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An evaluation of the intra-osseous arterial anastomoses in the human vertebral body at different ages. A microarteriographic study

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INTRODUCTION

The general anatomy of the intra-osseous arteries of the vertebral body has been described in the adult and immature human (Ratcliffe, 1980, 1981), but in these two studies it was impossible to assess the presence or effectiveness of intra-osseous anastomoses. Clearly the significance of an artery or group of arteries is very different if they are end arteries or part of an anastomosis.

Widespread intra-osseous arterial anastomoses in adult vertebral bodies were described by Mineiro (1965) but he failed to demonstrate anastomoses in children. Guida, Cigala & Riccio (1969) claimed that there were multiple intra-osseous anastomoses in the vertebral bodies of a neonate.

This paper reports work to assess the presence and extent of intra-osseous anastomoses in the human vertebral body.

MATERIAL AND METHOD

Twelve lumbar and nine lower dorsal vertebrae from 11 subjects aged from 3 months to 51 years were examined. All had died from sudden brain catastrophe. Data concerning age, sex and vertebrae examined are presented in Table 1.

The vertebrae were excised from the fresh cadavers and dissected down to periosteum, leaving periosteal vessels and segmental arteries intact. The neural arches were removed.

In each vertebral body a periosteal artery, usually the ascending branch of the spinal artery, or a short segment of a lumbar artery, was cannulated with a fine polythene tube which was tied in place (Figs 1, 2). The periosteal branches were ligated at a little distance from the site of cannulation and the periosteum peripheral to these ligatures scraped away. An isolated island of periosteum with an intact and cannulated arterial supply was thus created. A dissecting microscope was often used.

Methylene blue or brilliant green was injected through the cannula to identify other cut vessels which were then ligatured. These dyes permeated the arterial distribution of the cannulated artery and stained the tissues of the capillary bed supplied by the cannulated artery and some tissue around the draining veins (Figs. 3, 4).

Hand injection of 0·1–0·5 ml of 50 % Micropaque (Damancy & Co.) in water was made, followed by a similar volume of warm Micropaque 50 % in a 10 % gelatin solution. The specimen was cooled, radiographed, fixed in formol saline and

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Table 1. *Material*

Subject no.	Age years	Sex	Vertebrae examined		
1	0·5	M	D10		
2	1·5	F	D10	D11	
3	0·25	M	D10	D11	
4	7	M	D9	D10	
5	15	M	D9	D10	
6	30	M	L_1	L_2	L_3
7	38	F	L_2	L_4	
8	42	F	L_3	L_5	
9	45	F	L_2		
10	47	M	L_3	L_4	
11	51	F	L_1	L_4	
			Total		21

decalcified in 10 % nitric acid. Most specimens were sectioned by hand into slices from 1 mm to 5 mm thick. The sections were radiographed serially on fine emulsion film using a low kV. Unfortunately the specimens from the 7 years old child were accidentally destroyed before decalcification.

RESULTS

(1) Infants. All seven vertebral bodies showed a profuse arterial opacification both near to, and distant from the site of injection (Fig. 5). Rupture of vessels with extravasation of Micropaque was rarely seen.

(2) In the child of 7 years, both undecalcified specimens showed filling of vessels adjacent to the site of injection and only a few vessels distant from the site of injection were identified (Figs. 6, 7). These two specimens were accidentally destroyed.

(3) In the adolescent of 15 years, there was filling of very few arteries distant from the site of injection via intra-osseous anastomoses (Figs. 8, 9, 10). The extra-osseous post-central anastomosis which was not ligatured in one specimen carried barium suspension up to the nutrient artery of the adjacent vertebra (Fig. 8). There was

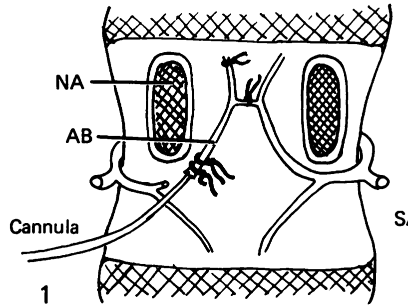
Fig. 1. Diagram of the cannulation of arteries of the post-central anastomosis. The neural arch (NA) has been sawn off. The ascending branch (AB) of the left spinal artery (SA) has been cannulated. It has been isolated by ligating the communicating arteries.

Fig. 2. This diagram shows the lateral surface of a vertebral body. A short segment of the lumbar artery (LA) has been isolated with its periosteal arteries and has been cannulated.

Fig. 3. Photograph of a cut, decalcified vertebral body after selective cannulation of part of the post-central anastomosis as in Fig. 1. Brilliant green and Micropaque have been injected and the area supplied has been stained darkly. × 1.

Fig. 4. Photograph of a coronal section of decalcified adult (42 years) vertebral body after selective cannulation of part of the lumba rartery, as in Fig. 2. Brilliant green and Micropaque were injected and the region supplied by the intra-osseous arteries arising from this part of the lumbar artery has been stained darkly. There was also some slight staining around the central emissary vein. This was more evident in the fresh specimen and in colour photographs. × 1.

Fig. 5. Radiograph of a horizontal section through a dorsal vertebral body from an infant of 18 months. Part of the post-central anastomosis on the right (Inj) had been cannulated and isolated by clearing the adjacent periosteum. It was injected with Micropaque. There was exceptionally good and widespread arterial filling within the vertebral body and in adjacent soft tissue on the right – extending into the right neural arch. On the left arterial filling is less complete. No extravasation is evident. × 5.



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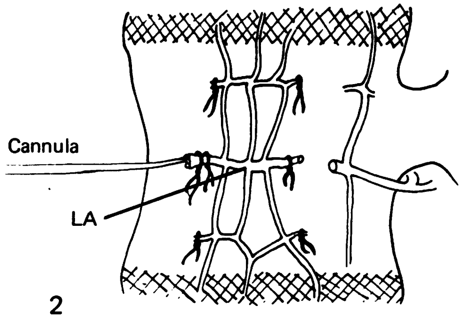

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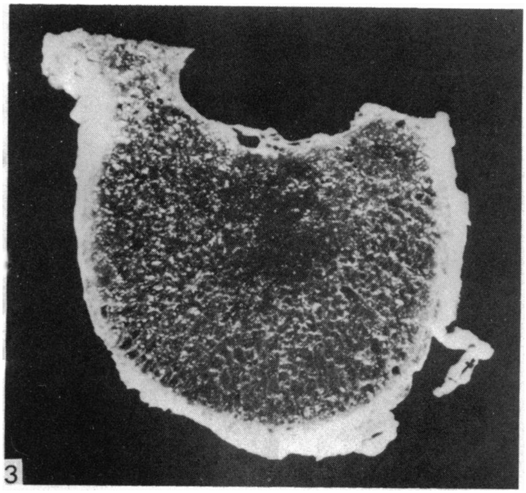

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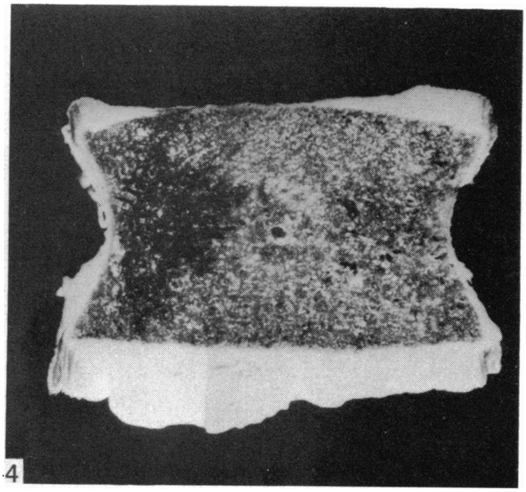

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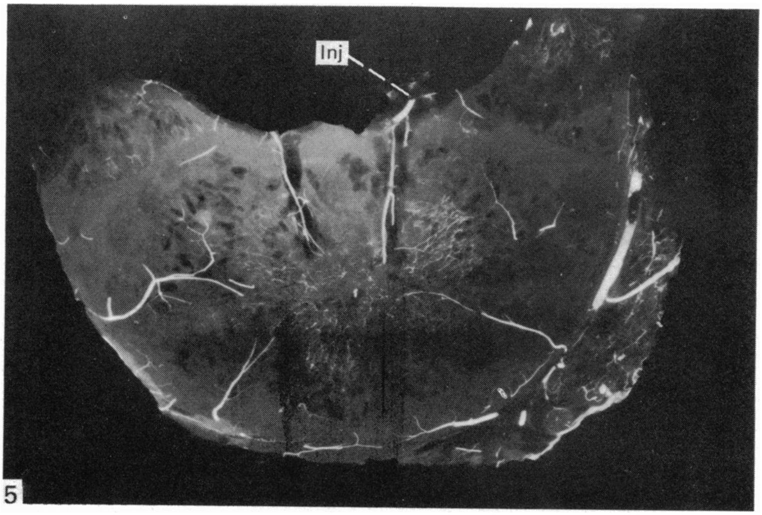

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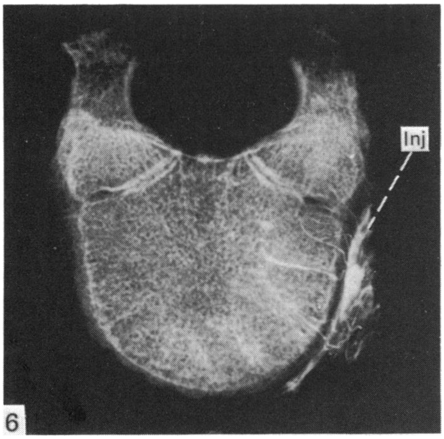
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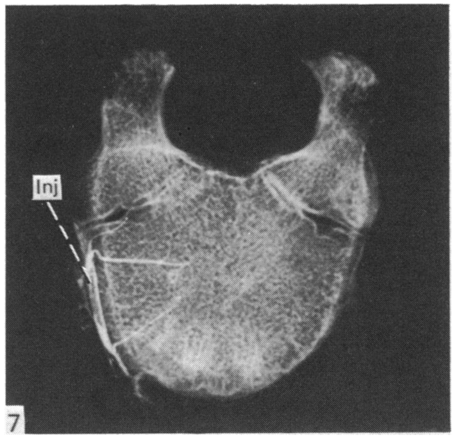
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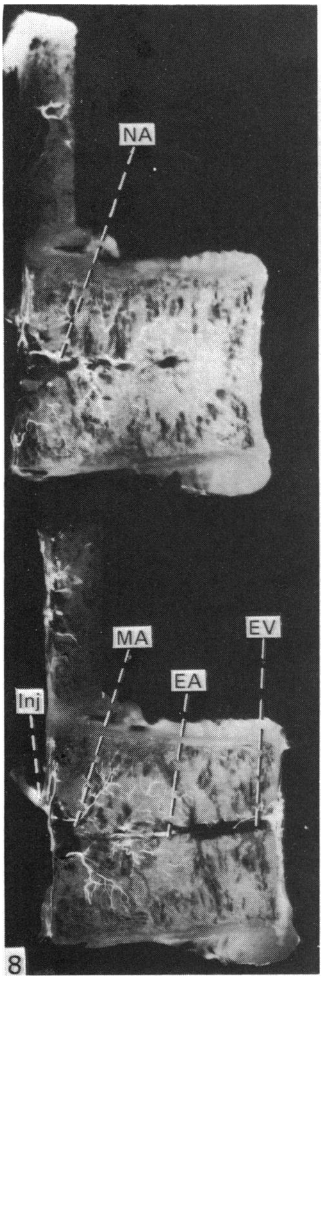
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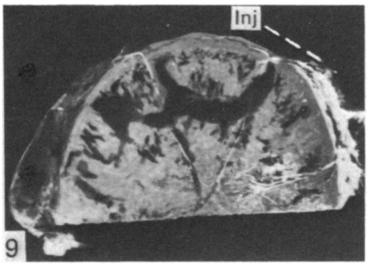
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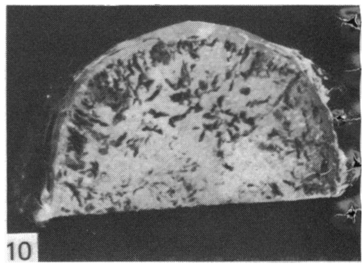
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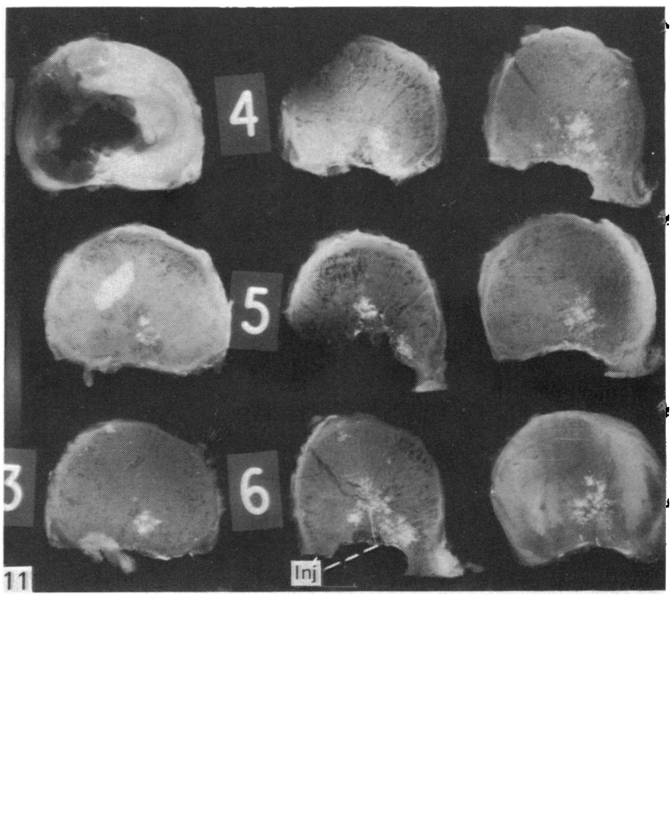
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extravasation in the other specimen, where no extra-osseous anastomoses were left (Figs. 9, 10).

(4) In adults, there was good filling of intra-osseous arteries adjacent to the site of injection but almost no filling of arteries distant from the site of injection (Figs. 11, 12, 13, 14, 15, 16). Extravasation was almost universal in adults, usually intra-osseous, but occasionally in the periosteum (Fig. 16).

DISCUSSION

These observations show that infant vertebral bodies had very widespread and effective intra-osseous arterial anastomoses. These anastomoses resulted in the opacification of most of the intra-osseous arteries and prevented rupture of the arterioles and extravasation of barium sulphate suspension during the injection.

During the course of maturation these anastomoses became less effective, presumably by the closure of vessels. This process had started in the 7 years old child. A few intra-osseous arterial anastomoses had persisted in the 15 years old adolescent, but these were insufficient to opacify many distant arteries and insufficient to prevent extravasation. There were very few intra-osseous arterial anastomoses in healthy adult vertebral bodies. In adult life intra-osseous arteries were effectively end-arterial and overfilling resulted in extravasation.

The regional distribution of intra-osseous arteries described elsewhere (Ratcliffe, 1980) takes on a greater significance during adult life when each artery supplies an exclusive and isolated volume of vertebral body (Fig. 17).

Fig. 6. Radiograph of an undecalcified lower dorsal vertebral body from a 7 years old child. A segment of the left intercostal artery had been isolated and injected (Inj). Several large intra-osseous arteries have been opacified in the region adjacent to the injection. No intra-osseous artery can be identified distant from the injection site. × 1·3.

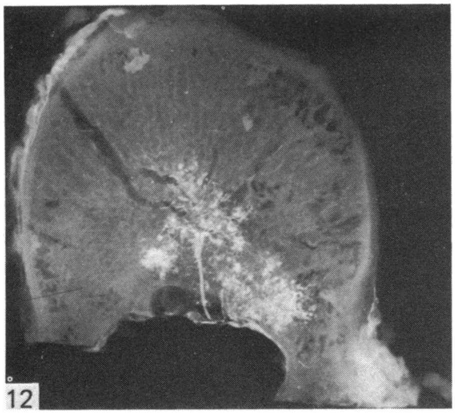
Fig. 7. A similar specimen to that illustrated in Fig. 6, but the right intercostal artery was injected (Inj). Similarly, distant arteries cannot be identified. Unfortunately both these specimens were accidentally destroyed before decalcification.

Fig. 8. Radiograph of sections of two decalcified adjacent dorsal vertebrae from a 15 years old adolescent. The anterior two thirds of the upper vertebral body had been sawn off prior to selective cannulation of the post-central anastomosis of the lower vertebral body which was injected with Micropaque (Inj). The L-shaped specimen was sectioned sagittally and two adjacent sections are presented. There was filling of the nutrient artery (NA) and metaphyseal arteries (MA) arising from the post-central anastomosis. The anterolateral equatorial artery (EA) has also been opacified, presumably via an intra-osseous anastomosis. There was some contrast in an artery accompanying the anterior emissary vein (EV) and this contrast escaped onto the anterior surface of the vertebral body. This artery also presumably filled via an anastomosis. Contrast escaped via the post-central anastomosis to the cephalad vertebra. × 0·8.

Fig. 9. A radiograph of a horizontal section from the anterior two thirds of the upper vertebra illustrated in Fig. 8. Part of the segmental artery had been isolated and injected (Inj) with Micropaque. Several adjacent arteries have been opacified and also one which originated from the opposite side. This artery filled via an anastomosis and accompanied a venous sinus. × 0·8.

Fig. 10. A section from the upper metaphysis of the same specimen shown in Fig. 9. This shows considerable extravasation to have taken place in the region supplied.

Fig. 11. Radiograph of serial horizontal sections of a decalcified lumbar vertebral body from a subject aged 47 years. The post-central anastomosis (Inj) had been cannulated and injected with Micropaque, as in Fig. 1. The region supplied by the nutrient artery and one upper metaphyseal artery have been clearly shown. It should be noted that the core of tissue supplied by the nutrient artery lay behind the coronal plane through the centre of the vertebral body and therefore lay subjacent to the nucleus pulposus. × 0·5.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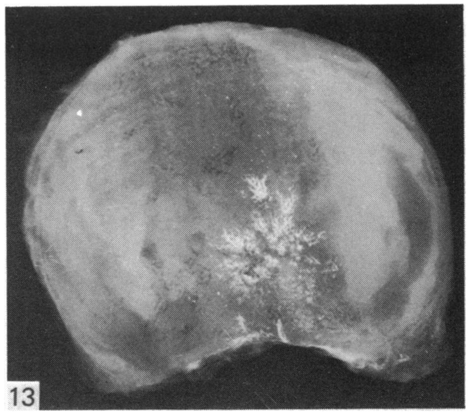
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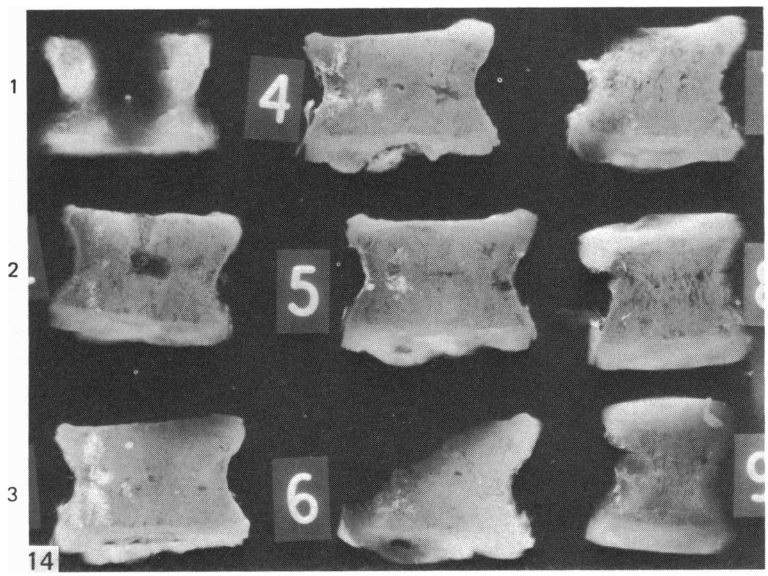
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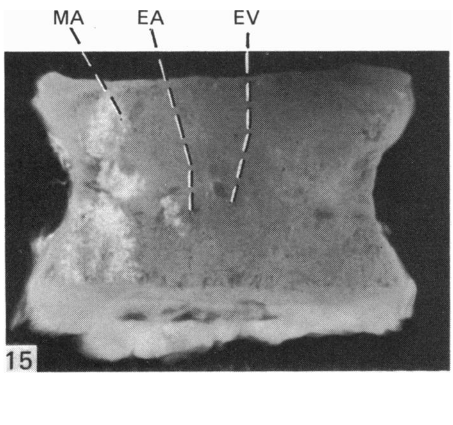
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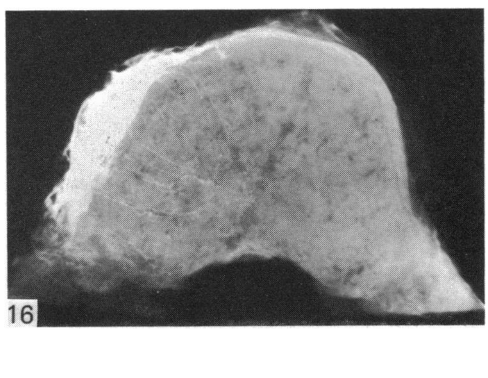
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Vascular accidents, or blood-borne pathogens, would thus have an effect in an anatomically predetermined region of vertebral body.

Wiley & Trueta (1959) showed that the extra-osseous anterolateral arterial anastomosis was present and might be a route for the spread of osteomyelitis from one vertebral body to the next. It has been shown that the metaphyseal arteries are the largest intra-osseous arteries arising from this anastomosis (Ratcliffe, 1980), and this would account for the predeliction of osteomyelitis for the juxtadiscal region.

Vertebral osteomyelitis is unusual in children and decidedly rare under the age of 9 (Pritchard & Thomson, 1960; Allen, Cosgrove & Millard, 1978). In the infant and young child the effective widespread intra-osseous arterial anastomosis may prevent a septic embolus in an intra-osseous artery resulting in a septic infarct of bone. In adults and adolescents the intra-osseous arteries are end arterial and a septic embolus will result in septic infarction of a wedge of bone in the metaphysis. Vertebral osteomyelitis may be segmental (Fig. 18).

The disc is avascular and has little defence against infection. It is rapidly involved by contiguity with the septic metaphyseal infarct and septic cellular necrosis occurs simultaneously in bone and disc. The disc is soft and collapses before bone. Disc space narrowing is an early radiological sign of vertebral osteomyelitis.

The reduction in effective intra-osseous anastomoses would result in disturbed bone growth in adolescence if the normal arteries were deficient, even though infantile growth may have been normally supported by anastomoses. This phenomenon may have already been observed by Brookes (1957) who destroyed the femoral diaphyseal artery on one side in day old rabbits. Follow-up radiographic measurement showed that growth proceeded normally and equally to 90 days, but at 120 days and 150 days the operated bones were shorter than controls. Brookes demonstrated intra-osseous diaphyseal–metaphyseal anastomoses. These were presumably adequate for growth to 90 days but thereafter, during the equivalent of adolescence, may have become inadequate.

In idiopathic adolescent scoliosis growth of one half of the vertebral body is grossly reduced, whereas it is near normal on the unaffected side. This disease becomes manifest from late childhood through adolescence. It could be due to failure of the extra-osseous arterial supply on the affected side: in infancy and childhood the intra-osseous anastomoses supply sufficient blood to the affected side for

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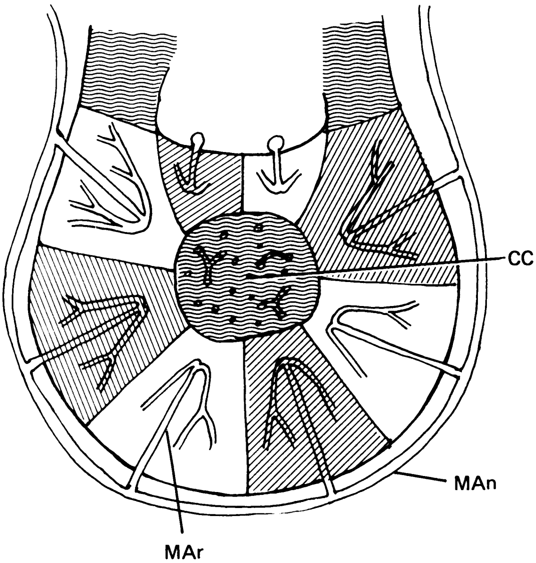
Fig. 12. An enlargement of the middle section from Fig. 11. This shows the right nutrient artery and some of its branches with extensive extravasation. This was the same specimen as that photographed in Fig. 3. × 1·1.

Fig. 13. An enlargement of the most cephalad section illustrated in Fig. 11 showing extravasation in the subnuclear region originating from branches of the nutrient artery. Discal material is more radio-opaque than decalcified bone. × 1·1.

Fig. 14. Radiograph of serial coronal sections of a decalcified adult (42 years) lumbar vertebral body. A short segment of the lumbar artery had been cannulated, isolated and injected with Micropaque. A very limited region of vertebral body has been opacified, but this extended from disc surface to disc surface. Extravasation has occurred. × 0·5.

Fig. 15. An enlargement of the third section from Fig. 14. The extravasation from the anterolateral equatorial artery (EA) and metaphyseal artery (MA) is shown. This is the same specimen as that photographed for Fig. 4. There were some faint traces of Micropaque around the central emissary vein (EV). × 1.

Fig. 16. Axial radiograph of a whole decalcified lumbar vertebral body from a subject aged 51 years. A segment of lumbar artery had been isolated and injected. Adjacent arteries have been opacified, but none distant from the site of injection. There was a lot of extravasation into the periosteum and associated soft tissues. No extravasation is seen in the bone. × 1.



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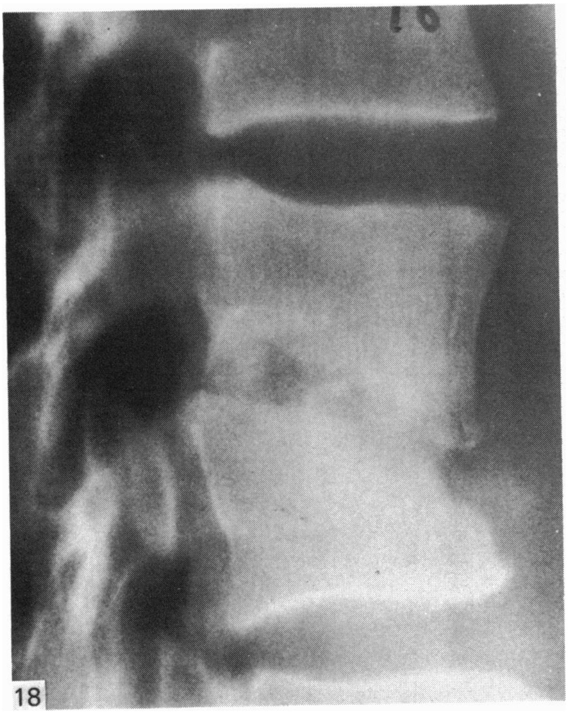

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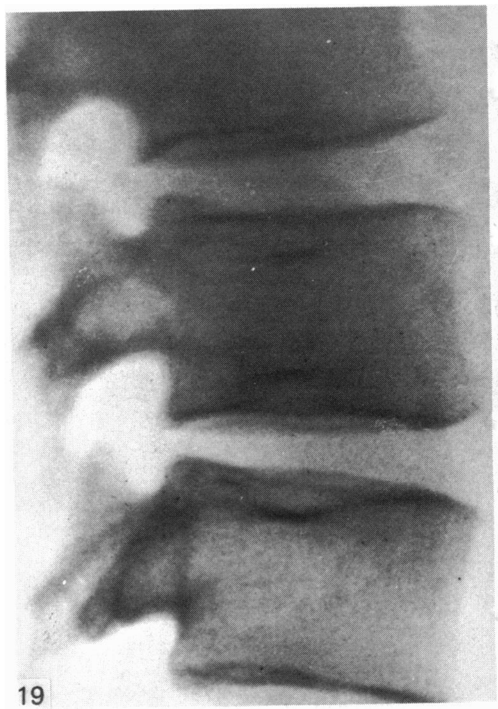

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normal symmetrical growth but, as the anastomoses become less effective during late childhood and adolescence, growth on the affected side becomes retarded and a scoliosis develops.

Another phenomenon related to non-uniform vertebral growth is observed in adolescents with sickle-cell disease. An area of the end plate, supplied by the nutrient artery, appears depressed towards the centre (Fig. 19); it is referred to as the 'step sign'. It is not seen on radiographs of infants, becomes evident in adolescence and early adult life, but is less clearly seen in older spines. Reynolds (1966) suggested that this phenomenon was due to differential growth because the hyperplastic and hypermetabolic marrow would reduce the pH in the centre of the vertebral body, but not in the periphery. He assumed a simple vertebral blood supply and suggested that the discal surfaces would be uniformly concave. The low pH may result in reduced perfusion by the nutrient artery, but this is compensated in infancy and early childhood by flow through anastomoses from metaphyseal arteries. The anastomoses become less adequate during adolescence and growth in the region supplied by the nutrient artery slows down whilst the growth in the annular region supplied by the metaphyseal arteries proceeds normally. Thus a fairly sharp step in the discal surface of the vertebral body is formed during adolescence.

SUMMARY

Selective cannulation and injection of barium sulphate suspension into the arteries of isolated areas of periosteum of 21 vertebral bodies of cadavers aged 3 months to 51 years have been performed. This showed that in infants there is a very extensive intra-osseous arterial anastomotic network. Conversely, in normal adults the intra-osseous arteries were end arteries. The reduction in intra-osseous anastomoses probably had started by age 7 and had become almost complete by the age of 15 years.

The blood supply of the adolescent and adult vertebral body is thus zoned into isolated regional compartments. These observations may help to explain the distribution of vertebral osteomyelitis, the possible aetiology of idiopathic adolescent scoliosis and the development of the 'step sign' in sickle-cell haemoglobinopathy.

My thanks to Professor J. H. Middlemiss of Bristol are expressed for encouragement and advice. Finance for this study was provided in part by the Hospital Medical Research Committee, Bristol Royal Infirmary and by the Department of Radiology, Bristol University.

Fig. 17. Diagram of the regions of arterial supply on the discal surface of an adult vertebral body. The central core (CC) is supplied by axial branches of the equatorial arteries. An annulus around it is supplied in sectors by individual metaphyseal arteries (MAr), which arise from the metaphyseal anastomosis (MAn). There is no effective communication between the arteries supplying these regions.

Fig. 18. Lateral sagittal tomogram of a lumbar spine with segmental destruction of vertebral bodies by a staphylococcal osteomyelitis. In the upper vertebral body a posterolateral segment has been destroyed. In the lower vertebral body an anterior and an anterolateral segment have been destroyed.

Fig. 19. Lateral radiograph of the lumbar spine of a male aged 19 years who had sickle-cell disease. This shows the 'step sign'. The area of delayed growth of the end plate corresponds with the region supplied by the nutrient artery.

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