti) from the pulmonary adventitia (vi). x 55.

Fig. 60. Micrograph of the right pulmonary artery. Note the terminal arteriolar branch of the bronchial artery (a) approaching the wall of the pulmonary artery (w) obliquely to divide and distribute arterioles (ai) to the adventitia (v). x 50.

Fig. 61. Micrograph of the left pulmonary artery. Note the longitudinal coiled arterioles (a) in the adventitia (v). x 20.

Fig. 62. Micrograph of the right upper lobar pulmonary artery. Note the longitudinal sinuous arterioles (a) in the adventitia (v). x 40.

Fig. 63. Micrograph of a terminal branch of the left upper lobar pulmonary artery. Note the straight arterioles (a) in the adventitia (v). x 20.

Fig. 64. Micrograph of 1mm. longitudinal section of the left pulmonary artery. Note the arterioles (a) penetrating the outer third of the media (m) from the adventitia (v). Middle third of media (mi) is avascular. Capillary-venule bed (c-v). x 30.

Fig. 65. Micrograph of 1mm. longitudinal section of the middle lobar pulmonary artery. Note the arteriole (a) in the adventitia (v) distributing branches (b) to the deep layers of the adventitia (V). The media (m) is avascular. Capillary-venule bed (c-v). x100.

Fig. 66. Micrograph of the right pulmonary artery. Note the irregular plexus of veins (p) in the adventitia (v) draining into a tributary (t) of the bronchial veins. x 40.

Fig. 67. Micrograph of the lingular branch of the pulmonary artery. Note the irregular plexus of veins (p) in the adventitia (v). x 35.

Fig. 68. Micrograph of 1mm. longitudinal section of the left pulmonary artery. Note the origin of the venous plexus (p) at the junction of the outer and middle thirds of the media (m:mi) draining into tributaries (t) of the adventitial veins (v). x 50.

Fig. 69. Micrograph of 1mm. longitudinal section of the left upper lobar branch of the pulmonary artery. Note the origin of the venous plexus (p) in the deep layers of the adventitia (v). x 50.

Fig. 70. Micrograph of the proximal part of the left pulmonary artery, showing the increased coiling of the arterioles (a) in the adventitia (v). Note the anastomoses (a-s) between the arterioles from the pulmonary bifurcation (a) and the arterioles from the bronchial arteries (ai). Specimen aged 60 years. x 30.

Fig. 71. Micrograph of the brachio-cephalic trunk (B). Note the origin of the coiled arterioles (a) from an arteriole (ai) on the summit of the aortic arch (S). Adventitia (v). x 20.

Fig. 72. Micrograph of the junction of the brachio-cephalic trunk (B) and the origin of the right subclavian artery (A). Note the arterioles (a) in the adventitia (v) of the subclavian artery anastomosing (s) with the arterioles (ai) in the adventitia (vi) of the brachio-cephalic trunk. x 35.

Fig. 73. Micrograph of 1mm. transverse section of the left common carotid artery. Note the arteriole (a) in the adventitia (v) penetrating and supplying the outer third of the media (m). Middle third of the media (mi) is avascular. x 40.

Fig. 74. Micrograph of 1mm. longitudinal section of the left subclavian artery. Note the origin of the venous plexus (p) in middle third of the media (m) draining into tributaries (t) of the adventitial veins (v). Inner third of the media (mi) is avascular. Capillary-venule bed (c-v). x 60.

Fig. 75. Micrograph of the left common carotid artery (C). Note the irregular plexus of veins (p) in the adventitia (v) draining into longitudinal channels (c), which are tributaries (t) of the veins (vi) on the summit of the aortic arch (A). x 50.

Fig. 76. Micrograph of the internal carotid artery. Note terminal branch of the occipital artery (a) approaching the adventitia (v) to distribute longitudinal arterioles (ai). x 30.

Fig. 77. Micrograph of the internal carotid artery. Note the arterioles (a) in the adventitia (v). Occasional sinuosity (s) and coiling (c) can be observed. x 45.

Fig. 78. Micrograph of 1mm. transverse section of the internal carotid artery. Note the arteriole (a) in the adventitia (v) penetrating and supplying the outer third of the media (m). Middle third of the media (mi) is avascular. Capillary-venule bed (c-v). x 50.

Fig. 79. Micrograph of the cervical part of the vertebral artery. Note the arterioles (a) in the adventitia (v) showing sinuosity (s) and occasional coiling (c). x 20.

Fig. 80. Micrograph of 1mm. transverse section of the vertebral artery. Note the arteriole (a) in the adventitia (v) penetrating and supplying the outer third of the media (m). Middle third of the media (mi) is avascular. Capillary-venule bed (c-v). x 60.

Fig. 81. Micrograph of the intracranial part of the vertebral artery. Note the arteriole (a) in the adventitia (v) from the extracranial adventitial plexus anastomosing (s) with arterioles (ai) from the posterior inferior cerebellar artery. x 40.

Fig. 82. Micrograph of the intracranial part of the internal carotid artery. Note the arteriole (a) in the adventitia (v) from the extracranial adventitial plexus anastomosing (s) with arterioles (ai) from the inferior hypophyseal arteries. x 60.

Fig. 83. Micrograph of 1mm. longitudinal section of the intracranial portion of the internal carotid artery. Note the longitudinal arterioles (a) in the adventitia (v). Media (m) is avascular. Capillary-venule bed (c-v). x 40.

Fig. 84. Micrograph of 1mm. longitudinal section of the intracranial portion of the vertebral artery. Note the arteriole (a) in the adventitia (v). Media (m) is avascular. Capillary-venule bed (c-v). x 100.

Fig. 85. Micrograph of the internal carotid artery at the base of the skull. Note the irregular plexus of veins (p) in the adventitia (v). x 35.

Fig. 86. Micrograph of the vertebral artery at the base of the skull. Note the irregular plexus of veins (p) in the adventitia (v). x 40.

Fig. 87. Micrograph of the internal carotid artery, half an inch from its origin. Note the increased density of the irregular venous plexus (p) in the adventitia (v). x 50.

Fig. 88. Micrograph of the cervical portion of the vertebral artery. Note the increased density of the irregular venous plexus (p) in the adventitia (v). x 50.

Fig. 89. Micrograph of 1mm. transverse section of the internal carotid artery, at its origin. Note the origin of the venous plexus (p) in the outer third of the media (m) draining into tributaries (t) of the adventitial veins (v). Middle third of the media (mi) is avascular. x 50.

Fig. 90. Micrograph of 1mm. longitudinal section of the cervical portion of the vertebral artery. Note the origin of the venous plexus (p) in the outer third of the media (m) draining into the adventitial veins (v). Middle third of the media (mi) is avascular. x 50.

Fig. 91. Micrograph of the internal carotid artery at the origin of the anterior and middle cerebral arteries. Note the terminal arteriolar distribution (a) in the adventitia (v) and the avascular distal zone (z). x 40.

Fig. 92. Micrograph of the vertebral artery, aged 65 years. Note the increased sinuosity of the arterioles (a) in the adventitia (v). x 30.

Fig. 93. Micrograph of the internal carotid artery, at the base of the skull, aged 70 years. Note the increased sinuosity of the arterioles (a) in the adventitia (v). x 40.

Fig. 94. Micrograph of the basilar artery. Note the terminal arteriolar branch of the basilar artery (a) approaching the adventitia (v) to distribute arterioles (ai). x 40.

Fig. 95. Micrograph of lmm. longitudinal section of the basilar artery. Note the arterioles (a) in the adventitia (v). Media (m) is avascular. x 50.

Fig. 96. Micrograph of the junction of the posterior communicating artery (p) and the basilar artery (b). Note the terminal arteriolar distribution (a) extending from the basilar artery onto the adventitia (v) of the posterior communicating artery. x 80.

Fig. 97. Micrograph of the basilar artery, aged 70 years. Note the increased vascularity and sinuosity (s) of the arterioles (a) in the adventitia (v). x 50.

Fig. 98. Micrograph of the subclavian artery. Note the coiled arterioles (a) in the adventitia (v). x 35.

Fig. 99. Micrograph of the axillary artery. Note the coiled arterioles (a) in the adventitia (v). x 25.

Fig. 100. Micrograph of the brachial artery. Note the coiled arterioles (a) in the adventitia (v). x 40.

Fig. 101. Micrograph of the ulnar artery, proximal third. Note the sinuous arterioles (a) in the adventitia (v). x 25.

Fig. 102. Micrograph of the palmar portion of the radial artery. Note the terminal straight arterioles (a) in the adventitia (v). x 20.

Fig. 103. Micrograph of 1mm. transverse section of the axillary artery. Note the arteriole (a) in the adventitia (v) penetrating and supplying the outer third of the media (m). Middle third of the media (mi) is avascular. x 50.

Fig. 104. Micrograph of 1mm. longitudinal section of the radial artery. Note arteriole (a) in the adventitia (v). Media (m) is avascular. x 65.

Fig. 105. Micrograph of the ulnar artery, middle third. Note the venous plexus (p) in the adventitia (v). x 50.

Fig. 106. Micrograph of the subclavian artery. Note the irregular plexus (p) of veins in the adventitia (v). x 60.

Fig. 107. Micrograph of 1mm. longitudinal section of the radial artery. Note the origin of the venous plexus (p) in the deep layers of the adventitia (v). Media (m) is avascular. Capillary-venule bed (c-v). x 75.

Fig. 108. Micrograph of 1mm. longitudinal section of the subclavian artery. Note the origin of the venous plexus (p) in the outer third of the media (m) draining into tributaries (t) of the adventitial veins (v). Middle third of the media is avascular(mi). Capillary-venule bed (c-v) x 50.

Fig. 109. Micrograph of the brachial artery. Note the longitudinal arteriolar chain (c) anastomosing proximally (p) and distally (d) with arterioles (a1) and (a2) in the adventitia (v). x 20.

Fig. 110. Micrograph of the superficial palmar arch. Note the terminal arteriole (a) in the adventitia (v). x 40.

Fig. 111. Micrograph of the subclavian artery, aged 65 years. Note the increased density of the arterioles (a) and coiling (c) in the adventitia (v). x 40.

Fig. 112. Micrograph of the femoral artery. Note the coiled arterioles (a) in the adventitia (v). x 20.

Fig. 113. Micrograph of the popliteal artery. Note the coiled arterioles (a) in the adventitia (v). x 30.

Fig. 114. Micrograph of the arteria profunda. Note the sinuous arterioles (a) in the adventitia (v). x 20.

Fig. 115. Micrograph of the lateral circumflex femoral artery. Note the sinuous arterioles (a) in the adventitia (v). x 20.

Fig. 116. Micrograph of the anterior tibial artery. Note the sinuous arterioles (a) in the adventitia (v). x 35.

Fig. 117. Micrograph of the dorsalis pedis artery. Note the longitudinal straight arterioles (a) in the adventitia (v). x 20.

Fig. 118. Micrograph of 1mm. transverse section of the femoral artery. Note the arterioles (a) in the outer third of the media (m). Middle third of media (mi) is avascular. x 50.

Fig. 119. Micrograph of 1mm. longitudinal section of the posterior tibial artery. Note the arterioles (a) in the adventitia (v). Media (m) is avascular. x 50.

Fig. 120. Micrograph of the femoral artery. Note the irregular plexus (p) of veins in the adventitia (v). x 30.

Fig. 121. Micrograph of the anterior tibial artery. Note the irregular plexus of veins (p) in the adventitia (v). x 45.

Fig. 122. Micrograph of the arteria profunda. Note the irregular plexus of veins (p) in the adventitia (v). x 50.

Fig. 123. Micrograph of 1mm. longitudinal section of the femoral artery. Note the origin of the venous plexus (p) in the outer third of the media (m) draining into tributaries (t) of the adventitial veins (v). Middle third of media (mi) is avascular. Capillary-venule bed (c-v). x 65.

Fig. 124. Micrograph of 1mm. longitudinal section of the anterior tibial artery. Note the origin of the venous plexus (p) in the deep layers of the adventitia (v). Media (m) is avascular. Capillary-venule bed (c-v). x 65.

Fig. 125. Micrograph of the popliteal artery. Note the longitudinal chain of arterioles (c) in the adventitia (v) anastomosing proximally (p) and distally (d) with arterioles (a1) and (a2). x 20.

Fig. 126. Micrograph of the distal part of the dorsalis pedis artery. Note the terminal straight arterioles (a) in the adventitia (v). x 40.

Fig. 127. Micrograph of the femoral artery, aged 55 years. Note the increase in density and coiling (c) of the arterioles (a) in the adventitia (v). x 35.

Fig. 128. Micrograph of the base of the ascending aorta, aged 3 weeks. Note the irregular network of arterioles (a) in the adventitia (v). x 100.

Fig. 129. Micrograph of the proximal half of the ascending aorta, aged 2 years. Note the longitudinal sinuous arterioles (a) in the adventitia (v) replacing the irregular neonatal network of arterioles (n). x 35.

Fig. 130. Micrograph of the ascending aorta, aged 5 years. Note increased sinuosity (s) and beginning of coiling (c) of the adventitial arterioles (a) in the adventitia (v). x 30.

Fig. 131. Micrograph of 1mm. longitudinal section of the ascending aorta, aged 4 years. Note arterioles (a) in the adventitia (v) dividing to supply the outer third of the media (m). Middle third of media (mi) is avascular. x 100.

Fig. 132. Micrograph of the ascending aorta, aged 3 weeks. Note irregular plexus of veins (p) in the adventitia (v). x 60.

Fig. 133. Micrograph of the ascending aorta, aged 4 years. Note venous channels (c) receiving tributaries (t) in the adventitia (v). x 90.

Fig. 134. Micrograph of 1mm. longitudinal section of the ascending aorta, aged four years. Note origin of venous plexus (p) in the outer third of the media (m) draining into the adventitial veins (v). Middle third of the media is avascular (mi). x 100.

Fig. 135. Micrograph of the arch of the aorta, aged three weeks. Note irregular network of arterioles (a) in the adventitia.(v). Summit of arch (S1): sides of arch (S2). Note anastomoses (a-s) between arterioles (a) on aortic arch and arterioles (a1 : a2) from distal ascending aorta (D) and thoracic aorta (T). x 25.

Fig. 136. Micrograph of the summit of the aortic arch (S), aged 2 years. Note arterioles (a) and the sinuosity of their branches (b) in the adventitia (v). x 100.

Fig. 137. Micrograph of the summit of the aortic arch (S), aged 5 years. Note increased sinuosity of the arterioles (a) in the adventitia (v). x 40.

Fig. 138. Micrograph of the side of the aortic arch (S), aged 5 years. Note longitudinally arranged plexus of arterioles (a) in the adventitia (v). x 20.

Fig. 139. Micrograph of 1mm. transverse section of the aortic arch, aged 4 years. Note arterioles (a) in the adventitia (v) penetrating and supplying the outer third of the media (m). Middle third of the media (mi) is avascular. x 100.

Fig. 140. Micrograph of the aortic arch, aged 4 weeks. Note plexus of veins (p) in the adventitia (v). x 60.

Fig. 141. Micrograph of the summit of the aortic arch (S), aged 4 years. Note reduction in the density of the venous network (n) in the adventitia (v). x 60.

Fig. 142. Micrograph of 1mm. longitudinal section of the aortic arch, aged 4 years. Note origin of venous plexus (p) in the outer third of the media (m) draining into veins in the adventitia (v). Middle third of the media (mi) is avascular. x 100.

Fig. 143. Micrograph of the lower thoracic and upper abdominal aorta (A:Ai), aged three weeks. Note spiral arrangement (s) of the adventitial arterioles (a). x 20.

Fig. 144. Micrograph of the lower thoracic and upper abdominal aorta (At:Ai), aged 2 years. Note irregular network of arterioles (a) in the adventitia (v). x 20.

Fig. 145. Micrograph of the lower thoracic and upper abdominal aorta (At:Ai), aged 4 years. Note longitudinal arrangement of the arterioles (a) in the adventitia (v). Avascular zone (z). x 40.

Fig. 146. Micrograph of 1mm. transverse section of the abdominal aorta, aged 4 years. Note arterioles (a) in the adventitia (v) dividing to supply the outer third of the media (m) Middle third of the media (mi) is avascular. x 65.

Fig. 147. Micrograph of the lower thoracic and upper abdominal aorta (At:Ai), aged 3 weeks. Note irregular network of veins (n) in the adventitia (v). x 60.

Fig. 148. Micrograph of the lower thoracic and upper abdominal aorta (A;Ai), aged 4 years. Note reduction in the density of the venous network (n) in the adventitia (v). x 20.

Fig. 149. Micrograph of 1mm. longitudinal section of the thoracic aorta, aged 4 years. Note origin of venous plexus (p) in the outer third of the media (m) draining into the adventitial veins (v). Middle third of the media (mi) is avascular. x 100.

Fig. 150. Micrograph of the right common iliac artery, aged 4 weeks. Note irregular network of arterioles (a) in the adventitia (v). x 40.

Fig. 151. Micrograph of the left common iliac artery, aged 4 years. Note longitudinal arrangement of the arterioles (a) in the adventitia (v). x 30.

Fig. 152. Micrograph of the right common iliac artery, aged 4 years. Note arteriole (a) approaching the wall of the iliac artery (w) to divide and supply sinuous arterioles (si) to the adventitia (v). x 60.

Fig. 153. Micrograph of 1mm. transverse section of the left common iliac artery, aged 4 years. Note arteriole (a) in the adventitia (v) penetrating and dividing to supply the outer third of the media (m). Middle third of the media (mi) is avascular. x 80.

Fig. 154. Micrograph of the right common iliac artery, aged 4 weeks. Note the irregular plexus of veins (p) in the adventitia (v). x 65.

Fig. 155. Micrograph of the left common iliac artery, aged 5 years. Note the reduction in the density of the plexus of veins (p) in the adventitia (v). x 40.

Fig. 156. Micrograph of 1mm. longitudinal section of the right common iliac artery, aged 4 years. Note the origin of the venous plexus (p) in the outer third of the media (m) draining into the adventitial veins (v). Middle third of the media (mi) is avascular. x 100.

Fig. 157. Micrograph of the pulmonary trunk, aged 3 weeks. Note the irregular arteriolar network (n) around the base of the pulmonary trunk (b), and the sparse arteriolar distribution (a) to the pulmonary bifurcation. (p). x 30.

Fig. 158. Micrograph of the base of the pulmonary trunk, aged 2 years. Note the longitudinal sinuous arterioles (a) in the adventitia (v) replacing the irregular arteriolar network (n). x 30.

Fig. 159. Micrograph of the pulmonary trunk, aged 2.5 years. Note the terminal arteriolar distribution (a) on the pulmonary bifurcation (p) and the proximal parts of the pulmonary arteries (P:Pi). x 40.

Fig. 160. Micrograph of the pulmonary trunk, aged 5 years. Note the increased sinuosity (s) and coiling (c) of the arterioles (a) in the adventitia (v). x 30.

Fig. 161. Micrograph of 1mm. longitudinal section of the pulmonary trunk, aged 4 years. Note the arteriole (a) in the adventitia (v) penetrating and supplying the outer third of the media (m). Middle third of the media (mi) is avascular. x 70.

Fig. 162. Micrograph of the pulmonary trunk, aged 3 weeks. Note the irregular plexus of veins (p) in the adventitia (v). x 60.

Fig. 163. Micrograph of 1mm. longitudinal section of the pulmonary trunk, aged 4 years. Note the origin of the venous plexus (p) in the outer third of the media (m) draining into the adventitial veins (v). Middle third of media (mi) is avascular. x 100.

Fig. 164. Micrograph of the pulmonary trunk, aged 5 years. Note the longitudinal venous channels (c) in the adventitia (v) draining into tributaries (t) of the ventricular coronary veins. x 55.

Fig. 165. Micrograph of the right pulmonary artery, aged 3 weeks. Note the irregular plexus of arterioles (a) in the adventitia (v). x 100.

Fig. 166. Micrograph of the left pulmonary artery, aged 2 years. Note the longitudinal sinuous arterioles (a) in the adventitia (v). x 80.

Fig. 167. Micrograph of the right upper lobar pulmonary artery, aged 2 years. Note the straight arterioles (a) in the adventitia (v). x 40.

Fig. 168. Micrograph of the left pulmonary artery, aged 5 years. Note the increased density of the arterioles (a) in the adventitia (v). x 25.

Fig. 169. Micrograph of a terminal branch of the left upper lobar pulmonary artery, aged 5 years. Note the straight arterioles (a) in the adventitia (v) terminating their distribution (d). x 30.

Fig. 170. Micrograph of 1mm. longitudinal section of the right pulmonary artery, aged 4 years. Note arterioles (a) in the adventitia (v) dividing to penetrate and supply the outer third of the media (m). Middle third of the media (mi) is avascular. x 50.

Fig. 171. Micrograph of 1mm. longitudinal section of the right lobar pulmonary artery, aged 4 years. Note arterioles (a) in the adventitia (v). Outer third of the media (m) is avascular. x 100.

Fig. 172. Micrograph of the left pulmonary artery, aged 3 weeks. Note the irregular plexus of veins (p) in the adventitia (v). x 60.

Fig. 173. Micrograph of the right pulmonary artery, aged 2 years. Note the reduction in the density of the plexus of veins (p) in the adventitia (v). x 50.

Fig. 174. Micrograph of 1mm. longitudinal section of the right pulmonary artery, aged 4 years. Note the origin of the venous plexus (p) in the outer third of the media (m) draining into adventitial veins (v). Middle third of the media (mi) is avascular. x 100.

Fig. 175. Micrograph of the left pulmonary artery, aged 5 years. Note tributaries (t) of the adventitial veins (v) draining into the origin of the bronchial veins (b). x 40.

Fig. 176, Micrograph of the lingular branch of the left pulmonary artery, aged 2 years. Note the irregular plexus (p) of veins in the adventitia (v). x 40.

Fig. 177. Micrograph of 1mm. longitudinal section of the right lower lobar pulmonary artery, aged 5 years. Note the origin of the venous plexus (p) in the deep layers of the adventitia (V) draining into the superficial adventitial veins (v). Media (m) is avascular. x 100.

Fig. 178. Micrograph of the brachio-cephalic trunk (B) and subclavian artery (S), aged 3 weeks. Note the irregular plexus of arterioles (a) in the adventitia (v), anastomosing with arterioles (ai) in the adventitia (vi) of the subclavian artery. x 60.

Fig. 179. Micrograph of the left common carotid artery, aged 2 years. Note the longitudinal sinuous arterioles (a) in the adventitia (v) originating from an arteriole (A) on the aortic arch (B). x 50.

Fig. 180. Micrograph of the brachio-cephalic trunk, aged 5 years. Note the increased sinuosity of the arterioles (a) in the adventitia (v). x 40.

Fig. 181. Micrograph of 1mm. transverse section of the left subclavian artery, aged 4 years. Note arteriole (a) in the adventitia (v) dividing and supplying the outer third of the media (m). Middle third of the media is avascular (mi). x 50.

Fig. 182. Micrograph of the left common carotid artery, aged 3 weeks. Note the irregular plexus of veins (p) in the adventitia (v). x 60.

Fig. 183. Micrograph of 1mm. transverse section of the brachio-cephalic trunk, aged 4 years. Note the origin of the venous plexus (p) in the outer third of the media (m) draining into the adventitial veins (v). Middle third of the media is avascular.(mi) x 75.

Fig. 184. Micrograph of the left common carotid artery, aged 5 years. Note the plexus of veins (p) in the adventitia (v) draining into the venous plexus (P) on the summit of the aortic arch (S). x 60.

Fig. 185. Micrograph of the junction of the axillary and brachial arteries, aged 4 weeks. Note irregular plexus of arterioles (a) in the adventitia (v). Axillary artery (A): brachial artery (B). x 40.

Fig. 186. Micrograph of the proximal third of the radial artery, aged 4 years. Note the longitudinal sinuous arterioles (a) in the adventitia (v). x 60.

Fig. 187. Micrograph of the distal third of the ulnar artery, aged 4 years. Note the sinuous arterioles (a) in the adventitia (v). x 60.

Fig. 188. Micrograph of the junction of the subclavian and axillary arteries, aged three years. Note the irregular plexus of veins (p) in the adventitia (v). Subclavian artery (S): axillary artery (A). x 80.

Fig. 189. Micrograph of the femoral artery, aged 4 weeks. Note the irregular plexus of arterioles (a) in the adventitia (v). x 60.

Fig. 190. Micrograph of the femoro-popliteal junction, aged 4 years. Note the longitudinal sinuous arterioles (a) in the adventitia (v). Femoral artery (F): popliteal artery (P). x 50.

Fig. 191. Micrograph of the posterior tibial artery, aged 4 years. Note longitudinal sinuous arterioles (a) in the adventitia (v). x 25.

Fig. 192. Micrograph of the proximal part of the femoral artery, aged 3 years. Note the irregular plexus of veins (p) in the adventitia (v). x 70.

Fig. 193. Micrograph of the distal half of the ascending aorta (A), aged 12 years, showing the longitudinally arranged sinuous arterioles (a) and beginning of coiling (c) in the adventitia (v). Note the avascular zone (z) which is now separating the ascending aorta from the aortic arch (B). x 20.

Fig. 194. Micrograph of 1mm. transverse section of the ascending aorta, aged 14 years. Note arteriole (a) in the adventitia (v) dividing to supply the outer and middle thirds of the media (m:m1). Inner third of the media is avascular (m2). x 60.

Fig. 195. Micrograph of the ascending aorta (A) and aortic-pulmonary groove (B) aged 14 years. Note the longitudinal venous channel (c) receiving tributaries (t) in the adventitia (v). Cross anastomotic channel with pulmonary adventitial veins (c-a). x 60.

Fig. 196. Micrograph of 1mm. longitudinal section of the ascending aorta, aged 15 years. Note the origin of the venous plexus (p) in the inner third of the media (m). Intima (I) is avascular. x 100.

Fig. 197. Micrograph of the summit of the aortic arch (S), aged 12 years. Note the sinuosity (s) and beginning of coiling (c) of the arterioles (a) in the adventitia (v). x 35.

Fig. 198. Micrograph of the side of the aortic arch, aged 12 years. Note sinuous arteriole (a) in the adventitia (v). x 40.

Fig. 199. Micrograph of 1mm. longitudinal section of the aortic arch, aged 14 years. Note arterioles (a) dividing to supply the outer third and middle third of the media (m:m1). Inner third of the media (m2) is avascular. x 100.

Fig. 200. Micrograph of the arch of the aorta, aged 12 years. Note the irregular venous network (n) in the adventitia (v) draining into tributaries (t) of the bronchial veins. x 60.

Fig. 201. Micrograph of 1mm. longitudinal section of the aortic arch, aged 15 years. Note the origin of the venous plexus (p) in the inner third of the media (m) draining into tributaries of the adventitial veins (t) in the middle third of the media (mi). Intima (i) is avascular. x 110.

Fig. 202. Micrograph of the thoracic aorta, aged 12 years. Note longitudinal sinuous arterioles (a) forming an anastomotic chain (c) in the adventitia (v). Proximal segment (p): distal segment (d). x 20.

Fig. 203. Micrograph of the posterior aspect of the thoracic aorta, aged 15 years. Note longitudinal sinuous arterioles (a) in the adventitia (v), and the avascular midline zone (z). x 35.

Fig. 204. Micrograph of the thoracic aorta, aged 14 years. Note the irregular plexus of veins (p) in the adventitia (v) draining into the circumferential veins (c). x 80.

Fig. 205. Micrograph of 1mm. longitudinal section of the thoracic aorta, aged 15 years. Note the origin of the venous plexus (p) in the inner third of the media (m) draining into tributaries of the adventitial veins (t). Intima (i) is avascular. x 100.

Fig. 206. Micrograph of the abdominal aorta, aged 12 years. Note the longitudinal sinuous arterioles (a) in the adventitia (v) forming an anastomotic chain (c). Proximal segment (p): distal segment (d). x 35.

Fig. 207. Micrograph of the anterior aspect of the abdominal aorta, aged 15 years. Note the longitudinal sinuous arterioles (a) in the adventitia (v). x 30.

Fig. 208. Micrograph of 1mm. transverse section of the abdominal aorta, aged 12 years. Note the arteriole (a) in the deep layers of the adventitia (v) penetrating and supplying the outer third of the media (m). Middle third of media (mi) is being vascularized. x 50.

Fig. 209. Micrograph of the abdominal aorta, aged 12 years. Note irregular venous network (n) in the adventitia (v) draining into the circumferential veins (c). x 50.

Fig. 210. Micrograph of the right common iliac artery, aged 12 years. Note the longitudinally arranged sinuous arterioles (a) in the adventitia (v). x 30.

Fig. 211. Micrograph of 1mm. transverse section of the left common iliac artery, aged 12 years. Note the arterioles (a) in the adventitia (v) dividing to supply the outer third of the media (m). Middle third of the media (mi) is avascular. x 110.

Fig. 212. Micrograph of the right common iliac artery, aged 12 years. Note the irregular plexus of veins (p) in the adventitia (v). x 75.

Fig. 213. Micrograph of 1mm. transverse section of the right common iliac artery, aged 15 years. Note the origin of the venous plexus (p) in the middle third of the media (m) draining into tributaries (t) of the adventitial veins. Inner third of the media (mi) is avascular. x 100.

Fig. 214. Micrograph of the anterior aspect of the pulmonary trunk, aged 12 years. Note the formation of the sinuous arterioles (a) in the adventitia (v). x 20.

Fig. 215. Micrograph of the base of the pulmonary trunk, aged 12 years. Note the increased sinuosity of the arterioles (a) in the adventitia (v), and coiling (c). x 40.

Fig. 216. Micrograph of the posterior aspect of the pulmonary trunk, aged 10 years. Note the arteriolar mosaics (m) in the adventitia (v). x 60.

Fig. 217. Micrograph of 1mm. longitudinal section of the pulmonary trunk, aged 15 years. Note the arterioles (a) in the adventitia (v) penetrating and supplying the outer third of the media (m). Middle third of the media (mi) is avascular. x 100.

Fig. 218. Micrograph of the anterior aspect of the pulmonary trunk, aged 12 years. Note the irregular venous plexus (p) in the adventitia (v) draining into longitudinal venous channels (c). x 40.

Fig. 219. Micrograph of 1mm. transverse section of the pulmonary trunk, aged 15 years. Note the origin of the venous plexus (p) in the middle third of the media (m) draining into tributaries (t) of the adventitial veins. Inner third of the media is avascular (mi). x 110.

Fig. 220. Micrograph of the right pulmonary artery, aged 10 years. Note the increased sinuosity (s) and beginning of coiling (c) in the arterioles (a) in the adventitia (v). x 35.

Fig. 221. Micrograph of the right upper lobar artery, aged 12 years. Note increased sinuosity of the arterioles (a) in the adventitia (v). x 40.

Fig. 222. Micrograph of 1mm. transverse section of the left pulmonary artery, aged 12 years. Note the arteriole (a) in the adventitia (v) penetrating and supplying the outer third of the media (m). Middle third of the media (mi) is avascular. x 100.

Fig. 223. Micrograph of the left upper lobar pulmonary artery, aged 15 years. Note the increased density of the arterioles (a) in the adventitia (v). x 40.

Fig. 223a. Micrograph of 1mm. longitudinal section of the middle lobar artery, aged 12 years. Note the arteriole (a) supplying the deep layers of the adventitia (v). The media (m) is avascular. x 100.

Fig. 224. Micrograph of the left pulmonary artery, aged 12 years. Note the irregular plexus of veins (p) in the adventitia (v). x 40.

Fig. 225. Micrograph of 1mm. longitudinal section of the right pulmonary artery, aged 14 years. Note the origin of the venous plexus (p) at the junction of the outer and middle thirds of the media (m:mi), draining into tributaries (t) of the adventitial veins. x 100.

Fig. 226. Micrograph of the right lower lobar pulmonary artery, aged 14 years. Note the irregular plexus of veins (p) in the adventitia (v). x 100.

Fig. 226a. Micrograph of 1mm. longitudinal section of the lingular branch of the pulmonary artery, aged 14 years. Note the origin of the venous plexus (p) in the deep layers of the adventitia (v). The media (m) is avascular. x 100.

Fig. 227. Micrograph of the aortic arch (A) and brachio-cephalic trunk (B), aged 12 years. Note the sinuosity (s) and coiling (c) of the arterioles (a) in the adventitia (v) after originating from the arteriole (ai) in the adventitia (vi) of the aortic arch. x 60.

Fig. 228. Micrograph of the left common carotid artery, aged 10 years. Note the arterioles in the deep layers of the adventitia (v) dividing to supply the outer third of the media (m). Middle third of the media (mi) is avascular. x 100.

Fig. 229. Micrograph of the left subclavian artery, aged 12 years. Note the longitudinal venous channels (c) replacing the irregular network of veins (n) in the adventitia (v). x 35.

Fig. 230. Micrograph of 1mm. longitudinal section of the brachio-cephalic trunk, aged 14 years. Note the origin of the venous plexus (p) in the middle third of the media (m) draining into tributaries (t) of the adventitial veins. Inner third of media (mi) is avascular. x 110.

Fig. 231. Micrograph of the proximal 1cm. of the right coronary artery, aged 4 years. Note the irregular arteriolar plexus (p) in the adventitia (v). x 40.

Fig. 232. Micrograph of the proximal 1cm. of the left coronary artery, aged 10 years. Note the longitudinal sinuous arterioles (a) in the adventitia (v). x 30.

Fig. 233. Micrograph of the left coronary artery, aged 12 years. Note the coiled arteriole (a) originating from the wall of the coronary ostium (w) to be distributed to the proximal 1cm. of the coronary artery in the adventitia (v). Lumen of ostium (L). x 30.

Fig. 234. Micrograph of 1mm. longitudinal section of the right coronary artery, aged 10 years. Note the arterioles (a) in the adventitia (v) penetrating and supplying the outer third of the media (m). Middle third of the media (mi) is avascular. x 40.

Fig. 235. Micrograph of 1mm. transverse section of the left coronary artery, aged 14 years. Note the direct arteriole (a) originating from the collateral branch of the coronary artery (c) to supply the outer third of the media (m). Middle third of the media (mi) is avascular. x 40.

Fig. 236. Micrograph of the left coronary artery, aged 5 years. Note the irregular plexus of veins (p) in the adventitia (v). x 60.

Fig. 237. Micrograph of the right coronary artery, aged 12 years. Note the similar irregular plexus of veins (p) in the adventitia (v). x 40.

Fig. 238. Micrograph of 1mm. longitudinal section of the left coronary artery, aged 14 years. Note the venous plexus (p) originating in the middle third of the media (m) and draining into tributaries (t) of the adventitial veins (v). Outer third of the media (mi). x 110.

Fig. 239. Micrograph of the subclavian artery, aged 11 years. Note the coiled arterioles (a) in the adventitia (v). x 35.

Fig. 240. Micrograph of the axillary artery, aged 11 years. Note the coiled arterioles (a) in the adventitia (v). x 40.

Fig. 241. Micrograph of the proximal third of the radial artery, aged 12 years. Note the increased sinuosity of the arterioles (a) in the adventitia (v). x 25.

Fig. 242. Micrograph of 1mm. longitudinal section of the axillary artery, aged 10 years. Note the arterioles (a) in the adventitia (v) penetrating and supplying the outer third of the media (m). Middle third of the media (mi) is avascular. x 100.

Fig. 243. Micrograph of 1mm. longitudinal section of the axillary artery, aged 10 years. Note the origin of the venous plexus (p) in the outer third of the media (m) draining into tributaries (t) of the adventitial veins (v). Inner two thirds of the media (mi) is avascular. x 110.

Fig. 244. Micrograph of the femoral artery, aged 11 years. Note the coiled arterioles (a) in the adventitia (v). x 35.

Fig. 245. Micrograph of the popliteal artery, aged 11 years. Note the coiled arterioles (a) in the adventitia (v). x 35.

Fig. 246. Micrograph of the anterior tibial artery, aged 12 years. Note the increased sinuosity of the arterioles (a) in the adventitia (v). x 40.

Fig. 247. Micrograph of 1mm. transverse section of the femoral artery, aged 10 years. Note the arteriole (a) in the adventitia (v) penetrating and supplying the outer third of the media (m). Middle third of the media (mi) is avascular. x 100.

Fig. 248. Micrograph of 1mm. longitudinal section of the femoral artery, aged 10 years. Note the origin of the venous plexus (p) in the outer third of the media (m) draining into tributaries (t) of the adventitial veins (v). Middle third of the media (mi) is avascular. x 110.

Fig. 249. Micrograph of the foetal abdominal aorta, aged 12 weeks. Note the irregular network (n) of mural vessels in the 'adventitia' (v). x 150.

Fig. 250. Micrograph of the distal thoracic foetal aorta, aged 16 weeks. Note the irregular plexus (p) of mural vessels in the 'adventitia' (v). x 100.

Fig. 251. Micrograph of the aortic bifurcation in a foetus, aged 16 weeks. Note the irregular plexus (p) of mural vessels in the 'adventitia' (v). x 100.

Fig. 252. Micrograph of the base of the foetal ascending aorta, aged 16 weeks. Note the irregular plexus (p) of vessels in the 'adventitia' (v). Aorta (A). Left ventricle (V). Distal ascending aorta (D) is avascular. x 80.

Fig. 253. Micrograph of the summit of the foetal aortic arch, aged 16 weeks. Note the irregular plexus (p) of vessels in the 'adventitia' (v). x 110.

Fig. 254. Micrograph of the distal thoracic aorta, aged 20 weeks. Note the increased density of the plexus of vessels (p) in the adventitia (v). x 50.

Fig. 255. Micrograph of the foetal abdominal aorta, aged 20 weeks. Note the spiral pattern (s) of vessels in the adventitia (v). x 40.

Fig. 256. Micrograph of the foetal ascending aorta, aged 24 weeks. Note the irregular plexus (p) of vessels in the adventitia (v), ascending towards the avascular distal part of the ascending aorta (A). Base of the ascending aorta (B). x 40.

Fig. 257. Micrograph of the foetal ascending aorta, aged 28 weeks. Note the irregular plexus of arterioles (a) in the adventitia (v) of the base (b) and proximal half of the ascending aorta (p). Distal avascular half (d). x 20.

Fig. 258. Micrograph of the foetal ascending aorta, aged 32 weeks. Note the irregular plexus of arterioles (a) extending from the proximal half of the ascending aorta (p) into the adventitia (v) of the distal half (d). x 20.

Fig. 259. Micrograph of the foetal ascending aorta, aged 34 weeks. Note the irregular arteriolar pattern of arterial vasa (a) in the adventitia (v). x 70.

Fig. 260. Micrograph of the foetal ascending aorta, aged 28 weeks. Note the irregular plexus (p) of veins in the adventitia (v). x 50.

Fig. 261. Micrograph of the foetal ascending aorta, aged 34 weeks. Note the irregular plexus (p) of veins in the adventitia (v). x 100.

Fig. 262. Micrograph of the summit of the foetal aortic arch, aged 28 weeks. Note the irregular plexus of arterioles (a) in the adventitia (v). x 60.

Fig. 263. Micrograph of the summit of the foetal aortic arch, aged 30 weeks. Note the increase in density of the arteriolar plexus (p) in the adventitia (v). x 60.

Fig. 264. Micrograph of the side of the foetal aortic arch, aged 32 weeks. Note the irregular arteriolar plexus (p) in the adventitia (v). x 60.

Fig. 265. Micrograph of the summit of the foetal aortic arch, aged 34 weeks. Note the irregular arteriolar plexus (p) in the adventitia (v). x 80.

Fig. 266. Micrograph of the summit of the foetal aortic arch, aged 28 weeks. Note the irregular plexus of veins (p) in the adventitia (v). x 60.

Fig. 267. Micrograph of the summit (s) and side (si) of the foetal aortic arch, aged 32 weeks. Note the irregular plexus of veins (p) in the adventitia (v). x 60.

Fig. 268. Micrograph of the foetal thoracic aorta, aged 32 weeks. Note the spiral pattern of arterioles (a) in the adventitia (v). x 40.

Fig. 269. Micrograph of the junction of the foetal thoracic (T) and abdominal aorta (A), aged 28 weeks. Note the irregular plexus of veins (p) in the adventitia (v). x 110.

Fig. 270. Micrograph of the foetal abdominal aorta, aged 32 weeks. Note the increased density of the venous plexus (p) in the adventitia (v). x 60.

Fig. 271. Micrograph of the base of foetal pulmonary trunk, aged 16 weeks. Note the irregular plexus of vessels (p) in the 'adventitia' (v). Distal half (d) is avascular. x 35.

Fig. 272. Micrograph of anterior aspect of the foetal pulmonary trunk (P) and the aortic-pulmonary groove (a-p), aged 20 weeks. Note the network of vessels (n) on the anterior aspect of the pulmonary trunk, originating from vessels (v) in the aortic-pulmonary groove. Aortic vasa (A). x 25.

Fig. 273. Micrograph of the proximal half of the foetal pulmonary trunk, aged 28 weeks. Note the irregular arteriolar plexus (p) in the adventitia (v) of the proximal half (P) of the pulmonary trunk. Distal half (D) is avascular. x 20.

Fig. 274. Micrograph of the anterior aspect of the foetal pulmonary trunk (P) and the pulmonary bifurcation (B), aged 32 weeks. Note the irregular plexus of arterioles (a) in the adventitia (v). Proximal part of pulmonary arteries (Pi). x 20.

Fig. 275. Micrograph of posterior aspect of the foetal pulmonary trunk, aged 34 weeks. Note the irregular plexus of arterioles (a) in the adventitia (v). x 35.

Fig. 276. Micrograph of the anterior aspect of the proximal half of the foetal pulmonary trunk, aged 28 weeks. Note the irregular plexus of veins (p) in the adventitia (v). x 40.

Fig. 277. Micrograph of the posterior aspect of the foetal pulmonary trunk, aged 34 weeks. Note the irregular plexus of veins (p) in the adventitia (v). x 70.

Fig. 278. Micrograph of the foetal ductus arteriosus, aged 28 weeks. Note the terminal branches of the internal mammary artery (b) distributing arterioles (a) to the adventitia (v). x 35.

Fig. 279. Micrograph of the foetal ductus arteriosus, aged 34 weeks. Note the arteriolar plexus from the internal mammary artery (a) and the arteriolar plexus from the thoracic aorta (ai) arborising (r) in the adventitia (v). x 40.

Fig. 280. Micrograph of the foetal ductus arteriosus, aged 34 weeks. Note the arteriolar plexus from the internal mammary artery (a) and the arteriolar plexus from the pulmonary artery (ai), in the adventitia (v). x 20.

Fig. 281. Micrograph of the postnatal ductus arteriosus, aged 5 days. Note the increased density of the arteriolar plexus (p) in the adventitia (v). x 50.

Fig. 282. Micrograph of 1mm. longitudinal section of the postnatal ductus arteriosus, aged 5 days. Note the arteriolar plexus (p) in the adventitia (v) penetrating and distributing arterioles (a) to the media (m). Inner media and intima (mi:i) are avascular. Lumen (L). x 60.

Fig. 283. Micrograph of the postnatal ductus arteriosus, aged ten days. Note the irregular plexus of arterioles (a) in the adventitia (v). x 20.

Fig. 284. Micrograph of 1mm. transverse section of the postnatal ductus arteriosus, aged twelve days. Note the arterioles (a) in adventitia (v) penetrating and supplying the media (m) and intima (i). x 40.

Fig. 285. Micrograph of 1mm. longitudinal section of the tissue contained in the lumen (L) of the postnatal ductus arteriosus, aged eighteen days. Note the arteriolar plexus (p). x 80.

Fig. 286. Micrograph of 1mm. transverse section of the ductus arteriosus, aged 20 days. Note the arterioles (a) in the media (m) distributing arterial vasa to the intima (i) and the tissue in the lumen (L) of the ductus arteriosus. x 50.

Fig. 287. Micrograph of 1mm. transverse section of the postnatal ductus arteriosus, aged 24 days. Note the reduction in density of the arteriolar distribution (a) to the adventitia (v); media (m) and intima (i). Lumen (L). x 25.

Fig. 288. Micrograph of 1mm. longitudinal section of the postnatal ductus arteriosus, aged 6 months. Note the sparse network of arterioles (a) in the adventitia (v), and avascular media (m). x 20.

Fig. 289. Micrograph of the ductus arteriosus, aged 1 year. Note the arteriolar network (n) in the adventitia (v) arborising with arterial vasa from the thoracic aorta (a1) and pulmonary artery (a2). x 20.

Fig. 290. Micrograph of the ductus arteriosus, aged 4 years. Note the sparse arteriolar network (n) in the adventitia (v). x 25.

Fig. 291. Micrograph of the ductus arteriosus, aged 5 years. Note the arterial vasa (a) in the adventitia (v) of the pulmonary half (P) and the avascular aortic half (A). x 25.

Fig. 292. Micrograph of the ductus arteriosus, aged 10 years. Note the arteriolar plexus (p) in the pulmonary half (P) of the adventitia (v). Aortic half (A) is avascular. x 25.

Fig. 293. Micrograph of the pulmonary half of the ductus arteriosus, aged 12 years. Note the sparse arteriolar network (n) in the adventitia (v) of the pulmonary half of the ductus (P). x 20.

Fig. 294. Micrograph of the ductus arteriosus, aged 48 years. Note the arterioles (a) in the adventitia (v) of the pulmonary half (P). Aortic half (A) is avascular. x 20.

Fig. 295. Micrograph of the origin of the intra-abdominal part of the foetal umbilical artery, aged 20 weeks. Note the arteriole (a) in the adventitia (v) of the iliac artery distributing arterioles (ai) to the adventitia (vi) of the umbilical artery. x 65.

Fig. 296. Micrograph of the proximal 1cm. of the intra-abdominal part of the umbilical artery, aged 26 weeks. Note the arteriolar plexus (p) in the adventitia (v) originating from an arteriole (a) in the adventitia (vi) of the iliac artery. x 85.

Fig. 297. Micrograph of the distal part of the intra-abdominal portion of the umbilical artery, aged 34 weeks. Note the terminal arteriole (a) from the epigastric plexus in the anterior abdominal wall (w) distributing arterioles (ai) to the adventitia (v) of the umbilical artery. x 40.

Fig. 298. Micrograph of the proximal part of the intra-abdominal portion of the umbilical artery, aged 34 weeks. Note the sinuous arterioles (a) in the adventitia (v), and the avascular area (A). x 40.

Fig. 299. Micrograph of 1mm. longitudinal section of the intra-abdominal portion of the umbilical artery, distal part. Age 34 weeks. Note the sinuous arteriolar plexus (p) in the adventitia (v), and the avascular media (m). x 40.

Fig. 300. Micrograph of the distal portion of the intra-abdominal part of the umbilical artery, 3 days old. Note the reduction in the density of the arteriolar plexus (p) in the adventitia (v). x 40.

Fig. 301. Micrograph of the proximal portion of the intra-abdominal part of the umbilical artery, aged 3 days. Note the reduction in the density of the arteriolar plexus (p) in the adventitia (v). x 25.

Fig. 302. Micrograph of the proximal 1cm. of the remains of the intra-abdominal part of the umbilical artery, aged ten days. Note the arterioles (a) in the adventitia (v) of the iliac artery, distributing arterioles (ai) to the adventitia (vi) of the umbilical artery. x 30.

Fig. 303. Photomicrograph of 8μ transverse section of the ascending aorta, aged 35 years, showing vasa vasorum(v) in the adventitia(a) and outer two thirds of the media(m). Inner third of media(mi) is avascular. Mallory. x 100.

Fig. 304. Photomicrograph of 8μ transverse section of the brachio-cephalic trunk, aged 12 years. Note the vasa vasorum(v) in the adventitia(a) and outer third of the media(m). Masson. x 140.

Fig. 305. Photomicrograph of 8μ longitudinal section of the pulmonary trunk, aged 5 years. Note the vasa vasorum(v) in the adventitia(a) and outer third of the media(m). Haematoxylin and eosin. x 300.

Fig. 306. Photomicrograph of 50μ longitudinal section of the abdominal aorta, aged 10 years. Note the vasa vasorum(v) in the adventitia(a) and outer third of the media(m). Middle third of the media(mi) is avascular. Sodium nitroprusside and benzidene. x 50.

Fig. 307. Photomicrograph of 8μ transverse section of the foetal pulmonary trunk, aged 32 weeks. Note the vasa vasorum(v) in the adventitia(a). Media (m) is avascular. Masson. x 400.

Fig. 308. Photomicrograph of 50μ longitudinal section of the foetal abdominal aorta, aged 26 weeks. Note the vasa vasorum(v) in the adventitia(a). Media(m) is avascular. Lumen(L). Sodium nitroprusside and benzidene. x 85.

Fig. 309. Photomicrograph of 8μ transverse section of the foetal ductus arteriosus, aged 36 weeks. Note the vasa vasorum(v) in the adventitia(a). Media (m) is avascular. Mallory. x 350.

Fig. 310. Photomicrograph of 8μ transverse section of the postnatal ductus arteriosus, aged 20 days. Note the vasa vasorum (v) in the adventitia(a) and outer media (m). Inner media(mi) is avascular. Masson. x 200.

Fig. 311. Photomicrograph of 50μ longitudinal section of the ductus arteriosus, aged 21 days. Note the vasa vasorum(v) in the adventitia(a) and outer media(m). Inner media(mi) is avascular. Sodium nitroprusside and benzidene. x 60.

Fig. 312. Photomicrograph of 3μ transverse section of the intra-abdominal part of the foetal umbilical artery, aged 36 weeks. Note the vasa vasorum (v) in the adventitia(a). Media(m) is avascular. Haematoxylin and eosin. x 200.

Fig. 313. Photomicrograph of 50μ transverse section of the intra-abdominal part of the umbilical artery, aged 72 hours. Note the vasa vasorum(v) in the adventitia(a). Media(m) is avascular. Sodium nitroprusside and benzidene. x 40.

Fig. 3I4. Micrograph of the adult abdominal aorta. Note the arterioles(a) in the adventitia(v) and the area of extravasation of injection medium(m). x I50.