THE NORMAL VASCULAR SUPPLY OF THE VERTEBRAL COLUMN IN THE GROWING RABBIT

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Only superficial accounts of the blood supply of the vertebral column are given in text-books of anatomy, and a search of the literature suggests that not very much is known about it. Much of what is described is by no means universally accepted, and contradictions exist with regard to nomenclature and the relative importance of the vessels described. Little or no attention is paid to the neural arch.

Lexer, Kuliga and Türk (1904) published their excellent monograph on the blood supply of bones, including some vertebrae, but it lacks detail of the intrinsic supply to the body and to the neural arch. Hanson (1926) discussed certain special diseases and anomalies of the spine, relating them to the vertebral blood supply, and described the smaller arteries and venous drainage. Böhmig (1930) gave an account of the blood supply of the vertebrae in the foetus and in infants. He described dorsal, axial and ventral intervertebral disc arteries, supporting his statements by illustrations of histological preparations.

Wagoner and Pendergrass (1932) studied the circulation in a still-born infant, after injection. They described sinusoidal plexuses in the body, and discussed a relationship between these and radiological appearances and pathological affections of diseased vertebrae. In 1939 they also described the causation of the anterior and posterior notch shadows in the vertebral bodies in relation to the penetration of blood vessels.

TABLE I

AGES OF RABBITS STUDIED

Age	Number studied
21-day foetus .	1
Birth–2 weeks .	4
2–6 weeks . .	6
6 weeks–3 months .	6
3–6 months . .	4
6–9 months . .	4

Ferguson (1950) reviewed the literature and submitted his conclusions from a study of the circulation in foetal and infant spines. He could not agree with Böhmig's findings and concluded that the only arteries to the body worthy of the name are: 1) one which enters the mid-dorsal surface of the centrum from an anastomosis in the floor of the spinal canal; and 2) two small antero-lateral branches which arise from the segmental arteries. According to him the neural arch receives a rich blood supply from an anastomosis between the arteries of the posterior rami of the segmental arteries.

In a study of the blood supply in the rabbit it became clear to us that the pattern of the intrinsic supply to the vertebrae was not a static one, but that there was a definite and orderly evolution during various stages of growth until adult life was reached.

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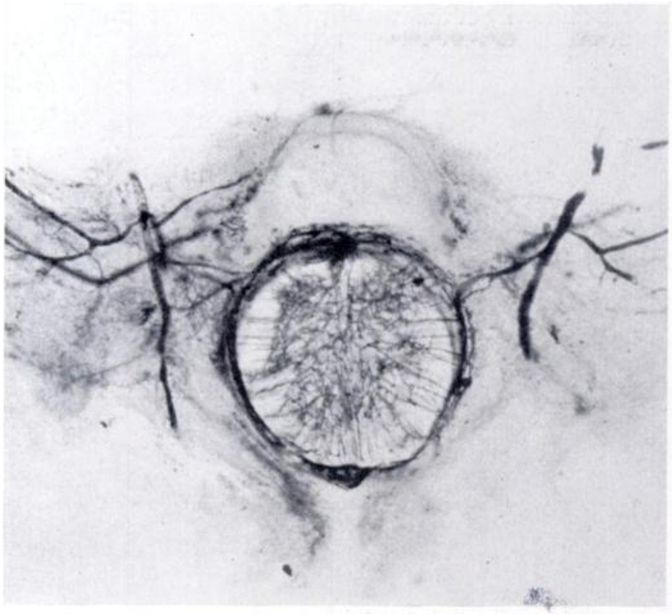


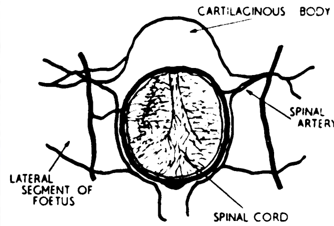


FIG. 1
Transverse section of a twenty-one-day-old foetal vertebra. The body is entirely cartilaginous and receives no blood vessels. The spinal artery only supplies the cord in which the well developed network of vessels is well shown.

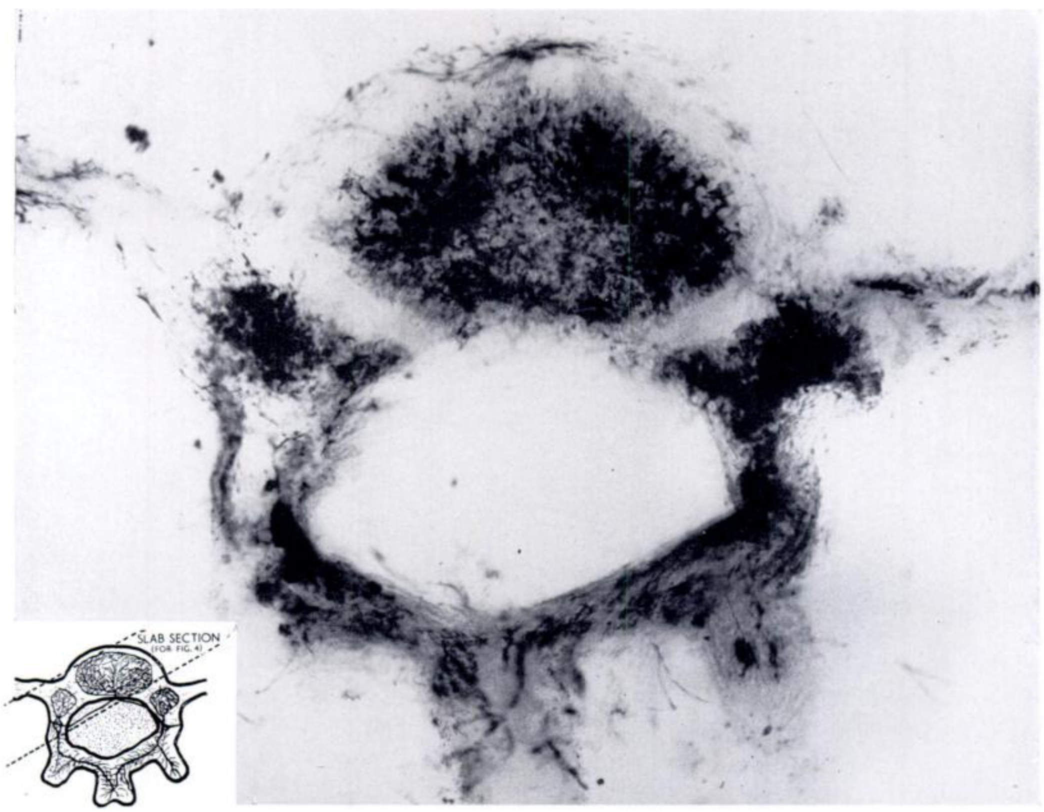


FIG. 2
Transverse section through centre of body of four-day-old rabbit. The nucleus is being developed around the stems of the vascular sprouts which have invaded the body from several directions.

The rabbit was chosen because it is readily available at the several ages required. Also, in other studies we have noted the similarity of the vascular distribution in corresponding bones of rabbit and man, and we are confident that a close comparison can be made. The vertebral body of the rabbit differs but little in fundamental architecture from that of the human, the differences being confined to the neural arch processes in matters of size only.

METHODS AND MATERIALS

Table I gives details of the twenty-five vertebral columns studied; twenty-one days of foetal life was the earliest at which it was found possible to inject a specimen (the injection was made through the left ventricle).

In all rabbits an injection mass of equal parts of barium sulphate (10 per cent) and Berlin blue (2 per cent) was used. It was introduced into the aorta or into the left ventricle soon after the animal had been killed by a lethal intravenous injection of Nembutal.

The vertebral columns were dissected free and radiographed. The preparations were decalcified and then rendered transparent in Spalteholz solution and studied unstained by means of a dissecting microscope (Trueta, Barclay, Daniel, Franklin and Pritchard 1947; Trueta and Harrison 1953). The vertebrae were cut at varying planes and levels. With twenty-five vertebrae to each column, the number of individual studies ran into hundreds. It should be mentioned that it was difficult to clean the specimens for examination as well as to leave the venous plexus undisturbed when removing the spinal cord in many cases. As the arteries lie under cover of the veins, the latter had to be removed for the arterial system to be studied.

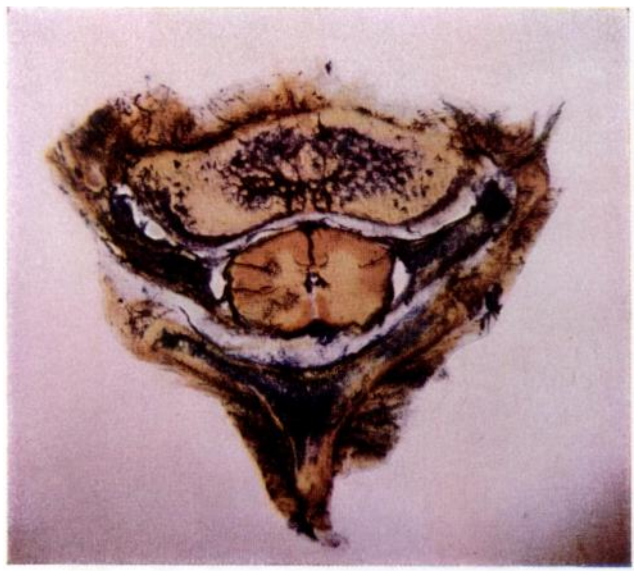
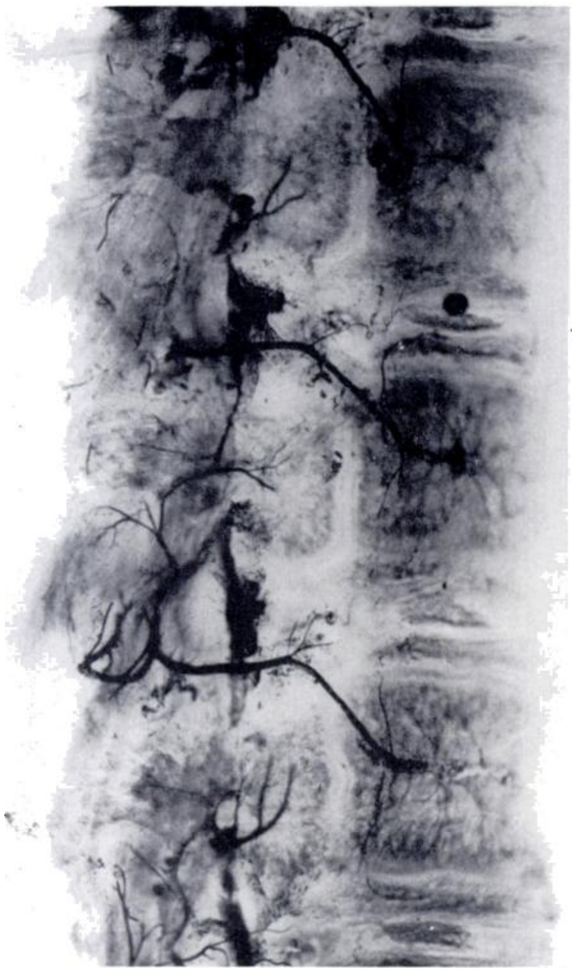


FIG. 3

Section through the same body as in Figure 2 but from the uppermost third, where it is still cartilaginous. The heads of the vascular sprouts only are visible.

FINDINGS

Development—In the youngest column studied, from the twenty-one day foetus, paired segmental arteries were given off from the aorta opposite the centre of each vertebra. Each of these, after giving off a posterior branch at the side of the column at the level of the intervertebral disc, continued laterally to supply the rest of the foetal segment. From the posterior branch, a spinal artery arose and immediately entered the intervertebral foramen. The vertebra, being at this stage entirely cartilaginous, received no vessels, the spinal artery being concerned solely with supplying the spinal cord and meninges. Cross sections showed a rich and orderly network of vessels supplying every section of the cord (Fig. 1).



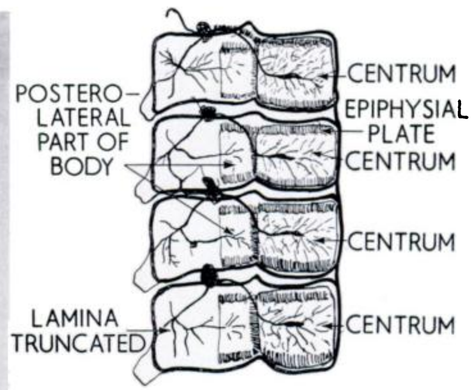


FIG. 4
The direction of this oblique section of the lumbar vertebrae is shown in Figure 2. The network of vessels in each centrum and neural arch can be seen.

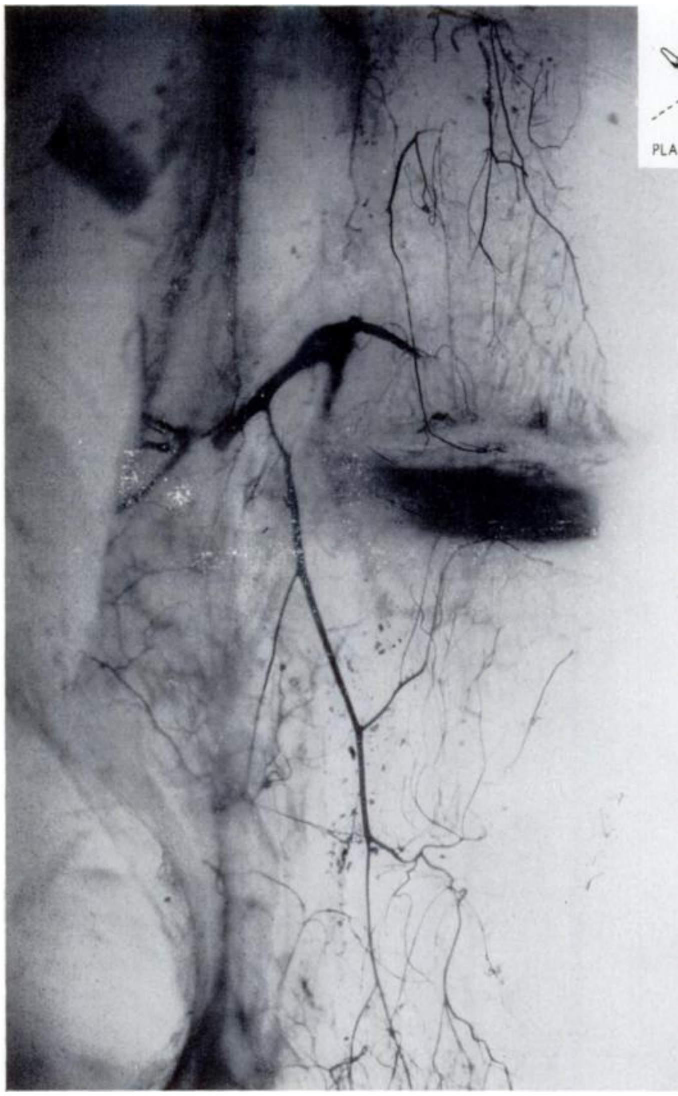
Immediately before birth the waist of the vertebral body is invaded by a number of vascular sprouts on all sides. These travel towards the centre and then turn at right angles forwards or backwards—that is, cephalad or caudad. Small ossific nuclei surround the stem of each " sprout " as soon as it changes direction.

In the four-day-old rabbit the ossific nucleus of the centrum was already well established, particularly in the thoraco-lumbar region. The sprout heads, similar to those described in the growing head of the femur by Trueta in 1957, always kept ahead of the developing nucleus (Figs. 2 and 3). An ossific nucleus was seen developing in the neural arch and it first appeared in the cervico-thoracic region.

Between the first and the third week the nuclei developed apace. The vessels entering the centrum from the posterior surface gradually enlarged and took over the supply of the whole ossifying area. Those entering anteriorly diminished in size and finally disappeared.

The neural arch vessels spread forwards into the antero-lateral part of the body, starting in the cervical and upper thoracic region and spreading towards the lumbar vertebrae; other branches grew into the laminae and the articular processes (Fig. 4).

In the three-week-old rabbit a new phase occurred. Vascular sprouts coming from the periosteal vessels externally and the spinal artery internally invaded the areas adjacent to the intervertebral discs; these areas were destined to become the epiphyses of the vertebral bodies.



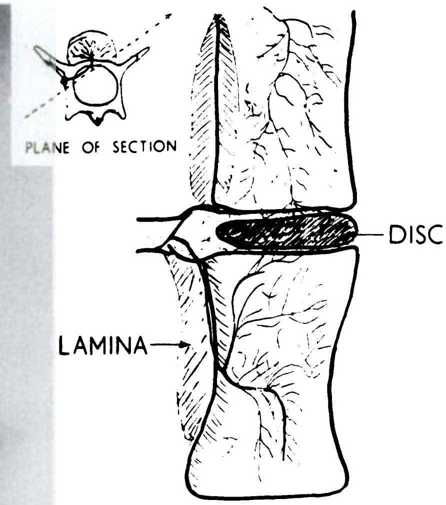


Fig. 5

The ventral artery. Section showing the ventral artery arising from the spinal artery at the level of the intervertebral disc. Note the ramifications inside the bone when it divides to supply both halves, and the epiphysial arteries entering the epiphysis from the posterior aspect, making a right-angled bend.

Thus, each pair of spinal arteries, at this stage, had branches supplying: 1) the cord, 2) the contiguous halves of the vertebral bodies, and 3) the contiguous halves of the neural arches. Each vertebral body had four nutrient arteries converging on the nutrient foramen posteriorly, one from each spinal artery: they supplied the centrum. The postero-lateral parts of the body had a vascular supply from the artery to the neural arch, and the two epiphysial regions were also getting their own blood vessels.

Between the third and sixth weeks the evolution of the blood supply continued. Of the vessels invading the epiphysial region, from four to six persisted posteriorly. They arose from

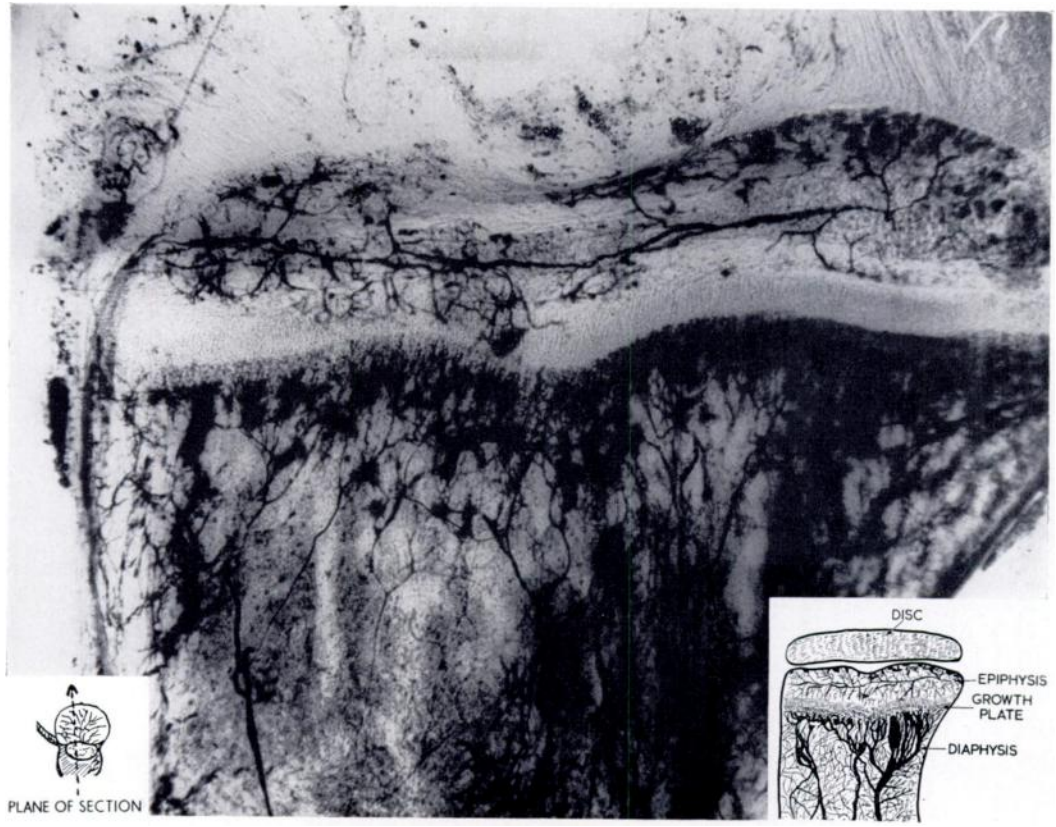


FIG. 6

The terminal ramifications of the nutrient artery at the metaphysial end, showing the capillary loops ending at one level. Note the horizontal epiphysial artery giving branches to the whole circumference of the epiphysis.

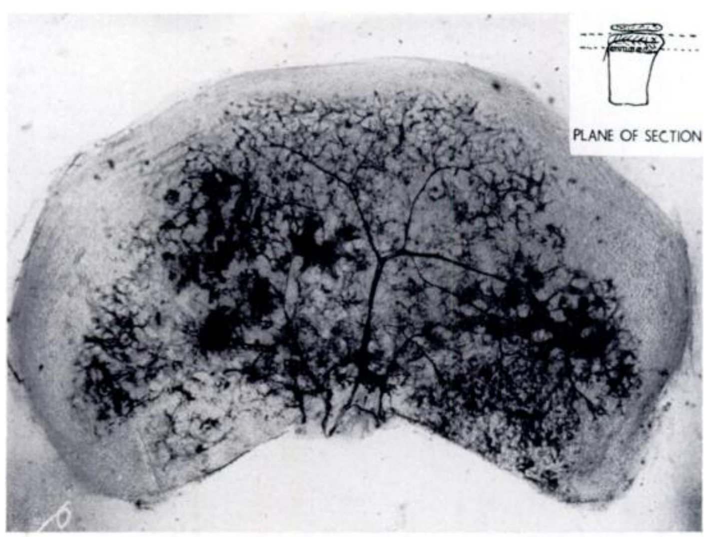


FIG. 7

Transverse section of an epiphysis showing the vessels entering its posterior surface and fanning out over its whole extent (compare with Fig. 6).

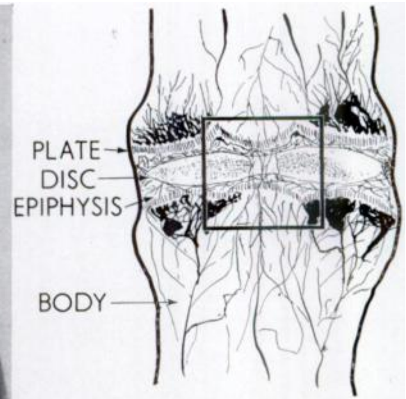


FIG. 8

The posterior surface of two vertebral bodies with the intervertebral disc. There are three zones of vascular supply—one, the centrum supplied from the " ventral " artery, and two lateral zones from the anterior branches of the " dorsal " artery. The centrum has not been injected, but the epiphysial branches can be seen entering the epiphysis.

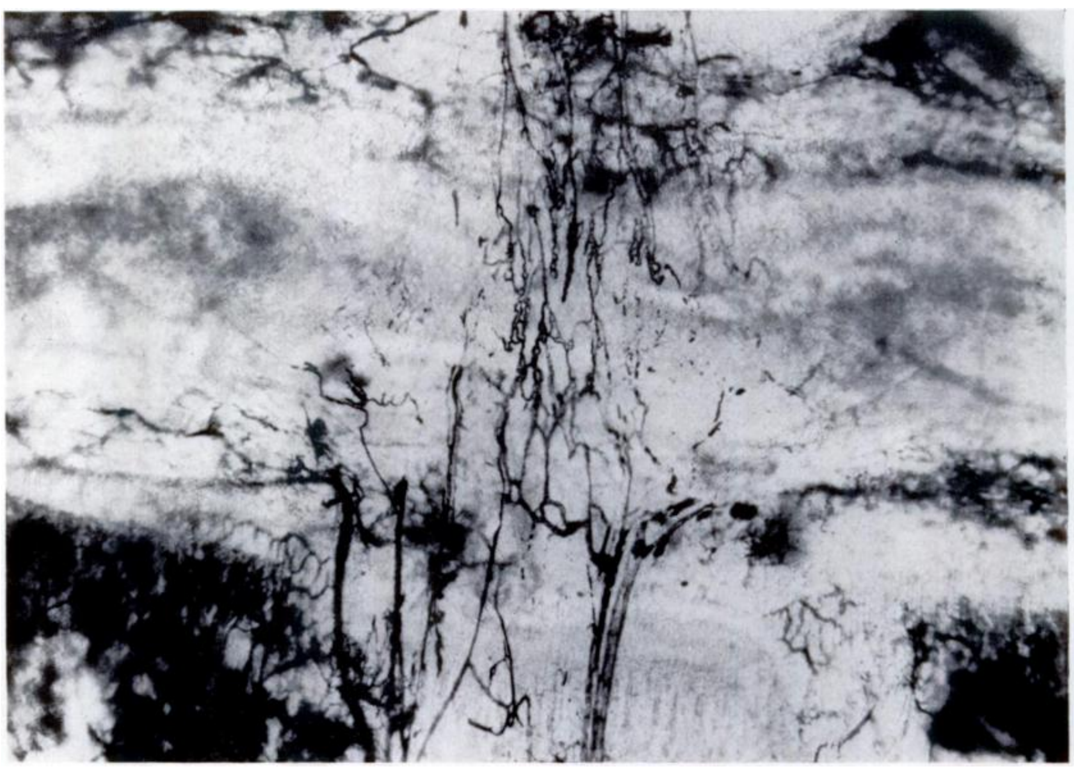
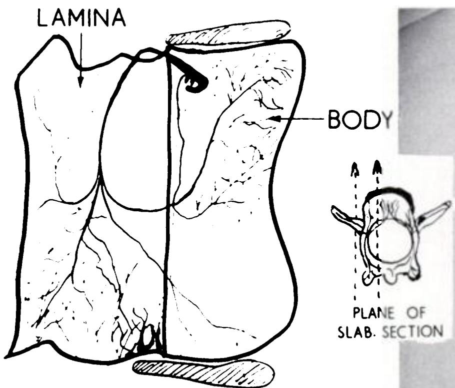


FIG. 9

An enlargement of the central portion of Figure 8 to show the anastomosis between the epiphysial arteries. On the bottom left-hand corner the metaphysial ramifications can be seen.

the nutrient arteries to the centrum. In most cases the arteries supplying the cephalad part of the vertebra took over the supply of the caudal half of the same vertebra, so that each vertebra was now supplied by one pair of spinal arteries. The arteries previously supplying the caudal halves persisted as small anastomotic branches.

Definitive pattern—This stage of the vascular pattern was reached when the epiphysis became established, and each body had epiphysis, cartilage plate and diaphysis, and the neural arch



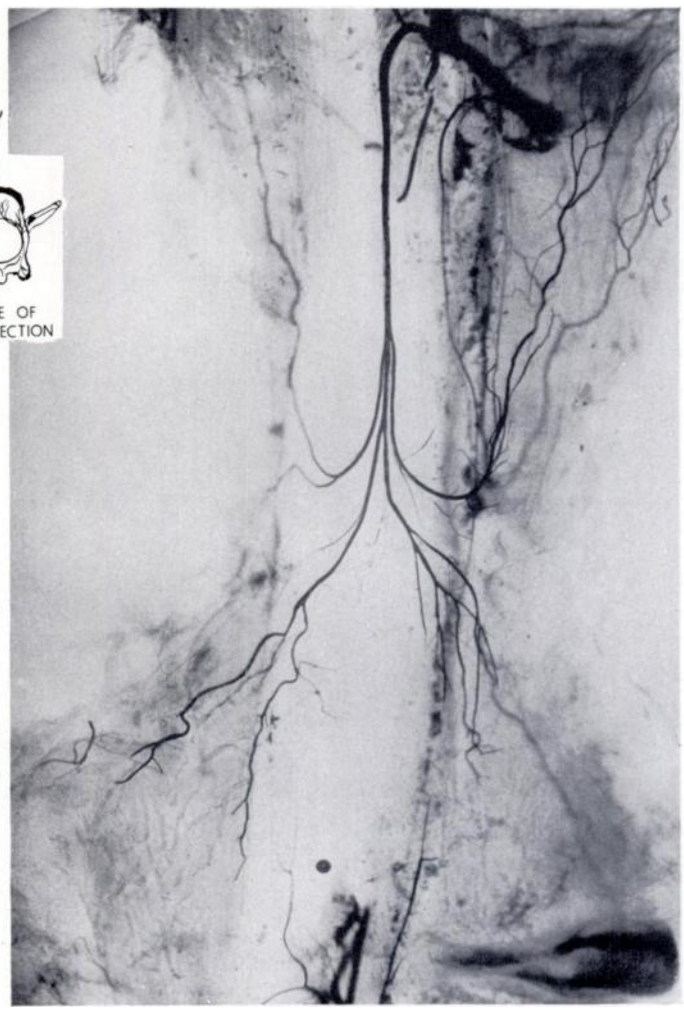


FIG. 10
The dorsal artery of a lumbar vertebra. Above is the spinal artery. The branches on the right are anterior and these supply the postero-lateral portion of the body. Above and below, the outlines of the discs can be made out. The vessels to the left, going out of focus, are those to the lamina and articular processes. Anastomotic branches from the adjacent spinal artery are visible below.

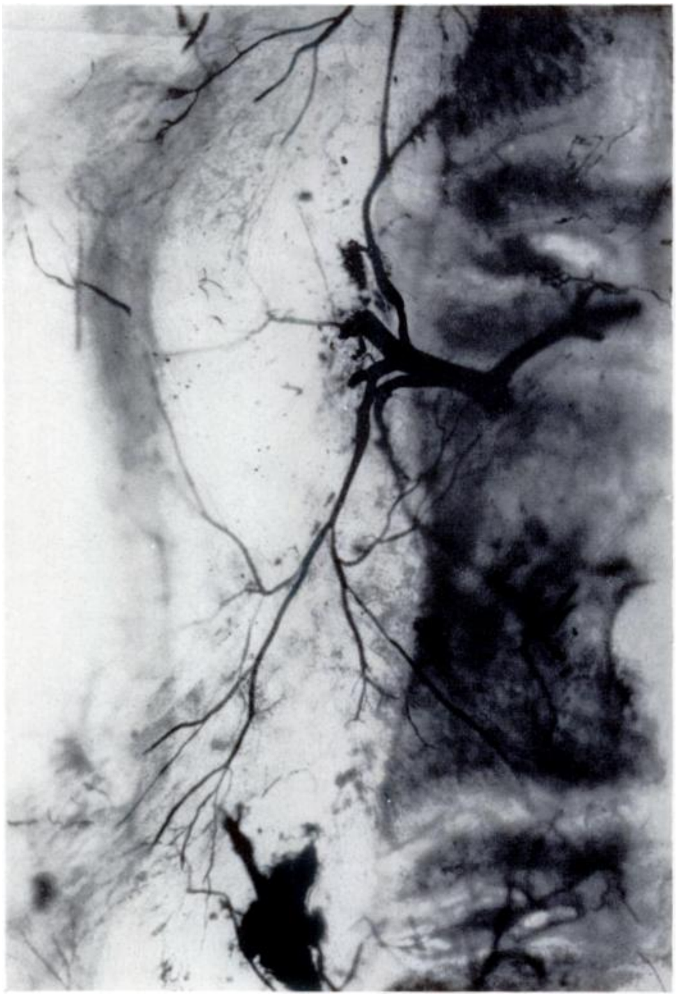
had all its processes fully developed. Three main branches arose from each spinal artery in the intervertebral foramen: 1) to the cord; 2) ventral to the centrum of the body and the epiphysis; 3) dorsal to the neural arch and the postero-lateral parts of the body.

The blood supply to the cord will not be described further as it does not form part of this study.

With the exception of small communications from the periosteal blood vessels, to be mentioned later, no artery usually enters the adult vertebra from its exterior; all arteries are found within the neural canal.

The ventral artery arises in the intervertebral foramen; it travels on the posterior surface of the body obliquely towards the nutrient foramen, forming a " V " with its fellow from the other side. It is joined, near the foramen, by a small anastomotic branch from the ventral artery immediately caudal to it. Before entering the vertebral body it gives off: 1) an anastomotic branch to the ventral artery immediately cephalad to it, and 2) two or three epiphysial arteries to the epiphysis at either end. These arise at varying levels and travel towards the central part of the epiphysis posteriorly, then turn at right angles to enter the epiphysis.

On entering the vertebral body the artery divides into cephalad and caudad branches, which in turn divide into smaller and smaller branches till they reach the central part of the



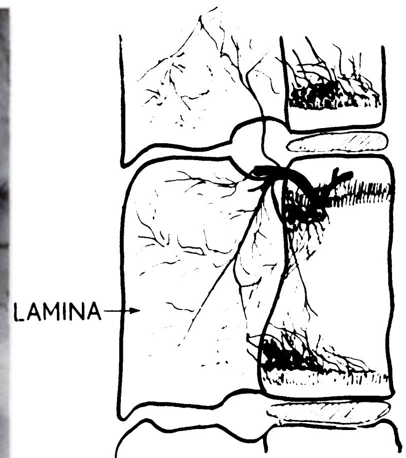


Fig. 11
The dorsal artery in a thoracic vertebra. A large anastomotic vessel is seen at the top of the picture.

metaphysis at either end (Fig. 5). The terminal ramifications are formed of a vast array of short straight capillary loops all ending at the same level—that is, at the calcified, metaphysial end of the growth plate (Fig. 6). The postero-lateral parts of the metaphysis are supplied by arteries from the neural arch, as will be described later.

The venous ends of the loops are drained by a system of veins which finally join up to form the basivertebral vein; this leaves the body posteriorly at the nutrient foramen.

The branches to the epiphysis have already been mentioned. Usually four enter the epiphysis from its posterior aspect; they fan out over the whole extent of the epiphysis, anastomosing with one another and giving off numerous short branches to the epiphysial side of the growth plate and to the boundaries of the intervertebral disc (Fig. 7). Just before entering the epiphysis these arteries give off numerous small branches, which anastomose behind the intervertebral disc with similar branches from the adjacent epiphysis and with a lattice work of vessels surrounding the annulus fibrosus (Figs. 8 and 9).

Most veins of the epiphysis drain into those on the posterior surface of the body. Two veins usually drain antero-laterally into vessels which join the external plexus near the intervertebral foramen. In the adult, with the disappearance of the plate, the metaphysial and epiphysial blood vessels unite and the looped appearance of the metaphysial vessels disappears. *The dorsal artery* arises in the intervertebral foramen and is directed towards the pedicle, which it enters through a nutrient foramen on the inner surface a little below its upper border.

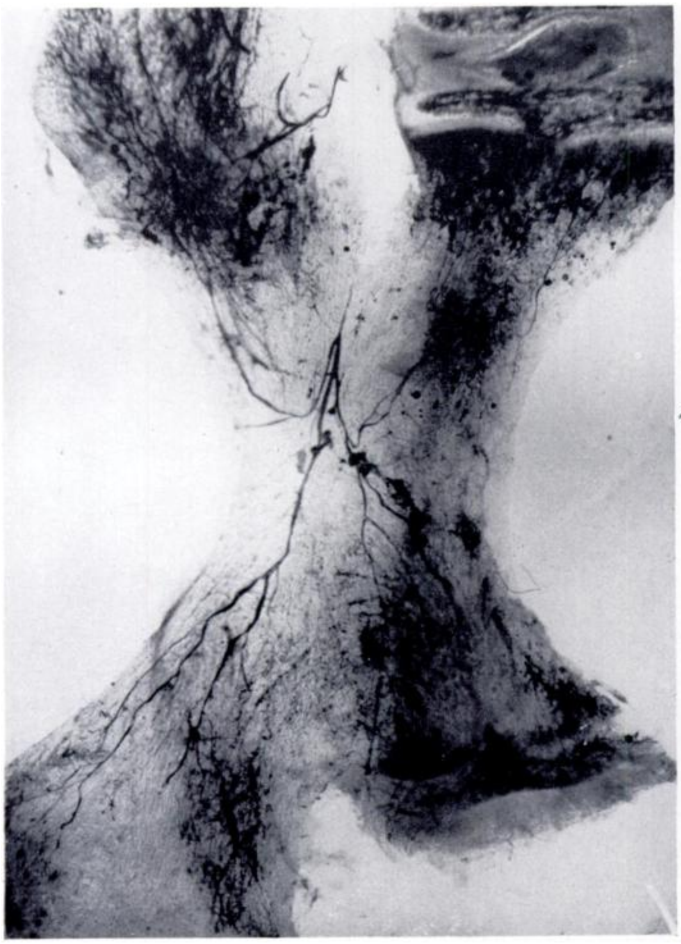


FIG. 12
Another dorsal artery in a lumbar vertebra, showing the terminal ramifications in the body (the extra-osseous portion of the artery is missing).

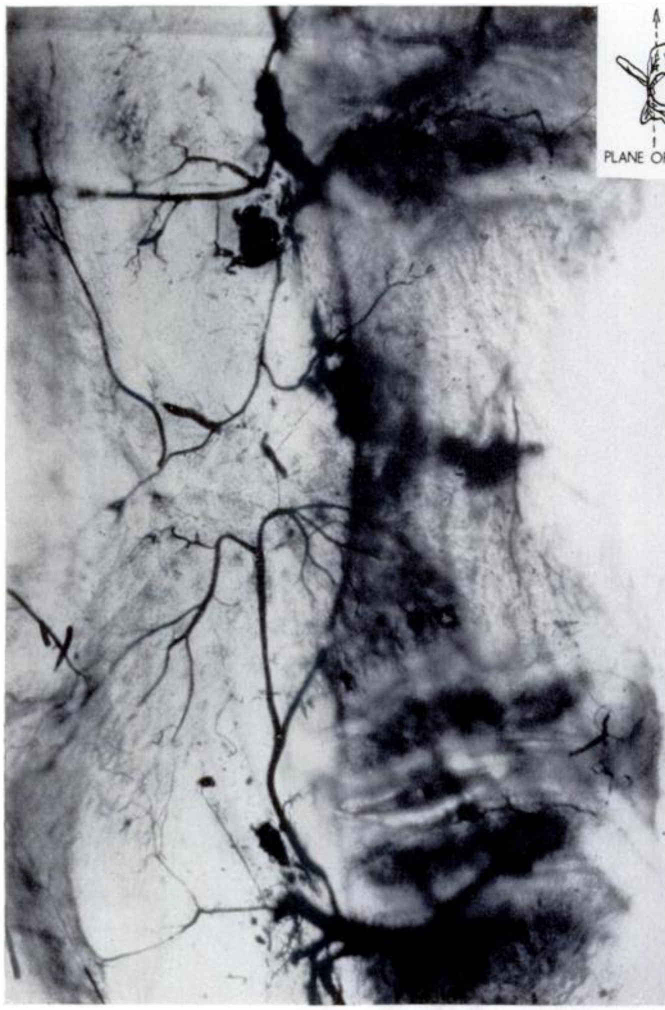
It supplies the whole of the neural arch and its processes, as well as the postero-lateral part of the vertebral body and the transverse process.

After entering its nutrient foramen the artery runs a straight intra-osseous course to the middle of the pedicle, where it divides like a spray into its terminal branches—namely, two anterior to the body and transverse process, and three posterior to the lamina and the spinous process, and to the anterior and posterior articular processes (Figs. 10 and 11).

The anterior branches enter the postero-lateral angle of the vertebral body and are directed to either growing end. They divide and end at the metaphysial side of the growth plate in exactly the same way as do the nutrient arteries to the centrum. They usually supply a wedge-shaped area based on the postero-lateral third of the growth plate (Figs. 8 and 12).

From the cephalad branch springs the artery to the transverse process; it is largest in the lumbar region, where the processes are long, and it runs a straight intra-osseous course to the tip where it ends at a growth plate in a manner similar to the arteries to the body. The growing tip is capped by an apophysis, which receives its blood supply from the surrounding soft tissue.

The posterior branches of the dorsal artery supply the rest of the neural arch. They run an intra-osseous course, fanning out to the articular processes, the laminae and the spinous processes. At the tips of the articular processes the arteries end at a growth plate in the same way as the arteries to the body. Each tip is capped by an apophysis.



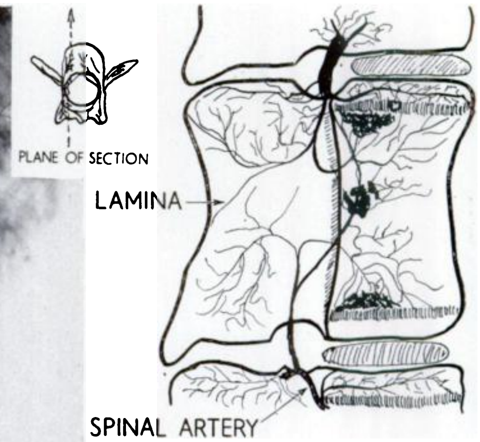


FIG. 13
Sagittal section of a lumbar vertebra showing the neural arch supplied by two spinal arteries.

In a number of cases the arteries to the neural arch spring from two spinal arteries and they restrict themselves to their own halves. A small anastomotic branch usually joins the two areas. This is a persistence of the pattern previously described as a developmental phase. It is found more commonly in the thoracic region (Fig. 13).

The periosteal supply—The periosteum receives a rich network of blood vessels from the segmental arteries and from the surrounding soft tissues. At the intervertebral discs it is intimately bound down to the annulus fibrosus, and its blood vessels form an intricate lattice work bridging one periosteal area to another. At the posterior surface of the

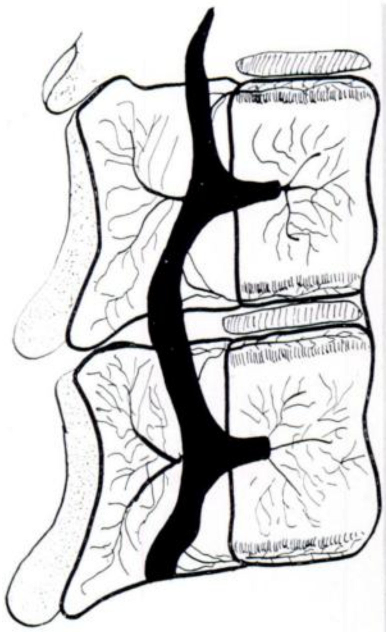
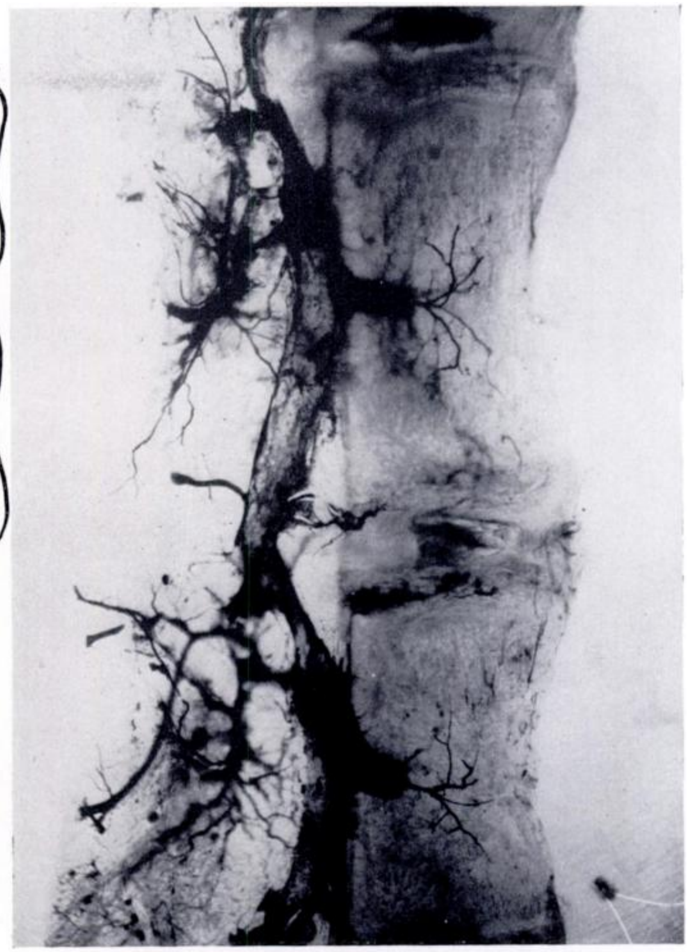


FIG. 14
Sagittal section of thoracic vertebrae of the rabbit to show the large vein on the posterior surface, overlying the ventral artery of which the ramifications can be seen in the body.



disc there is an anastomosis (already mentioned) between these vessels and the epiphysial arteries.

At the metaphysis of the bodies the periosteal vessels are in communication with the terminal branches of the nutrient vessels.

The periosteum over the neural arch is supplied by vessels from the posterior branch of the segmental arteries.

The venous drainage—The veins do not follow the strict pattern of the arteries. The veins are grouped into two longitudinal plexuses which run the whole length of the spine: 1) external, encircling the vertebrae, and 2) internal, in the neural canal.

The external plexus is arranged mainly along the antero-lateral aspects of the bodies and along the posterior surfaces of the laminae. Large segmental branches accompany the arteries and they communicate with the internal plexus at the intervertebral foramina. Small emissary veins from the metaphysial ends of the body and from the epiphyses join the external plexus.

The internal plexus in the neural canal drains two distinct areas which are separated by a thin membrane: one surrounds the spinal theca and the other lies close to the vertebra overlying the arteries. All the veins in the spinal canal are very large and bulky.

At the back of the vertebral bodies two large veins run longitudinally. They run a wavy course and are very near to one another near the middle of the body, where they are connected by the basivertebral vein; they deviate away towards the intervertebral foramina, where they connect with the external plexus (Figs. 14 and 15). The epiphysial veins drain into them at this level.

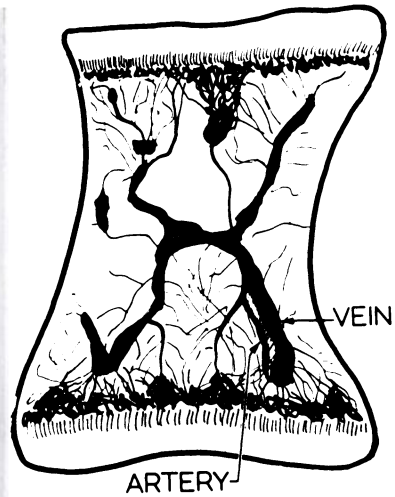


FIG. 15
A coronal section of the posterior surface of a vertebra to show the H-shaped vein overlying the thinner, straighter arteries.

A third column runs a longitudinal course at the junction of the two laminae.

The intervertebral disc—At no age have we been able to detect any blood supply to the disc. There is, however, a definite supply of vessels from the epiphysial arteries to the boundaries of the disc. This blood supply resembles that which, in long bones, supplies the articular cartilage.

DISCUSSION

The developmental phases of the blood supply to the spine present a continually changing picture. It is easy, therefore, to understand why descriptions in the literature are confusing and often at variance. Most authors have studied foetuses or still-born children which have presented a fragmented picture.

The evolution of the growth of the rabbit within a few months, compared with sixteen to eighteen years in man, has enabled us to construct, from the different phases, a more complete account. We realise that what we have described may be found to differ slightly from the actual state in man, but because the main structure and subdivisions of the vertebral column are so alike the main vascular pattern is likely to be similar.

SUMMARY

The blood supply of the vertebral column of the rabbit has been studied. A description of the embryological development of the blood supply is followed by a description of the blood vessels supplying the adult vertebra.

This work was carried out at the Nuffield Orthopaedic Centre, Oxford, and we are greatly indebted to Professor J. Trueta for his continued inspiration and advice and for all the facilities placed at our disposal. Some of the material used had been previously prepared for examination by Dr A. Viana, to whom we are also most grateful. Our thanks are also due to Mr W. Charles, who was responsible for the radiographs and photographs, and to Mr A. Mann, who prepared our sections.

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