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The arterial anatomy of the adult human lumbar vertebral body: a microarteriographic study

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INTRODUCTION

Microarteriography is now a widely used technique for the investigation of the blood supply to bones. It was first used to demonstrate the arteries of the vertebrae by Lexer, Kuliga & Turk (1904). These and subsequent investigators using microarteriography confirmed the description of the extra-osseous arteries made in 1803 by Antoine Portal who used a simple dissection technique. He described four pairs of lumbar arteries arising from the aorta and a fifth pair arising from the median sacral artery. The spinal artery arises from the lumbar artery at the intervertebral foramen through which it passes to enter the spinal canal. Deep to the posterior longitudinal ligament the spinal artery divides into an ascending and a descending branch. Each branch anastomoses with its counterpart from above and below to form a longitudinal series of arches. The apex of each arch anastomoses with the apex of the opposite arch and from this conjunction arise one or two nutrient arteries which pass forward into the vertebral body through the centre of its dorsal surface.

Little was added to this basic description until the presence of anastomotic vessels on the anterolateral surfaces of the vertebral body were shown to exist between the metaphyseal regions of adjacent vertebral bodies (Wiley & Trueta, 1959; Mineiro, 1965; Crock & Yoshizawa, 1977).

This uniformity and agreement between authors on the extra-osseous arteries is not shared by their descriptions of the intra-osseous arterial supply, although all authors agree that there is at least one intra-osseous nutrient artery which arises from the posterior longitudinal anastomosis.

Using either infant or fetal spines, one or two intra-osseous arteries arising directly from the lumbar arteries as they lie on the vertebral body are described by the majority (Hanson, 1926; Wagoner & Prendergrass, 1932; Furguson, 1950; Mineiro, 1965; Guido, Cigala & Riccio, 1969). The presence of any anterolateral arteries has been denied by one investigator who claimed that all the foraminae on the anterolateral surfaces of vertebral bodies were venous channels (Willis, 1949).

In adult material, multiple anterolateral intra-osseous arteries have been shown (Wiley & Trueta, 1959; Mineiro, 1965; Crock & Yoshizawa, 1977).

Bohmig (1930), whose work is still extensively quoted, described a single mid-line anterior artery which passes backwards to anastomose with the posterior nutrient artery to form a vertically running axial artery in the original site of the notochord, to ramify within the depths of the disc. No other investigator has described any arteries of consequence in the depths of the adult disc.

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Table 1. *Material*

Subject no.	Age (years)	Sex	Length of illness (days)	Cause of death
1	21	M	1	RTA
2	71	M	1	PE
3	70	M	1	MI
4	77	F	1	CVA
5	72	F	1	MI
6	74	M	1	PE
7	56	M	1	MI
8	48	M	3	PE×2
9	65	F	3	CVA
10	79	F	3	MI
11	47	M	2	RTA
12	69	F	2	MI
13	66	M	1	PE
14	36	F	3	RTA
15	72	F	2	RTA
16	23	M	1	RTA
17	90	M	3	MI
18	56	F	1	RTA
19	69	M	2	RTA
20	67	M	1	PE
21	57	F	1	CVA
22	30	M	1	CVA
23	41	M	1	RTA
24	43	F	1	RTA

RTA, Road traffic accident, usually a brain trauma death; PE, pulmonary embolism; CVA, cerebrovascular accident; MI, myocardial infarction.

MATERIALS AND METHOD

A total of 93 vertebrae from the lumbar regions of 24 adults was examined. Ages ranged between 21 years and 90 years (Table 1). There were 14 males and 10 females. All had enjoyed good health prior to a sudden death due to accident or cerebrovascular, cardiovascular or pulmonary embolic catastrophe. The interval between the catastrophe and death was short, in no case longer than three days.

The arteries of the vertebrae were injected whilst the spine was still in the fresh, unfixed cadaver. The aorta, if intact, or three adjacent pairs of lumbar arteries were cannulated and injected by hand, first with a warm suspension of 50 % Micropaque (Damancy & Co. Ltd.) in water and secondly with a warm suspension of 50 % Micropaque in 10 % gelatin. A technique of injection which resulted in filling 90 % of the microscopically observed arterioles was used: the technique and its assessment has been described elsewhere (Ratcliffe, 1978). After injection the specimens were allowed to cool in the cadavers and then excised *en bloc* and fixed in formol saline after removal of excess soft tissues. The specimens were decalcified in 10 % nitric acid and sectioned into slices of varying thickness, from 0·3 to 1 cm in one of the three planes of space.

Radiographs were taken at several stages in the preparation of the specimens and finally of the decalcified slices. These final films were made on fine grain film, Ilford B, Kodak Industrex C or Kodak Industrex M. A table mounted A.E.I. Raymax 50 tube was used with a focus-film distance of 90 cm and Kv of about 15. Long exposure times were used and the films were hand-processed.

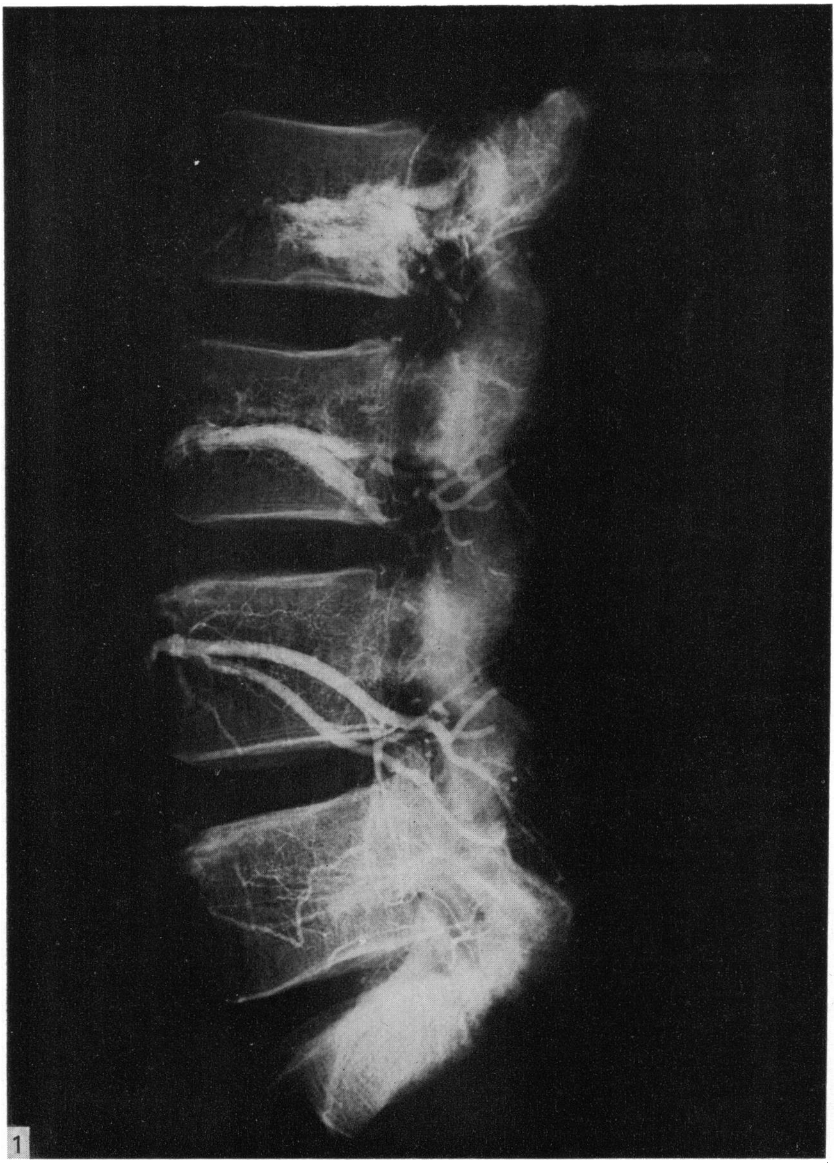


Fig. 1. The lower four lumbar vertebrae from subject 18 (female, 56 years) before decalcification. The narrow fifth lumbar arteries which are reinforced posteriorly from the fourth by the precostal anastomosis are shown. A few branches crossing the disc spaces can be seen, and the post-central anastomosis which is markedly displaced posteriorly by the discs.

RESULTS

Anterolateral surfaces

There are four pairs of lumbar arteries arising from the aorta which pass backwards around the vertebral body supplying many extra-osseous branches. At the intervertebral foramen each lumbar artery breaks up into several branches.

The fifth pair of arteries, the arteria lumbalis ima, arise from the median sacral artery and are much smaller than the lumbar arteries. These are reinforced posteriorly by branches from the iliolumbar arteries and particularly by one communicating

Fig. 2. Lateral view of a 1 cm slice of decalcified vertebral body from subject 2 (M, 71 years). The lumbar artery and the primary periosteal arteries arising from it and some crossing the disc are shown. (In the decalcified specimen, the disc is more radio-dense than decalcified bone.)

artery on each side from the fourth lumbar artery (Fig. 1). This anastomosis exists at all levels but is most pronounced between the fourth and fifth arteries. Because of its anatomical position lying in front of the embryological costal element of the lumbar vertebra, it has been tentatively called the pre-costal anastomosis.

From the upper and lower surfaces of the lumbar artery there arise between 10 and 20 periosteal arteries which pass upwards and downwards on the vertebral body surface (Fig. 2). Some of these cross the disc spaces in the peridiscal tissues to anastomose with their counterparts on the vertebra above or below respectively. These vessels could be called the primary periosteal arteries and the most posterior pair form the pre-costal anastomosis.

Near the upper and lower surface of the vertebral body and deep to the most superficial layers of the origin of the annulus fibrosus, there is a generally horizontal vessel which anastomoses with the vertically directed primary periosteal arteries. These horizontal vessels are more prominent in the upper metaphyseal region than in the lower (Fig. 3). This horizontal component of the anastomosis may be called the metaphyseal anastomosis.

Arising from all vessels, more marked in the elderly, are many smaller periosteal vessels, which have been called secondary periosteal arteries (Fig. 2).

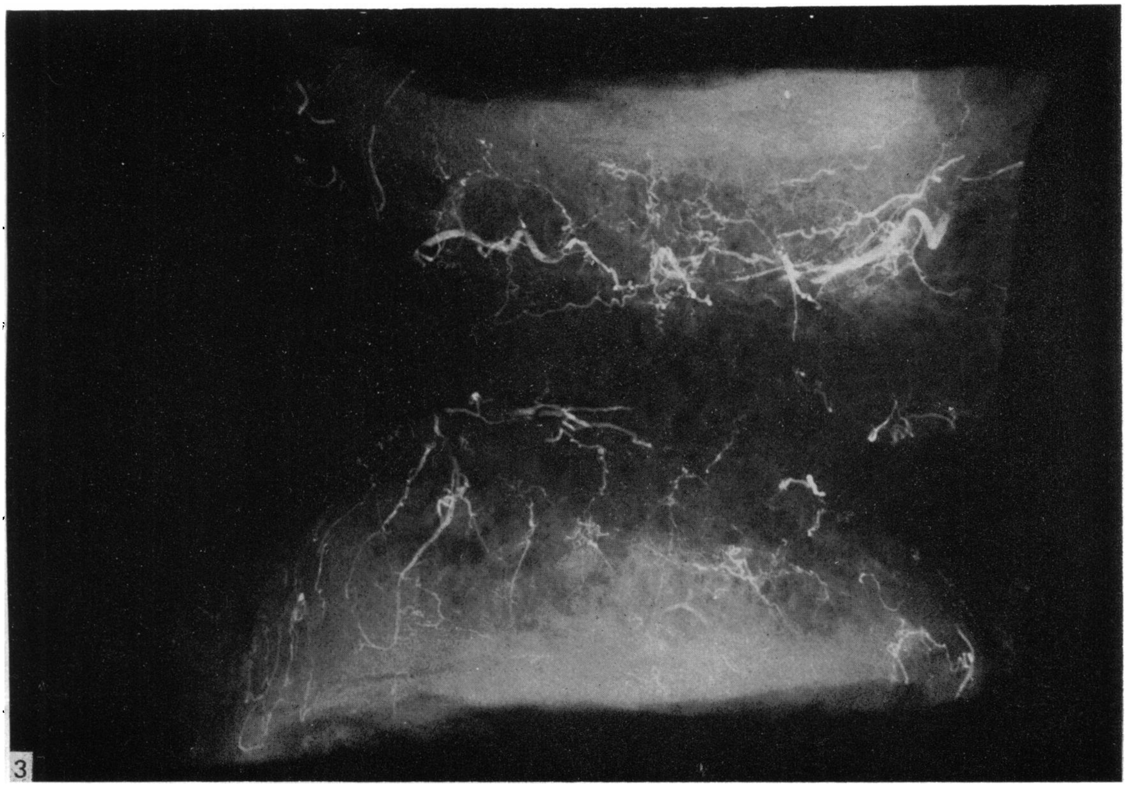


Fig. 3. The same specimen as in Fig. 2, but with most of the soft tissues removed. In the upper metaphyseal region, the metaphyseal anastomosis is clearly shown and in the lower, a much finer generally horizontal but incomplete vessel is seen. The anterolateral equatorial artery is shown 'end-on'.

Posterior surface

At the intervertebral foramen the lumbar artery sends a branch, the spinal artery medially, which hooks over the lateral process of the posterior longitudinal ligament. Deep to this ligament it divides into an ascending and a descending branch which anastomose with their counterparts from above and below to form a series of arches on each side. There is also an anastomotic channel, which anastomoses each arch to its opposite number across the mid-line. This longitudinal anastomosis has been called the post-central anastomosis (Fig. 4).

In some specimens, particularly the elderly, the anastomosis between different levels was lost as the descending branch crossed the intervertebral disc (Fig. 5). Thus, in the elderly, the arterial appearance was one of a series of 'H's rather than a long intervertebral chain.

Even when the A–P projection suggested that a good longitudinal anastomosis existed as in Figure 4, the lateral view of the same specimen before coronal sections were made shows that the anastomosis was narrowed and projected backwards over the intervertebral disc (Fig. 6).

Intra-osseous arteries

Horizontal sections through the vertebral body at approximately 0·3 cm intervals from disc to disc show the vessels to be mainly distributed in the middle three sections

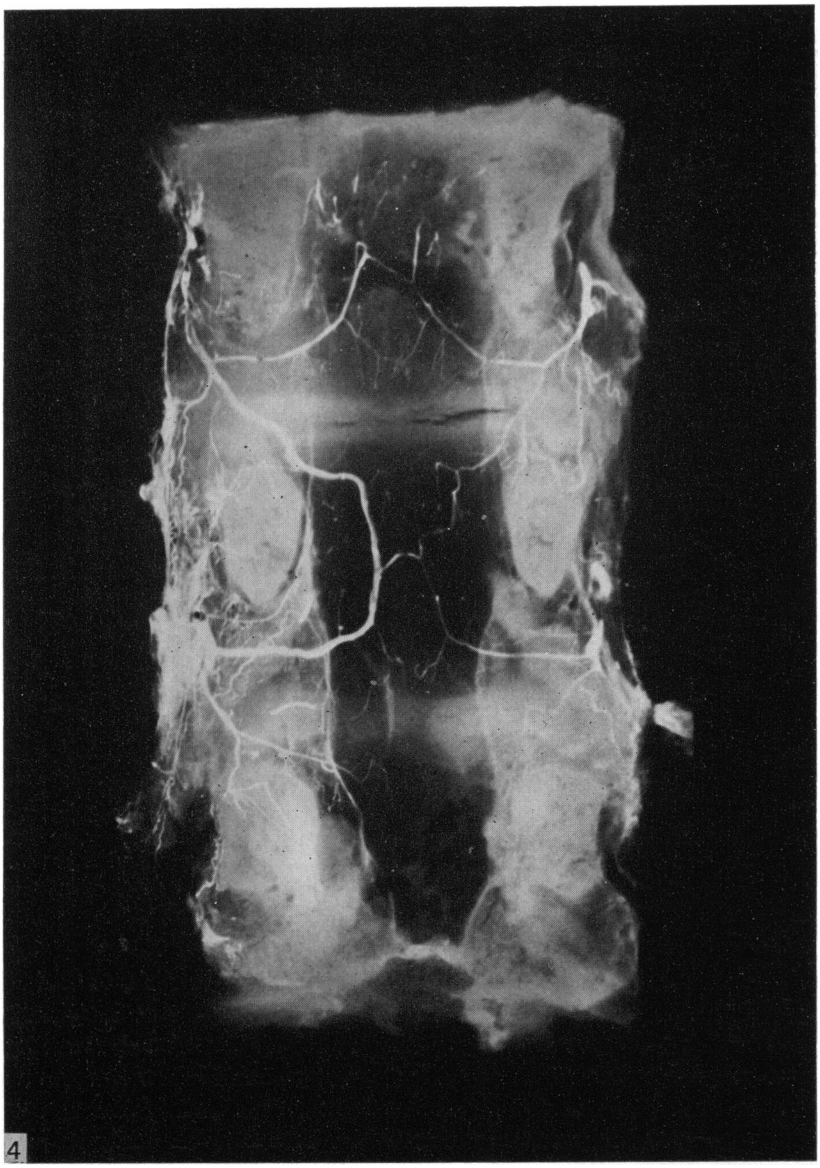


Fig. 4. A dorsal view of a 1 cm coronal section of the fourth and fifth lumbar and first sacral vertebral bodies after decalcification and removal of the neural arches of subject 11 (M, 47 years). There are anastomotic vessels (larger on the left) between the fourth and fifth lumbar arteries, even though in this case the fifth lumbar arteries were larger than usual. The rhomboidal pattern of the post-central anastomosis is shown.

(Fig. 7), the immediately subdiscal zones being relatively free of major vessels. These three layers can be more clearly seen in coronal (Fig. 8) or sagittal section (Fig. 9). The main trunks of the vessels are arranged horizontally and are themselves also arranged in three layers: in the equatorial plane, and in a plane above and below the equatorial plane (Figs. 7–9).

The arteries of the equatorial plane are the main nutrient arteries from the post-central longitudinal anastomosis and one or two arteries on either side which arise

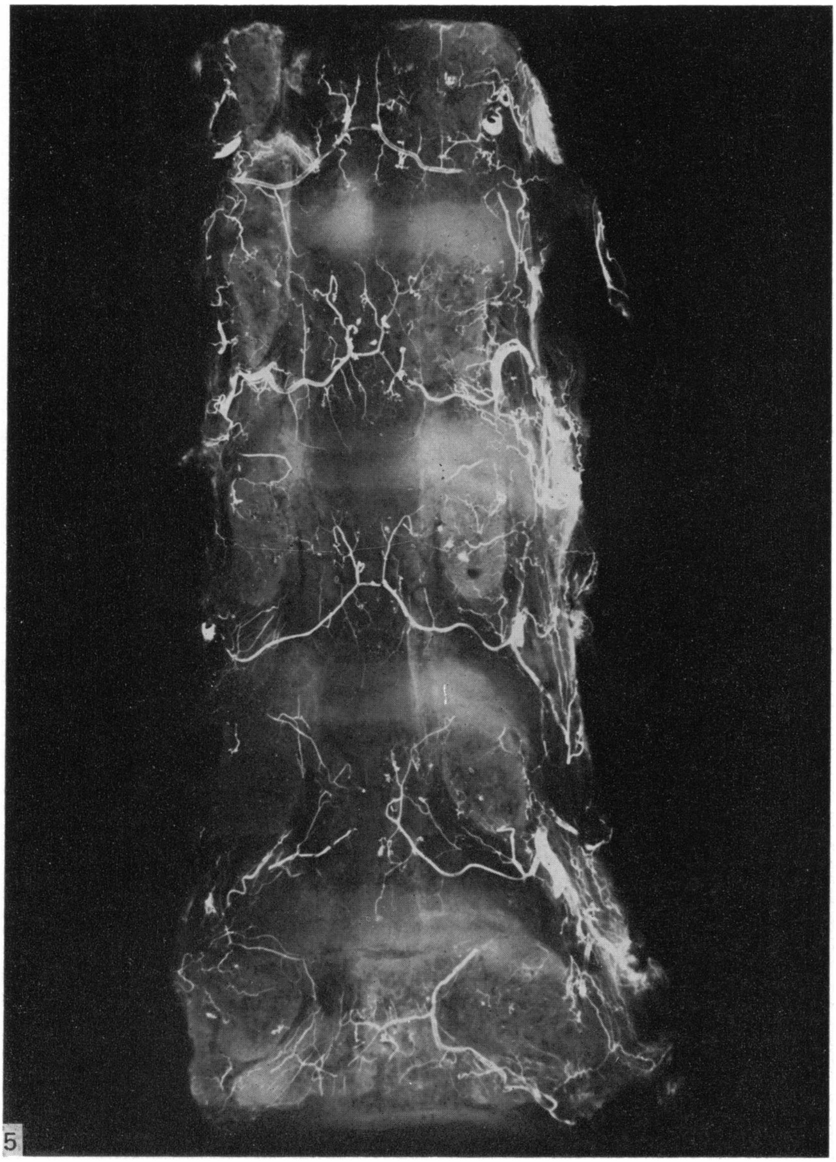


Fig. 5. A dorsal view of a 1 cm thick coronal section of the five lumbar vertebrae from subject 3 (M, 70 years) after decalcification and removal of the neural arches. The general loss of the descending branch of the spinal artery as it crosses the disc space is demonstrated. The longitudinal 'anastomosis' is now a series of 'H's.

directly from the lumbar artery as it traverses the anterolateral surface of the vertebral body (Figs. 7–10), which have been called the anterolateral equatorial arteries. The planes on either side of the equatorial plane have been called metaphyseal planes and the long-stemmed horizontally and radially disposed arteries in the metaphyseal planes have been called metaphyseal arteries. These metaphyseal arteries arise either from the primary periosteal arteries or from the metaphyseal anastomosis deep to the most superficial layers of the annulus fibrosus (Figs. 8–10).

If the vertebral body is sliced horizontally in thick sections, then all the three

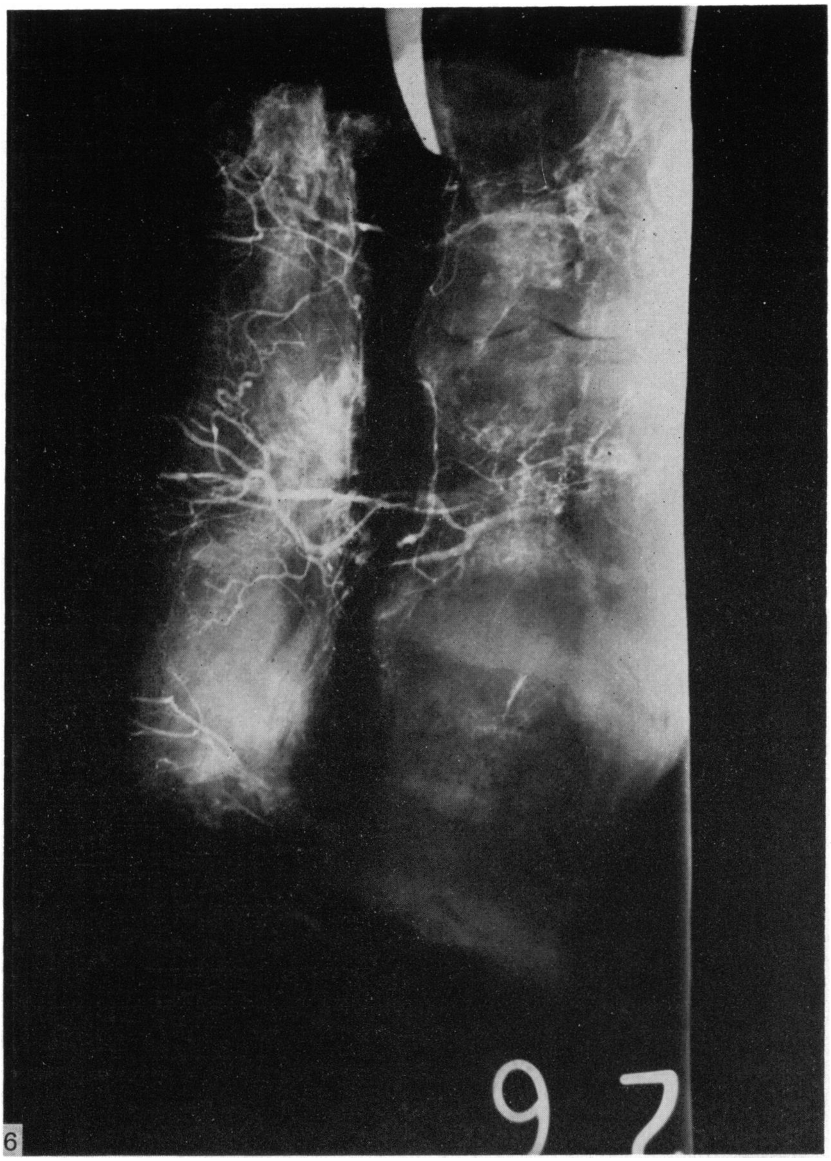


Fig. 6. The same specimen as in Fig. 4, but before decalcification and sectioning. The post-central anastomosis is shown to be projected posteriorly at the level of the disc and to be compressed, although when viewed dorsally in Fig. 4, this is not apparent.

vascular layers are superimposed on axial projection and the horizontal distribution into three layers of vessels is not appreciated (Fig. 11).

The equatorial and metaphyseal arteries have four unusual features in common: They do not branch in the peripheral third of the vertebral body, they have a variable number of pre-terminal coils, they break up into a terminal leash of vessels, and these nutrient terminal branches are centrifugally directed (Figs. 7–13). The centrifugal branches of the nutrient and anterolateral equatorial arteries are discally directed (Figs. 8–10). The centrifugal branches of the metaphyseal arteries are both discally centrifugal and radially centrifugal (Figs. 8, 9, 11–13). The nutrient arteries differ from the other main intra-osseous arteries in that they are significantly wider in diameter, and much more coiled in their stems and branches. It would appear that these vessels in older spines were more coiled than in the younger (Figs. 7–11).

Morphologically quite different from the foregoing intra-osseous arteries is a distinct third type. These arteries are short stemmed, branch peripherally and have centripetally directed nutrient branches (Figs. 11–13). These have been called peripheral arteries and occur more frequently in older spines. They arise from the secondary periosteal arteries.

In four spines the fifth lumbar vertebra had an unusual intra-osseous supply in that the main nutrient artery arose from the median sacral artery on its anterior surface, and not from the post-central anastomosis (Fig. 14).

DISCUSSION

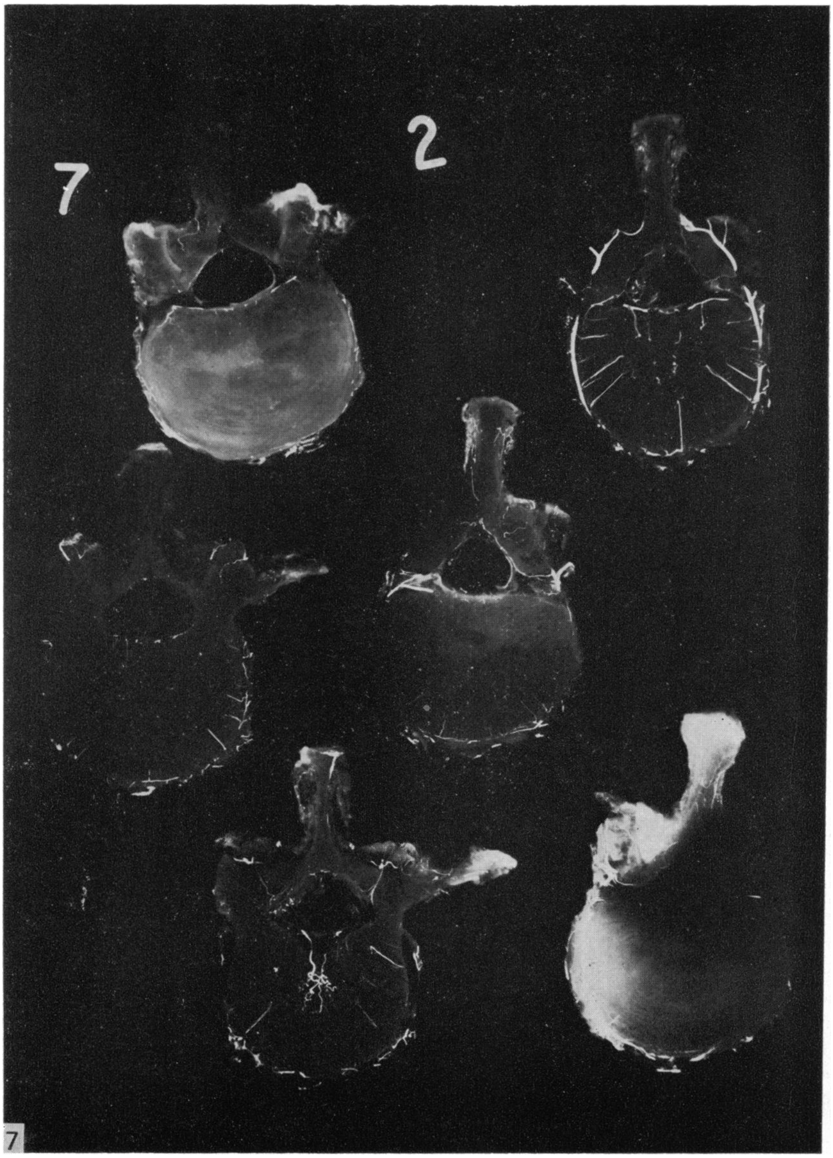
From this material it is possible to delineate a complex periosteal intersegmental network (Fig. 15). On the anterolateral surfaces the network has horizontal and vertical components. The horizontal components are the lumbar arteries and the upper and lower metaphyseal anastomoses which both cross the mid-line behind the aorta. The vertical component consists of the primary periosteal arteries arising from the lumbar arteries. The primary periosteal arteries anastomose with the metaphyseal anastomoses and then cross the disc space in the superficial layers of the disc to anastomose with the primary periosteal arteries from the adjacent segmental artery. A prominent vertical component between the fourth and fifth lumbar arteries might be named the pre-costal anastomosis.

The pre-costal anastomosis might correspond embryologically to the superior intercostal artery. In the lumbar region, this vessel would appear to convey blood to the fifth vertebral body and its division during surgical anterior or lateral approaches to the disc space should be avoided.

The post-central anastomosis, so called because it lies behind the centra, may be illustrated as a rhomboidal ladder-like longitudinal anastomosis (Fig. 15). In youth and early middle age there is a fairly prominent anastomosis between the arteries of the fourth and fifth lumbar vertebrae. The disappearance of the descending branch of the post-central anastomosis in spines of advancing years may be due to compression between the bulging disc and the lateral process of the posterior longitudinal ligament.

The intra-osseous arteries may be illustrated as in Figure 16. It should be noted that the nutrient artery supplies that part of the vertebral body behind the centre which is subjacent to the nucleus pulposus. The significance of the anterior mid-line artery in a few of the fifth vertebral bodies is unknown. It may be that these were noted by Bohmig (1930) who erroneously considered them to be a usual type of intra-osseous artery. It should be noted that the anterior mid-line artery breaks up behind the mid-point and its branches are distributed to the vertebral body mainly behind the mid-point (Fig. 14). The regions of distribution of the intra-osseous arteries can be zoned as in Figure 17.

No arteries were seen within the depths of the intervertebral discs. Anastomotic vessels with few or no nutrient branches crossed the disc spaces between adjacent metaphyseal anastomoses in the superficial layers of the annulus fibrosus. Oxygen and nutrients essential for the metabolism of the disc must arrive by diffusion from the subjacent lumbar vertebral body. This diffusion is speeded up by the agitation of



extracellular fluid by the frequent movement between the lamellae of the annulus fibrosus. The fluid trapped between these lamellae would tend to channel the oxygen and nutrients in solution in the same vertical plane from which they originated in the vertebral body. Because the discal surface of the vertebral body has a zoned blood supply, then the supply of oxygen and nutrients to the intervertebral disc will also be correspondingly zoned, as in the lower diagram in Figure 17.

Discal degeneration and the low back pain syndrome being the result of discal hypoxia and starvation secondary to a reduced blood supply of the adjacent vertebral bodies is an attractive theory, but one which would be difficult to prove directly. There are a number of observations which would tend to support such a theory.

It has been shown that the pH and lactic acid concentrations of symptomatic discs differ from normal and it has been suggested that these biochemical changes are due

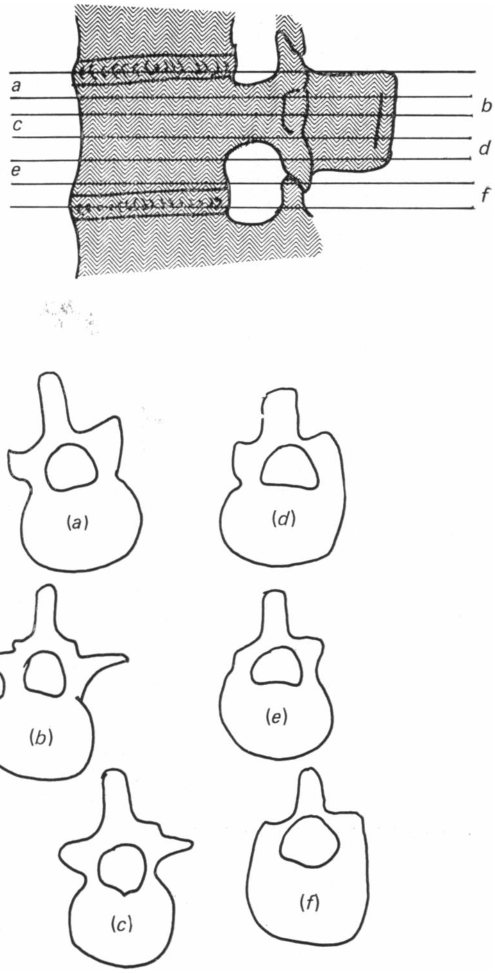


Fig. 7. Horizontal sections 0·3 cm thick through the second lumbar vertebra of subject 7 (M, 56 years) after decalcification. The top diagram shows how the vertebra was cut into six sections (*a–f*) and the lower shows how these six sections are laid out in the radiograph. The majority of vessels lie in sections *b* (upper metaphyseal), *c* (upper metaphyseal and equatorial), and *d* (equatorial and lower metaphyseal). The two nutrient arteries can be seen in *c*.

to anoxic respiration within the discs (Diamant, Karlsson, & Nachemson, 1968; Nachemson, 1969).

The central zone of the disc is supplied from the nutrient and metaphyseal arteries of the adjacent vertebral bodies. The outer ring of the annulus fibrosus is supplied from the peripheral arteries. The nutrient and metaphyseal arteries are relatively long and convoluted arteries, which may be subject to arterial degeneration and catastrophes similar to any other artery. Atheromatous embolism within vertebral bodies has been observed (Zak & Elias, 1949). The peripheral arteries, although narrower, are shorter and less complex and, as age increases, apparently more numerous. Thus, as age advances, the outer sleeve of vertebral body may get a relatively better blood supply whilst the central zones receive relatively less. Discal degeneration and dessication appear at the centre of discs earlier than in the more peripheral parts which may remain apparently healthy, and capable of repair long after disintegration and extrusion of the central part of the disc.

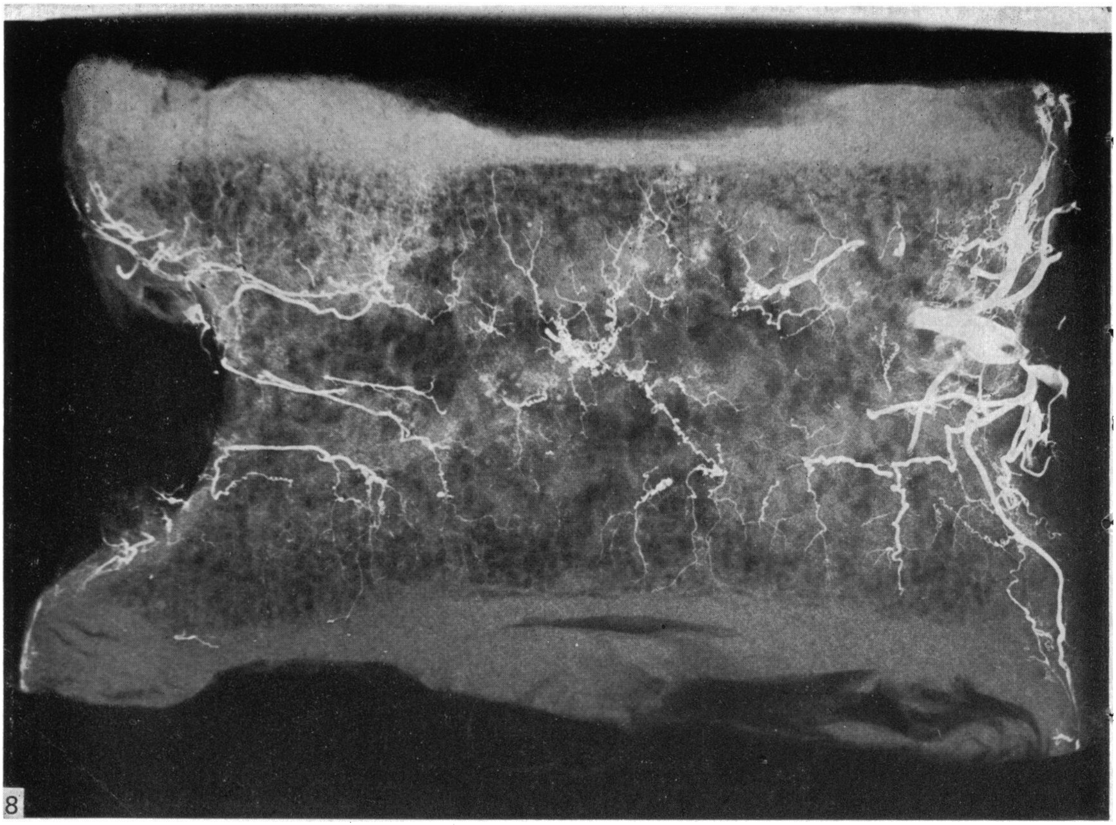


Fig. 8. Coronal section 0·3 cm thick through the third lumbar vertebra of subject 10 (F, 79 years). The periosteum and loose soft tissues have been dissected from the left side. This is the top section in Fig. 10. The relatively avascular zones in the subdiscal regions are shown. On the left, in the superficial layers of the origin of the disc, is shown the metaphyseal anastomosis, from which the upper metaphyseal intra-osseous arteries arise. Running discally from this anastomosis are vessels in the superficial layers of the disc running towards adjacent vertebrae above and below. Also on the left is shown the anterolateral equatorial artery. Metaphyseal arteries with discally directed branches are shown on both sides. In the centre the branches of the nutrient artery are shown *en face*. These branches are highly convoluted and terminally discally directed.

After interruption of the branches of the post-central anastomosis by the bulging fourth disc and the lumbosacral disc, the blood supply to the nutrient artery of the fifth lumbar vertebra depends solely on the spinal branches of the arteria lumbalis ima. These spinal branches are themselves particularly at risk from compression by the disc as they pass through the intervertebral foramen and have a largely circuitous and tenuous blood supply via the pre-costal anastomosis from the fourth lumbar artery, the narrow fifth lumbar arteries arising from the small median sacral artery and the iliolumbar arteries.

The jeopardised blood supply to the nutrient artery results in a jeopardised nutrition and oxygenation of the central core of the fifth lumbar vertebra and of the adjacent discs. This might result in a high incidence of discal degeneration on either side of the fifth lumbar vertebra. In one large series 95 % of all disc lesions occurred in either one or both discs immediately adjacent to the fifth lumbar vertebra (Rosen, 1969).

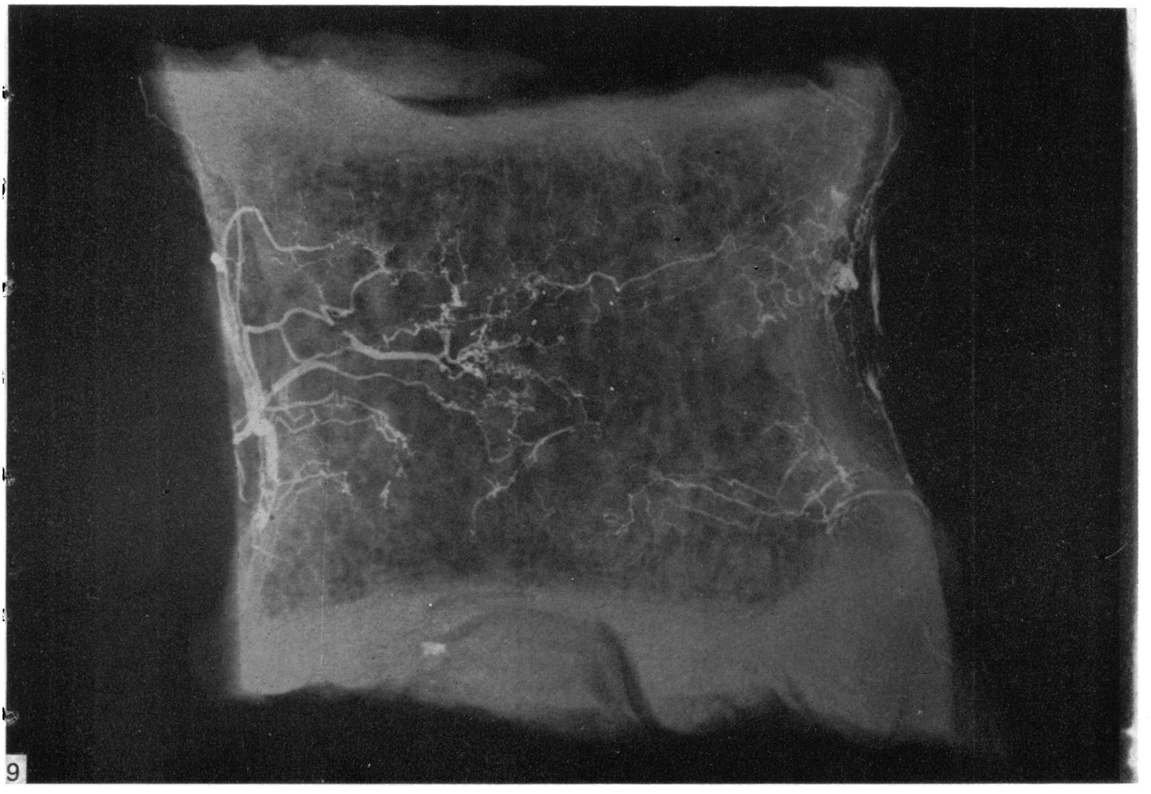


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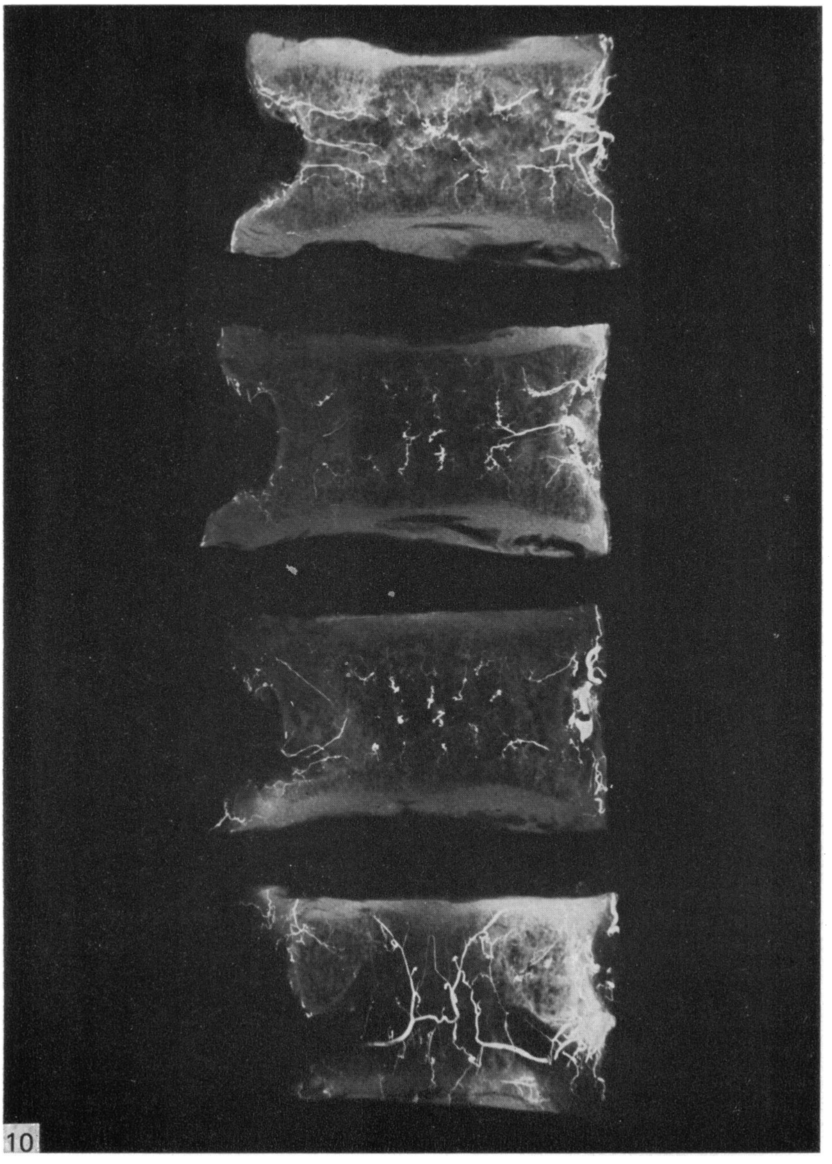
Fig. 9. The central 0·3 cm sagittal slice of the same vertebral body as shown in Figs. 2 and 3. The relatively avascular subdiscal zones are shown. The metaphyseal vessels anteriorly are prominent. The terminal portion of an anterolateral artery is seen. The two nutrient arteries are shown at the equator, breaking up behind the mid-point. No anterior equatorial artery is observed. The branches of the nutrient and metaphyseal arteries are discally directed.



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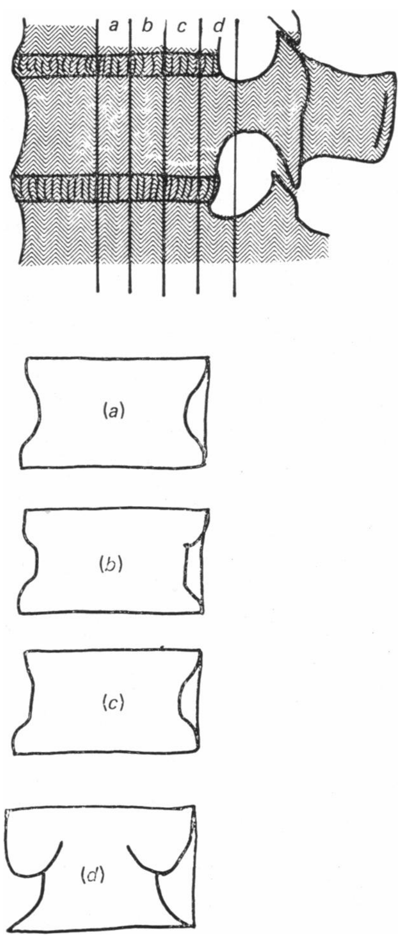

Fig. 10. Coronal sections 0·3 cm thick through the third lumbar vertebra of subject 10 (F, 79 years). The top diagram shows how the vertebral body was cut in vertical sections and the lower diagram shows how these sections were laid out on the radiograph. (*a*) is enlarged in Fig. 8 and shows the left anterolateral equatorial artery. In (*b*) the right anterolateral artery is shown arising directly from the lumbar artery. In (*c*) the arteries seen end on demonstrate that the posterior intra-osseous arteries are also arranged in three layers, the two nutrient, in the equator, and the metaphyseal, in layers above and below the equator, but with an avascular zone between them and the disc.

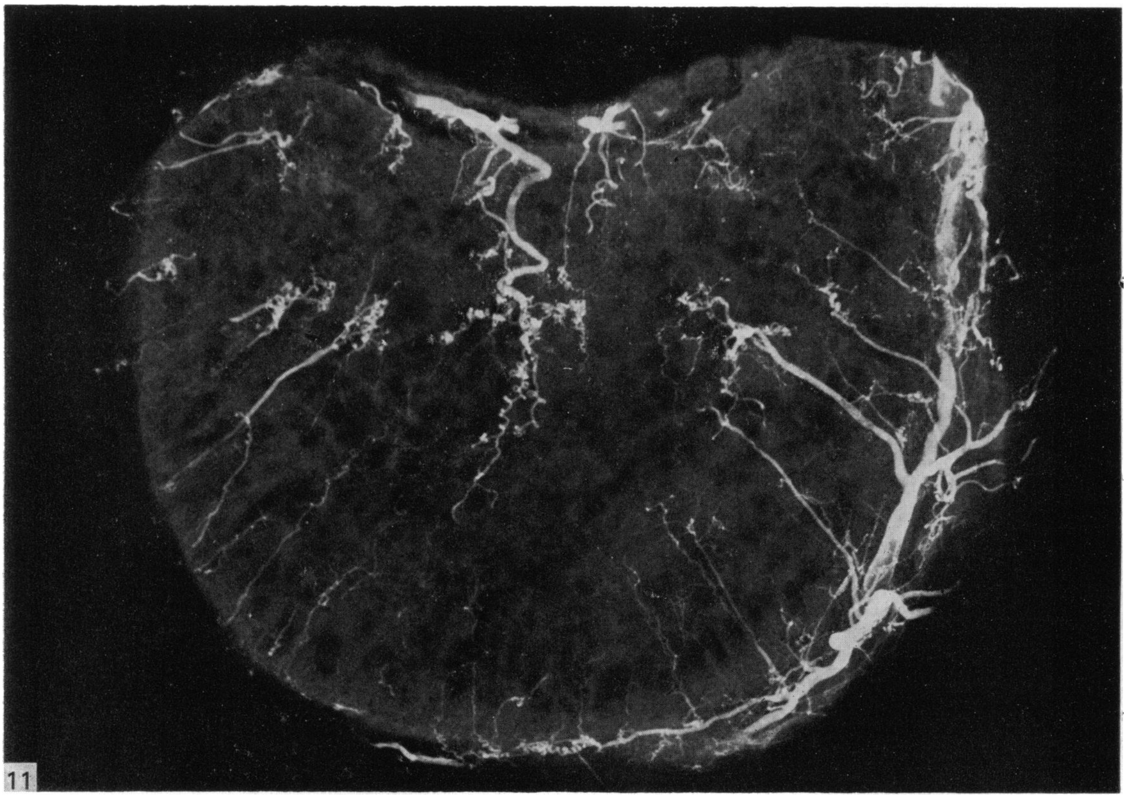

Fig. 11. Axial view of a horizontal slice 2 cm thick from a vertebra from subject 19 (M, 69 years). The periosteum on the left has been dissected off. All the intra-osseous vessels are superimposed. The metaphyseal arteries are shown to have radially centrifugal branches, and the nutrient and metaphyseal arteries are seen to be highly coiled.

Fig. 12. An enlargement of *d* in Fig. 7. This shows the straightness of the metaphyseal arteries and lack of peripheral branching of these vessels and fewer convolutions in the younger specimen than in Fig. 11. The radially centrifugal direction of branching is again seen.

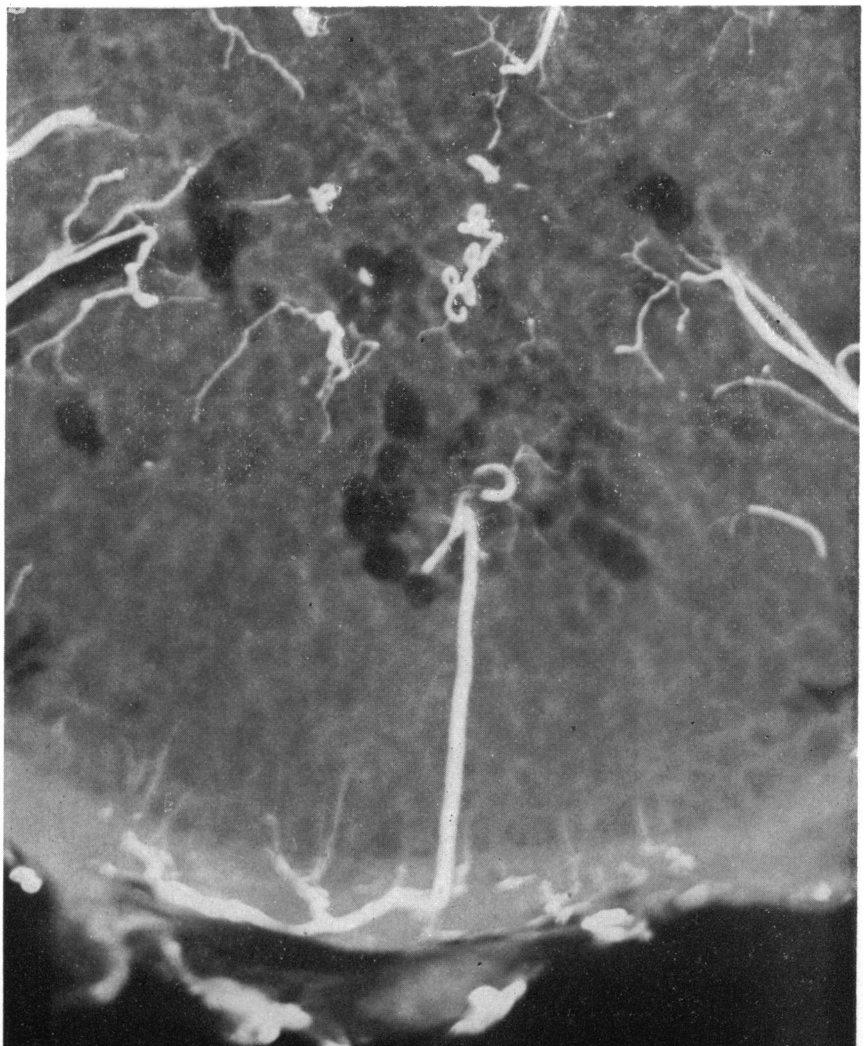

Fig. 13. An enlargement of Fig. 12. This shows a typical metaphyseal artery, and a number of peripheral arteries which are quite different in that they branch peripherally and have centripetally directed branches. They are also much smaller.

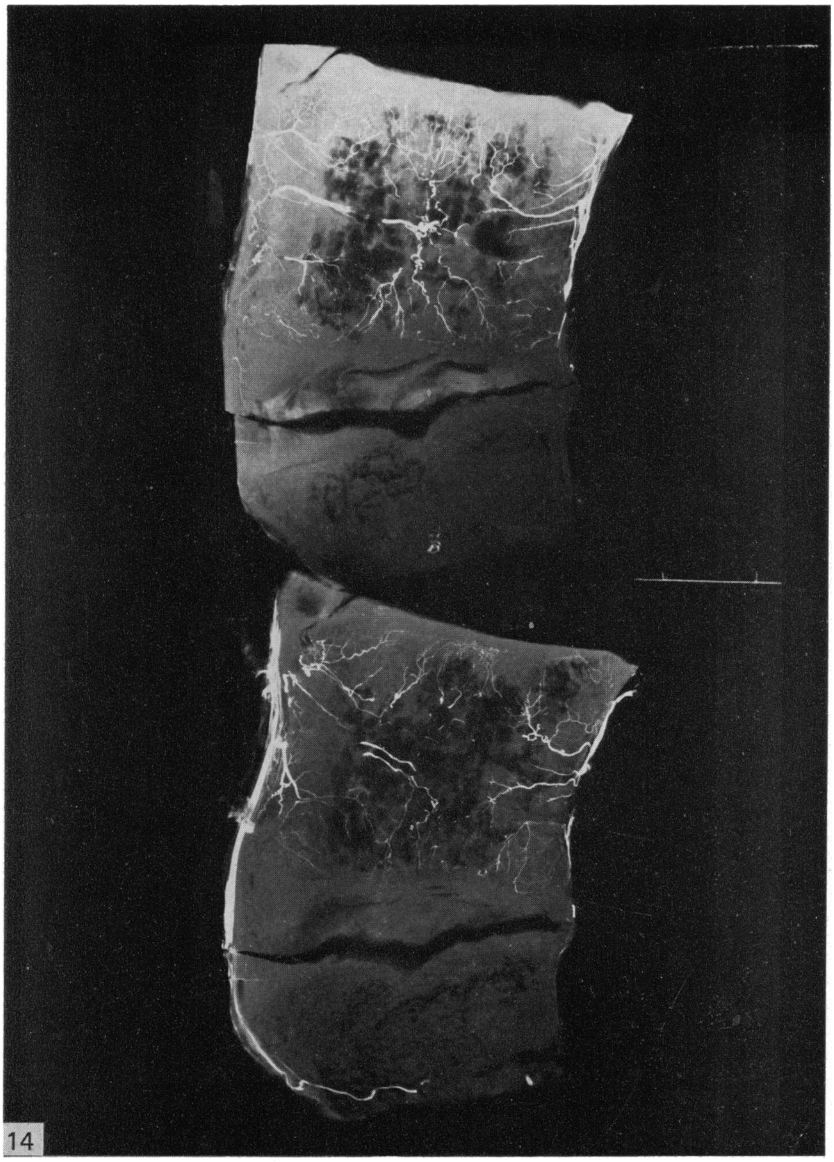

Fig. 14. The middle two sagittal sections 0·3 cm thick, of the fifth lumbar vertebral body from subject 1 (M, 21 years). The upper section shows an anterior almost mid-line artery which passes posteriorly to behind the mid-point before breaking up. The lower section shows the median sacral artery. It is interesting to note that the vessels in the subdiscal regions are exceptionally well filled in this specimen.

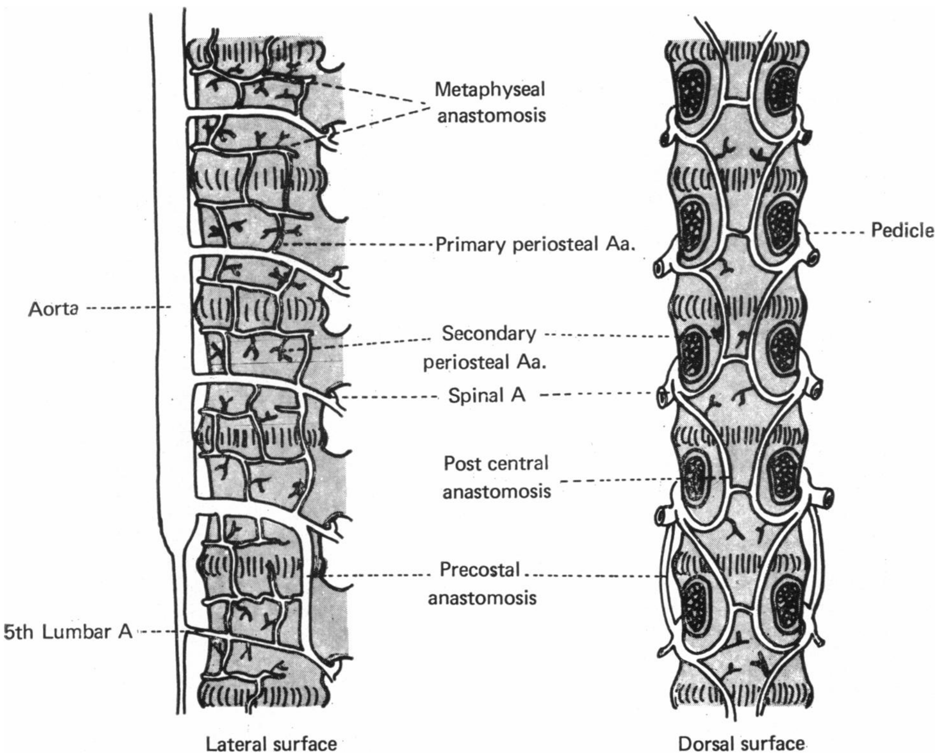

Fig. 15. Diagram of the extra-osseous arteries of the bodies of the human lumbar vertebrae with neural arches removed.

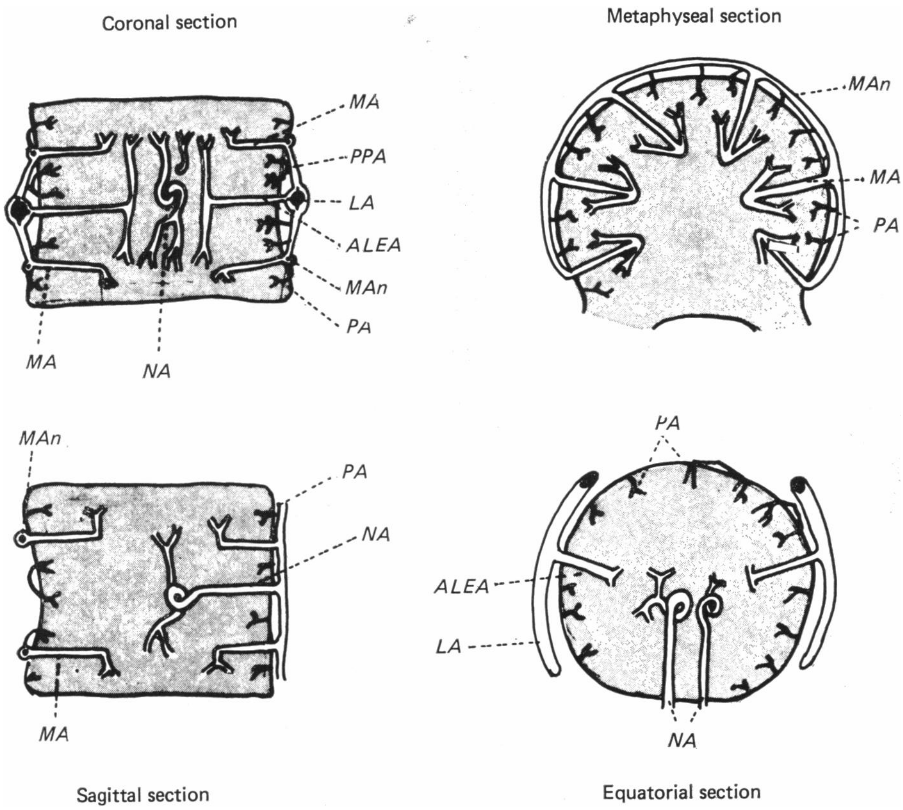

Fig. 16. Diagram of the intra-osseous arteries of the adult lumbar vertebral body. The vertical sections on the left show the relatively avascular zones immediately subjacent to the disc, and the more vascular central section which itself can be divided into equatorial and two metaphyseal sections. *ALEA*, anterolateral equatorial artery; *LA*, lumbar artery; *MA*, metaphyseal artery; *MAn*, metaphyseal anastomosis; *NA*, nutrient artery; *PPA*, primary periosteal artery; *PA*, peripheral artery.

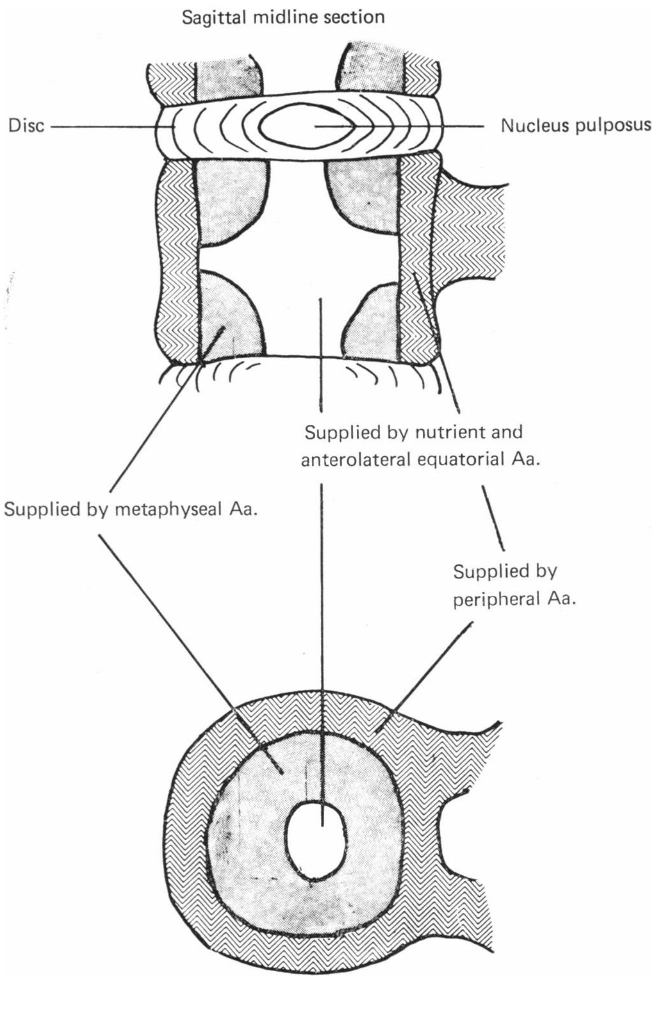

Fig. 17. Diagram of the zones of exclusive arterial distribution of the intra-osseous arteries of the adult lumbar vertebral body.

SUMMARY

The anatomy of the arteries of 93 adult human lumbar vertebral bodies was studied microarteriographically. There is a network of periosteal arteries joining the arteries of adjacent vertebrae on the anterolateral and posterior surfaces. These are prominent between the fourth and fifth lumbar arteries.

There are three types of intra-osseous arteries: equatorial, metaphyseal and peripheral. Each supplies a separate zone. The peripheral arteries are short, branch early and have centripetally directed terminal branches; they supply the outer collar of the vertebral body. The equatorial and metaphyseal arteries are morphologically similar, having straight unbranching stems, pre-terminal coils and centrifugal terminal branches. The equatorial arteries supply the central core of the vertebral body subjacent to the nucleus pulposus, and the metaphyseal arteries supply an annular zone between the other two types.

Some circumstantial evidence that discal degenerative disease is associated with discal, or vertebral body, anoxia is presented. The present study adds to this evidence.

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