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THE ARTERIAL BLOOD SUPPLY OF THE CERCIVAL VERTEBRAE OF THE OX (*BOS TAURUS* L.)

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ABSTRACT

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The arterial supply to the cervical vertebrae of the ox was studied in 22 animals (Friesland, Jersey and Guernsey cross-breeds), ranging from near full-term foetuses to adults. Various techniques, including angiography and clearing of bone, were employed to expose the extra- and intraosseous distribution of the arteries and a description is given of a modified Spalteholtz clearing technique. The extraosseous nutrient arteries are described and illustrated. A uniform pattern emerged from the investigation and it is suggested that the main branches be named: (a) the artery of the vertebral arch; (b) the artery of the transverse process; (c) the basivertebral arteries. Frequent anastomoses between epi- and metaphysial vessels in young animals are reported, and stress is laid on the effective collateral supply maintained by the extra- and intraosseous nutrient vessels.

Résumé

LA CIRCULATION ARTÉRIELLE DES VERTÈBRES CERVICALES DU BOEUF (BOS TAURUS *L*)

Cette étude porte sur 22 animaux (croisements des races frisonnes, jersiaises et guernesiaises) aux âges s'étendant de foetus à terme aux adultes. L'auteur a employé différentes techniques, entre autres l'angiographie et la dénudation osseuse pour mettre en vue la distribution extra-et intraosseuse. Une modification de la technique de dénudation de Spalteholtz est décrite. Les artères nourricières extra-osseuses sont décrites et illustrées. Un modèle uniforme ressort de cette enquête et l'auteur suggère la dénomination suivante des branches principales: (a) L'artère de l'arc vertébral; (b) l'artère de l'apophyse transverse; (c) les artères basiovertébrales. L'auteur signale des anastomoses assez fréquentes entre les vaisseaux épi-et metaphyséaux chez les animaux jeunes et souligne l'efficacité de la circulation collatérale grâce aux vaisseaux nourriciers extra-et intra-osseux.

INTRODUCTION

The arterial blood supply of the vertebral column in domesticated animals has so far received relatively little attention. In the ox the arterial blood vessels of the head were described initially by Chauveau (1855) and Fleming (1891), and later by Schmidt (1910). Schmidt (1910) described the circular anastomoses of the spinal branches of the vertebral artery, subsequently named the *circelli arteriosi* by Martin (1919), and their nutrient branches. The descriptions by Martin & Schauder (1938). Ellenberger & Baum (1943) and Nickel Schummer & Seiferle (1975) correspond in the main with those by Schmidt and Martin; other standard text books on veterinary anatomy do not mention these vessels at all.

The blood supply of the vertebral column was studied in the rabbit by Amato & Bombelli (1959); in the dog by Crock (1960) and Beron (1969); in the pig by Wissdorf (1970), and in the cat by Kayanja (1971).

It is common knowledge that the short, irregular bones of the vertebral column receive their blood vessels from the periosteum. The arteries enter at the nonarticular surfaces and are distributed to the compact and cancellous bone. In previous studies (Smuts, 1974, 1975) the vascular foramina of the cervical vertebrae of the ox were described and correlated with the areas of muscular attachment. The arteries were thought to enter around the circumference of the transverse process, particularly close to its base. The present study considers the source of the blood vessels supplying the cervical vertebrae of the ox, their mode of entry and their distribution in the osseous tissue.

MATERIALS AND METHODS

Twenty-two animals, all either Friesland, Jersey or Guernsey cross-breeds, were used for this study: 5 adults, 1 heifer aged 15 months, 12 calves aged 3–8 months, 2 newly-born calves and 2 foetuses.

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After chloral hydrate anaesthesia the animals were killed by exsanguination. To prevent clotting of the blood, 12 500 units heparin were injected intravenously 10 minutes before sacrifice. The trunk was divided behind the tricipital margin and the heart and lungs were removed. For injection of the arteries a cannula was placed in the left costocervical trunk after all the other arteries had been ligated. The frontal vein was used for injecting the venous system. In 6 animals the arterial and venous systems were injected simultaneously.

The following techniques were used to study the course and distribution of both the extraosseous and intraosseous nutrient vessels:

1. *Revultex injection and subsequent dissection:* Six specimens were used, in 2 of which both the arterial and the venous systems were injected. Revultex, coloured with vulcanosol carmine for the arteries and with blue (BASF) for veins was used and injected until noticeable back pressure was felt. The specimens were then fixed in 10% formalin.

2. *Revultex injection followed by maggot digestion:* Four specimens were used in 2 of which both blood systems were injected. After injection with revultex (as described above), the specimens were put in a water tank for 3–4 days to allow coagulation of the revultex, and subsequently transferred to a shaded area and covered with moist sacking, after removal of the skin. The soft tissues were soon cleared by maggots. The foetus was injected through the umbilical vessels; otherwise it was prepared in the same way.

Maggot digestion was the best way to expose the finer ramifications and anastomoses of the extraosseous vessels. If left exposed too long, however, the nutrient vessels would be disturbed by the maggots.

3. *Indian ink injection and clearing of bone:* One specimen was used. A 3-day-old calf was soaked for a few hours prior to injection in a warm water bath at 37 °C. A mixture of Indian ink (50 parts), gelatine (10 parts) and water (40 parts) was heated to the same temperature as the water bath and injected into the

left vertebral artery. The specimen was then placed in a cold room for 24 hours before the soft tissues were dissected away to prepare the vertebrae for clearing.

4. *Injection of contrast media for angiography and subsequent clearing of bone:* Eleven specimens were used in 2 of which both blood systems were injected. According to Crock (1960), Micropaque (Nicholas) was mixed with 10% (mass/volume) gelatine and Vulcanosol carmine or blue (BASF) was added for arteries and veins respectively. The mixture was heated and stirred constantly until the gelatine was dissolved. The cadaver was then prepared in the same way as for the Indian ink-gelatine injection.

Attempts at angiography with other contrast media, e.g. Endografin (Schering A. G. Berlin), red lead (Pb_3O_4) mixed with latex, and 25% $BaSO_4$ suspension, gave unsatisfactory results.

For roentgenographs the vertebrae were exposed individually or as an intact series sawn vertically through the median plane. Radiographs were taken before and after decalcification of the vertebrae. The latter gave superior definition of detail. For normal bone the following exposure factors were used: KV 90, mAs 1,6; time 0,006; distance 80 cm; with grid. For decalcified bone the KV was lowered to 80.

The following modification of the *Spalteholtz technique* was used for clearing the vertebrae:

(i) The specimens were fixed in 10% formalin for 2–5 days.
(ii) They were decalcified in 15% HNO_3 for 5–15 days, depending on age.
(iii) Bleaching in 12% H_2O_2 solution was carried out for 24 h.
(iv) They were washed in tap water.
(v) Dehydration was carried out in 70% alcohol for 24 h and then in absolute alcohol for 3–4 days.
(vi) They were cleared in xylene for 5–7 days.
(vii) The clearing process was completed in methyl salicylate for 3 days—3weeks, depending on age.
(viii) The cleared specimens were placed in a vacuum embedding tank to remove air bubbles.

RESULTS

Part 1: The extraosseous nutrient arteries

Three main blood vessels contribute to the arterial supply of the cervical vertebrae. In order of importance they are: A. vertebralis (Fig. 1a), A. cervicalis profunda (Fig. 1b) and A. carotis communis (Fig. 1,c). Ramifications of these vessels anastomose extensively, forming plexuses laterally in the periosteum of the transverse and articular processes, dorsally on the laminae and ventrally on the surface of the vertebral bodies as well as within the substance of the overlying intertransverse, multifid and lungus colli musculature. The left and right systems are connected by means of transverse anastomoses along the dorsal spines, on the dorsal surface of the vertebral bodies (Fig. 3) and along the ventral spines (Fig. 2).

The costocervical trunk (Fig. 1,d) arises from the subclavian artery (Fig. 1,z) at the first rib and follows a craniodorsal course along the deep surface of the Mm. scaleni, cranial to the homologous vein. It gives rise to the common trunk for the vertebral (Fig. 1,a) and deep cervical (Fig. 1,b) arteries which continues between the longus colli medially and the scaleni laterally and bifurcates into its final components ventrocaudally to the transverse process of C7. Here the vertebral artery enters the transverse foramen of C6 and runs cranialward in the transverse canal, lying dorsally to the vertebral vein.

(a) *A. cervicalis profunda* (Fig. 1,b): It arises directly caudoventrally to the transverse process of C7, runs dorsalward behind the latter, cranial to the homologous vein and covered by the middle scalene and dorsal intertransverse muscles. It curves craniodorsally across the ridge between the articular processes of C7, where it is covered by the M. longissimus cervicis. The main continuation of the artery runs cranialward along the deep face of the M. semispinalis capitis. Near its origin small branches supply the lateral surface of the vertebral body, the dorsal tubercle of the transverse process and the caudal articular process. A caudal branch supplies the spinous process of C7, while a cranioventral ramus (Fig. 1,b′) provides a few very small nutrient vessels to the free extremities of the spinous processes and dorsal laminae of C6–C3. They anastomose freely with the dorsal rami of the vertebral artery. The continuation of the deep cervical artery anastomoses with a branch (Fig. 1,k′′′) of R. descendens of the vertebral artery at the level of the spinous process of the axis.

(b) *A. carotis communis* (Fig. 1,c): It runs cranialward along the ventral surface of M. longus colli and gives rise to a number of slender vessels (Fig. 1,x) which follow a dorsocranial course and become dispersed in the musculature overlying the transverse processes of the vertebrae. Delicate twigs ramify in the periosteum, anastomosing with the ventral rami of the vertebral artery to the transverse process of the axis and ventral tubercles of the transverse processes of C4, C5 and C6 (Fig. 1).

(c) *A. vertebralis* (Fig. 1,a): Ventral, spinal and dorsal branches arise segmentally from the artery opposite each intervertebral foramen between C2–C6.

(i) *R. ventralis* (Fig. 1,2 and 4,e): The well-developed ventral ramus arises from the ventral aspect of the vertebral artery. It crosses the lateral face of the vertebral vein and runs under the intertransverse musculature to the medial aspect of the ventral tubercle of the transverse process which it supplies. It then bifurcates into cranial and caudal branches which run obliquely across the preceding and succeeding vertebral bodies, respectively. A few nutrient vessels of variable size are given off to each vertebral body. Diamond-shaped anastomoses are formed along the ventral spines of the vertebrae by contra- and ipsilateral branches (Fig. 2).

Near its origin the ventral ramus supplies small nutrient vessels (Fig. 4,e′) to the lateral aspects of contiguous vertebral bodies and to the periosteum at the caudal aspect of the dorsal tubercle of the transverse process of the preceding vertebra. Along its course a large cranial (Fig. 4,e′′) and a caudal (Fig. 4,e′′′) branch are given off which supply the overlying intertransverse muscles. The former ramifies over the caudal aspect of the preceding dorsal tubercle and sends small vessels into the

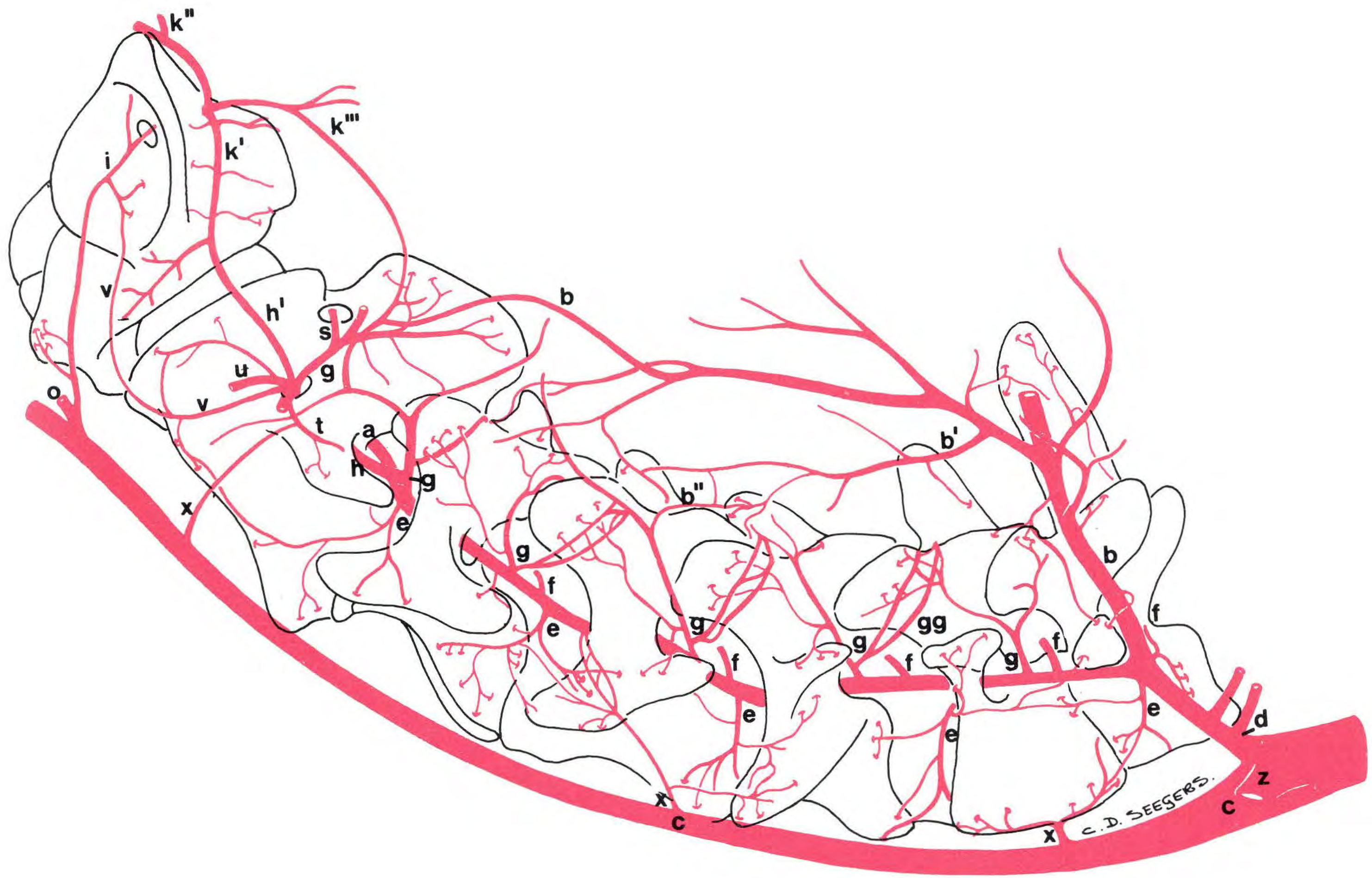

FIG. 1 Cervical vertebrae. Extraosseous arteries. Lateral view. **a** A. vertebralis, **b** A. cervicalis profunda, **b′** Ramus to spinous processes, **b′′** anastomosis with dorsal rami of A. vertebralis, **c** A. carotis communis, **d** Tr. costocervicalis, **e** R. ventralis, **f** R. spinalis, **g** R. dorsalis, **gg** succeeding R. dorsalis, **h** "artery of the transverse canal", **h′** its continuation towards the atlas (**h** and **h′** represent the continuation of the vertebral artery to the atlas), **s** anastomosis of its R. dorsalis with A. vertebralis, **t** branch to transverse process of axis, **u** cranioventral branch, **v** ventral branch, **i** anastomotic branch with A. occipitalis, **k** R. descendens, **k′** anastomotic branch to "artery of the transverse canal", **k′′** cranial muscular branch, **k′′′** caudal branch anastomosing with A. cervicalis profunda, **o** A. occipitalis, **x** Rami from A. carotis communis, **z** A. subclavia sinistra

bone on the ventral face of the tubercle. The latter similarly ramifies over the lateral and ventral aspects of the succeeding dorsal and ventral tubercles.

Between C6 and C7 the ventral ramus is the smallest of the series and usually arises from the common trunk for the vertebral and deep cervical arteries. In some cases it arises from the vertebral artery at or near its origin. It supplies nutrient vessels to the ventral surface of the dorsal tubercle of C7 and a muscular branch to the ventral intertransverse muscles. The terminal branches, 3 or 4 in number, ramify in the periosteum of the lamina of C6 where they anastomose with a branch from the common carotid artery. They send twigs into the vertebral bodies of C6 and C7 between the epiphysial lines. In some cases these branches are supplemented by twigs from the vertebral and deep cervical arteries.

(ii) *R. spinalis* (Fig. 1 and 3,f): This branch is smaller than the R. ventralis and arises from the dorsomedial aspect of the vertebral artery from the 3rd to the 6th segments. Caudally to C7 it arises from the deep cervical artery. At its origin the spinal branch trifurcates into cranial vertebral (Fig. 3,n), caudal vertebral (Fig. 3,m) and medullary branches.

The vertebral branches run within the periosteum on the dorsal surface of the vertebral bodies under cover of the Pl. venosus vertebralis internus ventralis.

The caudal vertebral ramus follows a caudomedial course and at the middle of the succeeding vertebral body anastomoses transversely (Fig. 3,r) with the cranial vertebral ramus of that segment and with the opposite vessels. The cranial vertebral ramus forms a mirror image of the caudal one, anastomosing with the preceding caudal branch. In this way *circelli arteriosi* are formed.

The most important nutrient vessel to the vertebral body arises from either the right or the left caudal vertebral ramus, near the transverse anastomosis. In most animals it is of large calibre. From C4 caudalwards an additional vessel may be given off which enters a foramen in the face of the pedicle.

From the *circelli arteriosi* delicate, usually minute, vessels (Fig. 3,p) are given off which ramify in the periosteum and supply the intervertebral discs and the vertebral bodies in the vicinity of the epiphysial lines.

The medullary ramus arises from the cranial vertebral ramus near or at its origin. It may be double or may divide immediately into dorsal and ventral root branches which accompany the respective spinal nerve roots. The ventral one joins the ventral spinal artery.

(iii) *R. dorsalis* (Fig. 1 and 5,g): The dorsal ramus usually leaves the vertebral artery at an angle of 45°. It runs craniodorsally under cover of the dorsal intertransverse musculature. The one behind C2 is always the largest; those behind C3 and C6 are relatively small and their cranial, or main division, is absent in about 30% of cases. The dorsal ramus continues along the lamina of the preceding vertebra, supplies a branch (Fig. 5,g^{V}) to the dorsal tubercle and lateral surface of the cranial articular process and ramifies in the overlying musculature and along the dorsal surface of the lamina.

At or near the origin of the R. dorsalis, or from the vertebral artery itself, a caudally directed branch (Fig. 5,g') is detached. Before supplying the overlying muscles it gives off 2 unequal-sized vessels (Fig. 5,g''). They flank the dorsal ramus of the corresponding spinal nerve along its course over the lateral face of the cranial articular process of the succeeding vertebra. On a level with the connecting ridge between the articular processes there are anastomoses with the succeeding dorsal ramus (Fig. 5,gg). In addition, delicate anastomoses are formed freely with branches (Fig. 1,b'') of the deep cervical artery along the dorsal surface of the lamina. From 1–3 small nutrient vessels supply the articular process and dorsal surface of the lamina.

From the deep aspect of the caudal branch, or from the R. dorsalis itself, one or more vessels (Fig. 5,g''') arise which enter the medial aspect of the caudal and cranial articular processes of the pre- and succeeding vertebrae, respectively; they terminate as delicate vessels which fan out cranially and caudally to supply the Lig. flavum and the internal face of the pedicle and lamina. Caudally in the series, 1 or 2 vessels (Fig. 5,g^{IV}) enter the cranial aspect of the pedicle of the succeeding vertebra. Sometimes a direct anastomosis occurs between dorsal and ventral rami near their origin.

Between C2 and C3 the R. dorsalis gives off a branch (Fig. 1,h) which enters the caudal transverse foramen of the axis. It traverses the canal as the "artery of the transverse canal" and at its emergence from the cranial transverse foramen gives off a number of prominent branches (Fig 1). The "artery of the transverse canal" is continued (Fig. 1,h') towards the dorsal surface of the wing of the atlas where it anastomoses with a branch (Fig. 1,k') of the R. descendens issuing from the lateral vertebral foramen of the atlas. The "artery of the transverse canal" undoubtedly represents the continuation of the vertebral artery to the atlas.

The most prominent branch (Fig. 1,g) arising at the cranial transverse foramen of the axis simulates the typical course of an R. dorsalis. At the lateral vertebral foramen of the axis an anastomotic branch (Fig. 1,s) is given off to the vertebral artery in the vertebral canal. The dorsal ramus continues along the lateral surface of the axial spine, supplying it with 2–5 nutrient arteries, and ramifies in the periosteum. Anastomoses are formed caudally with the succeeding dorsal ramus. A 2nd branch (Fig. 1,t) arising at the cranial transverse foramen supplies the overlying

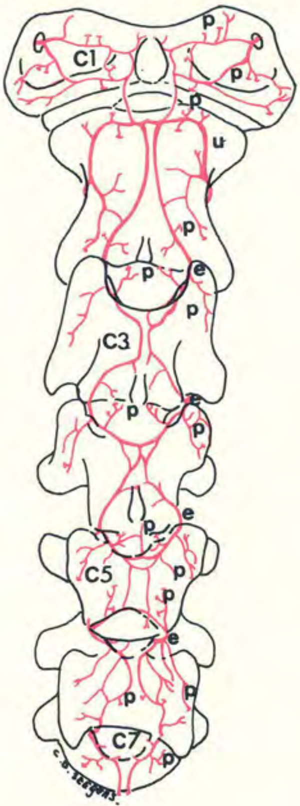

FIG. 2 Cervical vertebrae. Extraosseous arteries. Ventral view. **e** R. ventralis, **p** Aa. nutriciae, **u, v** branches of "artery of the transverse canal"

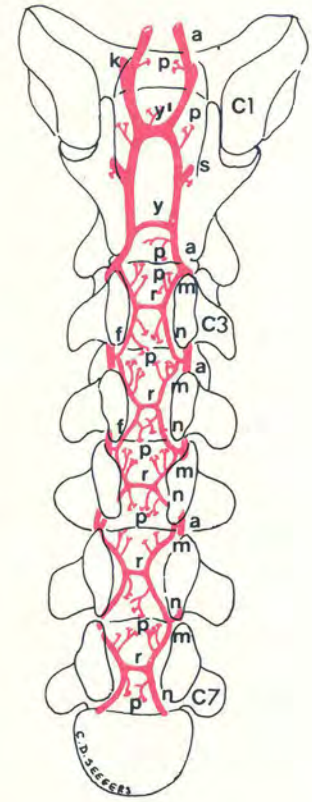

FIG. 3 Cervical vertebrae, laminae removed. Circelli arteriosi. Dorsal view. **a** A. vertebralis, **f** R. spinalis, **m, n** its caudal and cranial branches, **p** Aa nutriciae, **r** transverse anastomosis

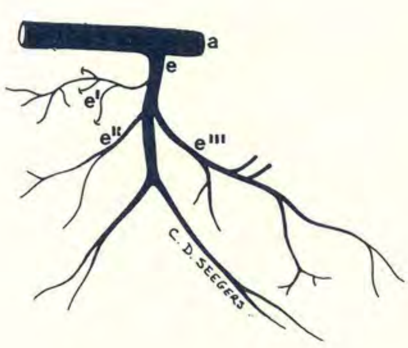

FIG. 4 R. ventralis of vertebral artery, schematic. **a** A. vertebralis, **e** R. ventralis, **e′** branch supplying nutrient arteries to lateral aspect of contiguous vertebral bodies, **e′′** branch to dorsal tubercle of transverse process of preceding vertebra, **e′′′** branch to transverse process of succeeding vertebra

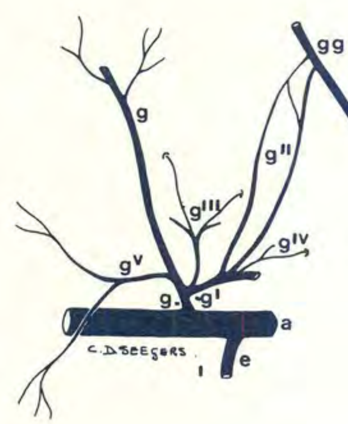

FIG. 5 R. dorsalis of vertebral artery, schematic. **a** A. vertebralis, **e** R. ventralis, **g** R. dorsalis, **g^{I}** its caudal branch, **g^{II}** its branches flanking the R. dorsalis of spinal nerve, **g^{III}** its branch to articular processes, internal surface of laminae and pedicles of contiguous vertebrae, **g^{IV}** its branch entering cranial aspect of pedicle of succeeding vertebra, **g^{V}** its branch to dorsal tubercle of transverse process and cranial articular process of preceding vertebra, **gg** succeeding R. dorsalis

muscles and proceeds to the dorsal surface of the transverse process of the axis, providing the latter with 1 or 2 nutrient arteries. It anastomoses with a slender branch from the common carotid artery (Fig. 1,x). A 3rd branch (Fig. 1 and 2u) runs cranioventrally, gives off a muscular ramus and then curves ventralward, caudal and parallel to the free edge of the cranial articular process of the axis. It supplies 2 or more nutrient arteries and anastomoses with a 4th branch (Fig. 1 and 2,v) which follows an oblique course along the lateral surface of the vertebral body.

A few nutrient arteries enter the cranial part of the vertebral body along the ventral spine. An anastomosis (Fig. 1, at i) is formed with the occipital artery in the atlantal fossa. In cases where a transverse canal is absent, the "artery of the transverse canal" runs on the external surface of the pedicle of the axis, and is distributed likewise.

Within the transverse canal of each vertebra from C2–C6, 1 or 2 fair-sized arteries arise from the vertebral artery and penetrate the pedicle and vertebral body, respectively.

The internal course of the vertebral artery (*Fig.* 3)

The vertebral artery enters the vertebral canal behind C2 (Fig. 3,a), lying ventrally to the internal ventral vertebral plexus. It detaches a medullary branch and proceeds cranialward along the floor of the canal. A transverse anastomosis (Fig. 3,y) joins the left and right arteries (which are often of unequal diameter) on the dorsal surface of the body of the axis. One or 2 nutrient arteries (Fig. 3,p) arise caudally to the anastomosis and enter the vertebral body on either side of the epiphysial line. From the deep face of the anastomosis 1 or 2 slender vessels may enter the bone. On a level with the lateral vertebral foramen a large anastomotic branch (Fig. 1 and 3, s) is given off to the dorsal branch of the "artery of the transverse canal" (*vide supra*). Before it enters the foramen it sends a branch through the vertebral opening of the transverse canal.

A 2nd transverse anastomosis (Fig. 3,y') connects the vertebral arteries on the dorsal surface of the dens. Small nutrient arteries supply the bone in its vicinity. Each vertebral artery now bifurcates. One branch, representing the continuation of the vertebral artery cranialward, is connected on the ventral arch of the atlas with its opposite number, which receives a number of small nutrient arteries. The other branch, the R. descendens (Fig. 3,k), traverses the lateral vertebral foramen of the atlas and immediately divides into several branches (Fig. 1).

One or 2 sturdy muscular rami (Fig. 1,k'') run cranialward within the M. capitis dorsalis minor over the atlanto-occipital joint capsule towards the base of the skull; a dorsal branch (Fig. 1,k''') curves caudalward to anastomose with the deep cervical artery on a level with the spinous process of the axis; a well-developed branch (Fig. 1,k') runs caudally along the wing of the atlas to anastomose with the continuation of "the artery of the transverse canal" (*vide supra*); finally, an equally well-developed vessel (Fig. 1,i) traverses the alar foramen, runs into the atlantal fossa and anastomoses with the occipital artery. The nutrient arteries supplied by these branches enter the atlas along the dorsal tubercle, the cranial part of the dorsal surface of the wing, the cranial aspect of the ventral tubercle, caudolaterally near the edge of the wing along the caudal articular surface, and in the atlantal fossa. A nutrient artery is also found dorsally in the medial and caudolateral angles of the common opening for the lateral vertebral and alar foramina.

Part II: *The intraosseous nutrient arteries*

The present study has confirmed the presence of intraosseous nutrient arteries to the main parts of a vertebra. In general, there is a main afferent vessel, or vessels, for the vertebral arch and its processes, for the transverse process and for the body.

For descriptive purposes these will be referred to as follows:

1. The *artery of the vertebral arch*, which arises from the vertebral artery in the transverse canal and pursues a dorsal course towards the summit of the spinous process.
2. The *artery of the transverse process*, arising from the lateral aspect of the vertebral artery in the transverse canal.
3. The *basivertebral artery*, arising from the *circelli arteriosi* in the vertebral canal.

The source and distribution of these vessels appear to be uniform for cervical vertebrae 3–5. The atlas and axis and C6 and C7 will be considered separately.

Cervical vertebrae 3–5

(i) *The artery of the vertebral arch* (Fig. 6 and 7/1) leaves the vertebral artery in the transverse canal approximately at its mid-length and soon divides into 3 or more diverging vessels which have a gently tortuous course. The cranial and caudal vessels run towards the respective articular processes. The middle vessel(s) follows a dorsal course towards the lamina and spinous process (Fig. 6 and 7/1') and 1 branch runs within the cranial part of the spinous process, giving off a few branches which anastomose with periosteal vessels (Fig. 6/6) from the internal and external surfaces and across the midline.

(ii) *The artery of the transverse process* (Fig. (6/2) arises either directly from the vertebral artery or from the artery of the vertebral arch. It soon divides into a cranial and caudal branch, supplying the respective tubercles, whose ramifications anastomose with periosteal vessels (Fig. 6 and 8/6) and with the network (Fig. 6 and 8/9) in the vertebral body. The cranial and caudal branches may, however, arise separately.

(iii) *The basivertebral artery* (Fig. 8/3): Single or paired basivertebral arteries arise from the transferse anastomosis of the *circelli arteriosi* and enter the body. A single vessel, or the larger vessel in an unequal-sized pair, runs ventrally towards the centre of the vertebral body, where it divides in rosette-like fashion and extends towards the metaphysis as well as towards the lateral aspects of the body (Fig. 8). When paired, the vessels run ventrally parallel to each other, and branch in the same way. All along the initial part of its, or their, course delicate branches are given off and form a meshwork of anastomoses with adjoining intraosseous vessels as well as with periosteal vessels (Fig. 6 and 8,6) which enter from the circumference, particularly along the epiphysial lines.

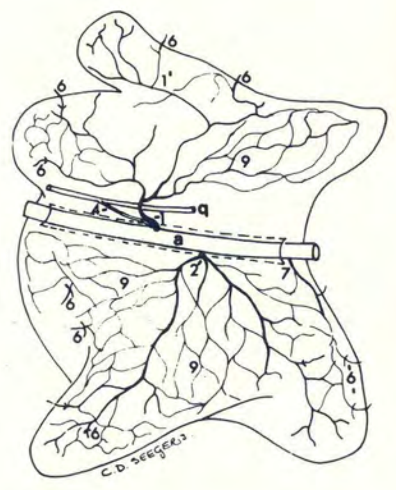

FIG. 6 C4—Intraosseous arteries. Lateral view, schematic. **1** artery of the vertebral arch, **2** artery of the transverse process, **a** vertebral artery, **q** circelli arteriosi; **4** anastomosis between **a** and **q**, **6** extraosseous periosteal vessels, **9** intraosseous arterial plexus

FIG. 7 C4—Röntgenograph. **1** artery of the vertebral arch, **1'** its continuation into the spinous process

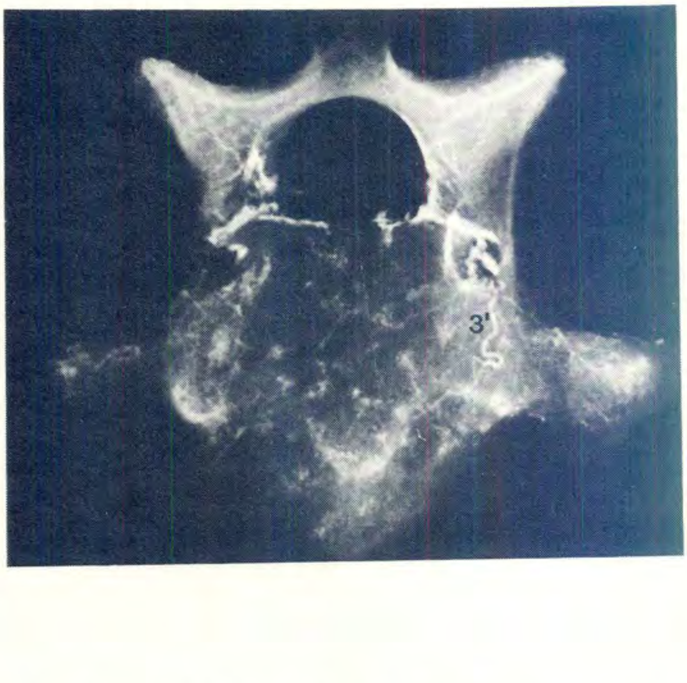

FIG. 8 C3—Röntgenograph. Left: cranial view; Right: caudal view. **3** unpaired basivertebral artery, **3'** additional arterty to vertebral body; **6** periosteal arteries; **9** intraosseous arterial plexus

FIG. 9 Sagittal section through vertebral body of C4 of 3 day-old specimen. Arteries and veins filled with Indian ink. Note numerous anastomoses between metaphysial and epiphysial networks. Photographed through clearing fluid

FIG. 10 C2–C7 of newly born—Photograph of cleared specimen. Arterial system injected. Photographed through clearing fluid

In the vertebrae of newly-born calves, 1–3 branches of the basivertebral artery clearly penetrate the growth plate to anastomose with epiphysial vessels (Fig. 9).

The basivertebral artery finally divides into a few terminal branches, which anastomose with nutrient vessels entering the lateroventral surface of the body and along the epiphyses. Additional supply to the vertebral body is furnished by a vessel (Fig. 8/3′) which arises from the vertebral artery. Its ramifications join those of the basivertebral arteries.

Cervical vertebra No. 6

(i) *The artery of the vertebral arch* supplies the vertebral arch, spinous and articular processes. A few delicate extraosseous vessels enter the dorsal surface of the vertebral canal and anastomose with the artery of the vertebral arch. A tributary of the branch to the caudal articular process, plus 1 or 2 of the middle branches, continue within the substance of the spinous process. In lateral view 2 or 3 of these vessels run along the length of the process. In craniocaudal view it appears that left and right vessels coalesce at the base of the process to form a single vessel along the midline. Anastomoses with extraosseous vessels are formed at the base and towards the free extremity.

(ii) *The artery of the transverse process* supplies the dorsal tubercle. Anastomoses occur with extraosseous vessels. The ventral lamina is supplied by an additional ventrally-directed branch from the vertebral artery as well as by extraosseous vessels entering from the medial and lateral surfaces.

(iii) The basivertebral arteries, single or paired, are detached by the *circelli arteriosi* along or near the transverse anastomosis. They enter the body in a vertical direction and are distributed as in the preceding vertebrae. The vertebral artery makes an additional contribution.

Cervical vertebra No. 7

In the absence of a transverse foramen, the source of the vessels is modified.

(i) *The artery of the vertebral arch* (Fig. 11/1) is formed by 1 or 2 nutrient vessels (Fig. 11/8,8′) derived from the preceding dorsal ramus of the vertebral artery and from the deep cervical artery lying behind it. They enter the cranial and caudal aspects of the pedicle and anastomose to form a transpedicular artery (Fig. 11/8,8′) from which the artery of the vertebral arch arises. (In about half the specimens the caudal vessel is absent, the cranial vessel being the sole source.) The artery of the vertebral arch runs dorsalward through the lamina into the base of the spinous process. At this level the vessels of the left and right sides anastomose and receive contributions from delicate extraosseous arteries which enter from the vertebral canal. A single vessel (Fig. 11/1′) now proceeds towards the summit of the spinous process. It detaches numerous small branches at right angles to its axis and these form a delicate network in the bone. Anastomoses are formed with both external (Fig. 11/6) and internal (Fig. 11/5) extraosseous vessels.

The artery of the vertebral arch typically supplies the articular processes. These processes also receive extraosseous nutrient arteries which enter their ventromedial surface and ramify in their substance.

(ii) *The artery of the transverse process* is a ventrolateral branch from the transpedicular artery or from the artery of the vertebral arch.

(iii) *The basivertebral arteries* (Fig. 11/3) arise in typical fashion to ramify in the vertebral body and connect up with extraosseous arteries entering on the ventrolateral aspect. Prominent extraosseous vessels enter around the epiphyses, with additional supplies to the epiphysial plates from the *circelli arteriosi*.

Axis

(i) *The artery of the vertebral arch* (Fig. 12,1) arises from the vertebral artery (Fig. 12, a) in the vertebral canal. It enters the vertebral opening of the transverse canal, supplies a branch (Fig. 12,4) to "the artery of the transverse canal" and follows a caudodorsal course. It then turns dorsally at a point approximately midway along the length of the pedicle, and branches into 3 or 4 slender rami which fan out dorsocranially and dorsocaudally to supply the pedicle, vertebral arch, spinous, and articular processes. These rami are interconnected and also anastomose with extraosseous vessels entering from the internal surface of the vertebral arch.

(ii) *The artery of the transverse process* (Fig. 12/2) arises from "the artery of the transverse canal". It enters the base of the transverse process in a ventral direction and ramifies in the free extremity of the transverse process. Anastomoses are formed with branches of the basivertebral artery and with periosteal vessels (Fig. 12/6).

In specimens where the transverse canal is absent or atypical, the supply to the transverse process is derived from the vertebral artery, reinforced by anastomotic branches from the continuation of the vertebral artery in this region. In such cases 1 or 2 vessels are given off by the vertebral artery within the vertebral canal, penetrate the pedicle and base of the transverse process and are distributed in the same manner.

(iii) *The basivertebral artery* (Fig. 9 and 13/3) which is large (and sometimes paired), arises from the anastomosis between the vertebral arteries and then follows an oblique ventro-medial course towards the centre of the vertebral body. When 2 vessels arise these descend parallel to each other. In lateral view the direction is vertical. Delicate tributaries and a few larger branches arise from the vessel(s) in bottlebrush-fashion, spread out towards the cranial articular process, the epiphysis and peripherally. Below the centre of the vertebral body the vessel divides into 2–4 terminal branches which anastomose with extraosseous vessels (Fig. 13/6) entering along the ventrolateral aspects of the vertebral body.

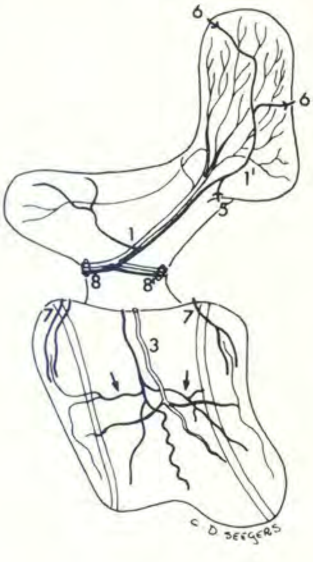

FIG. 11 C7, newly born; intraosseous arteries and veins Schematic. **1** art/vein of vertebral arch, **1′** their continuation in spinous process, **3** basivertebral vessels, **5** periosteal vessel from vertebral canal, **6** external periosteal vessel, **7** epiphysial vessels, **8** nutrient vessels entering cranial face of pedicle, **8′** nutrient vessels entering caudal face of pedicle, **8+8′**=transpedicular vessels, arrow: Anastomoses between epiphysial and basivertebral vessels

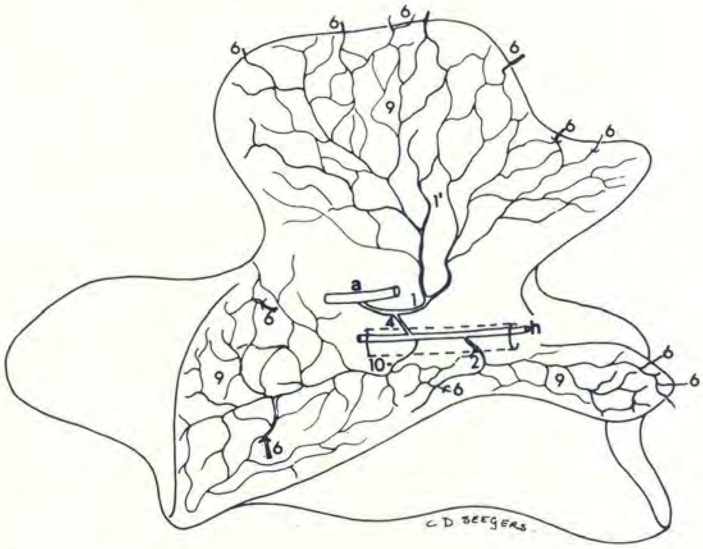

FIG. 12 Axis, lateral view. Schematic. **1** artery of the vertebral arch, **2** artery of the transverse process, **4** anastomotic branch from **1** to **h**, **6** extraosseous vessels, **9** intraosseous plexus, **10** branch to cranial articular process, **a** vertebral artery, **h** artery of the transverse canal

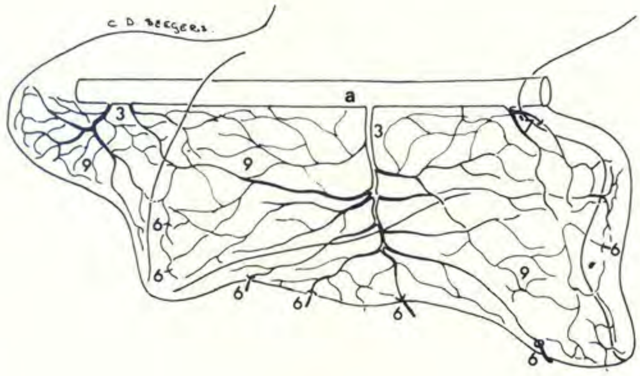

FIG. 13 Axis, dens and corpus, median view. Schematic. **a** basivertebral artery, **6** extraosseous vessels, **7** epiphysial branch, **9** intraosseous arterial network

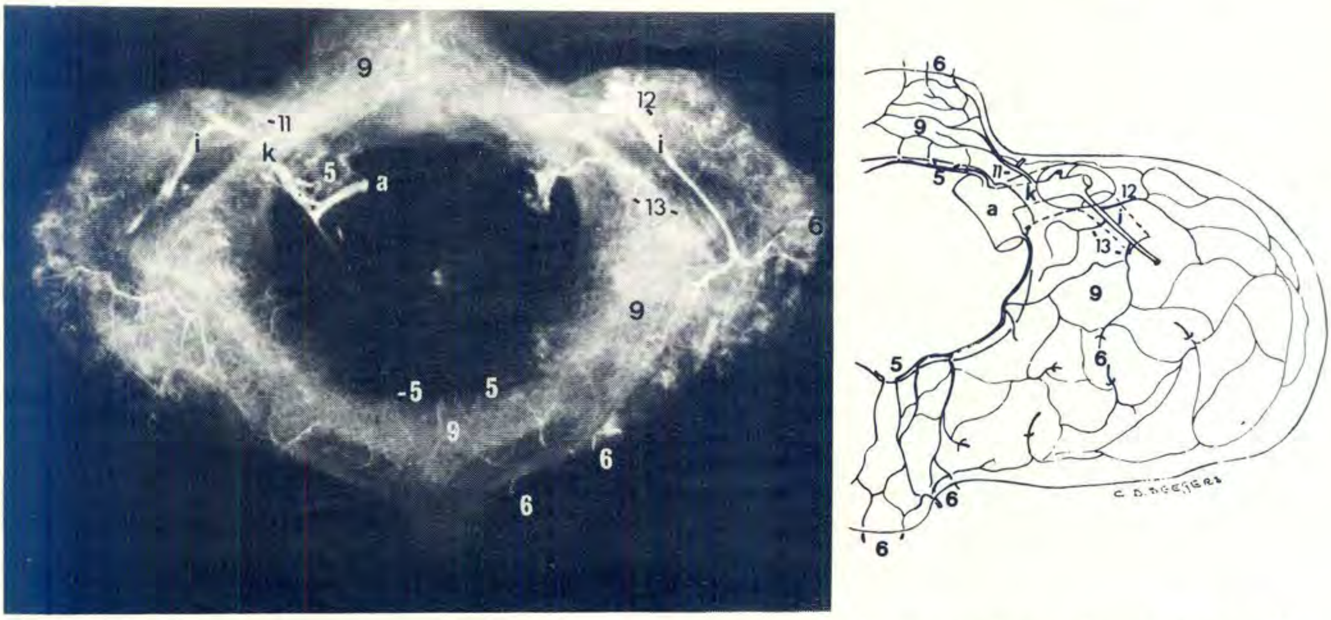

FIG. 14 Atlas—Röntgenograph with schematic insert, caudal view. **5** nutrient vessels from vertebral artery, **6** extraosseous vessels, **9** intraosseous network, **11** branch arising at level of lateral vertebral foramen, **12, 13** branches arising in alar foramen, **a** A. vertebralis, **k** its ramus descendens, **i** anastomotic branch to occipital artery

The cranial articular process receives an additional supply f·om a vessel (Fig. 12/10) given off by "the artery of the transverse canal". The *caudal epiphysis* is supplied by extraosseous vessels (Fig. 13/6) entering along the epiphysial line, and by a vessel (Fig. 13/7) arising from the vertebral artery.

The *dens* is also supplied by basivertebral vessels. From 4–6 arteries enter the bone in a vertical or oblique direction (Fig. 13). Some of these vessels may coalesce within the bone and detach radially-directed branches towards the dental contour. They also spread out caudolateralward into the substance of the cranial articular process, where they communicate with the intraosseous network (Fig. 12 and 13/9) and with extraosseous rami (Fig. 13/6).

Atlas

The chief source of nutrient arteries to the atlas is the R. descendens of the vertebral artery and its branches along the dorsal and ventral surfaces of the vertebra.

(i) *Arcus dorsalis*: In the lateral vertebral foramen, a branch (Fig. 14/11) arises from the dorsomedial aspect of the R. descendens (Fig. 14,k). Its branches spread out within the dorsal tubercle, forming a loose network (Fig. 14/9). They anastomose with the vessels from the opposite side as well as with extraosseous vessels from the external surface (Fig. 14/6). A few very small nutrient vessels (Fig. 14/5) arise from the vertebral artery before it gives off the R. descendens. They penetrate the dorsal arch from the vertebral canal and connect with the network of vessels in the tubercle.

(ii) *Massa lateralis*: This region is supplied from the alar foramen and by extraosseous branches (Fig. 14/6) entering along the dorsal and ventral surfaces of the wing.

Within the foramen the following branches arise:

(i) A lateral vessel (Fig. 14/12) distributed within the craniolateral part of the wing and cranial articular process. It divides frequently and anastomoses with vessels supplying the dorsal arch.

(ii) One or 2 medial branches (Fig. 14/13) supplying the bone along the lateral part of the vertebral foramen.

Extraosseous nutrient vessels (Fig. 14/6) entering the wing and atlantal fossa form a loose, delicate meshwork within the substance of the bone (Fig. 14/9).

(iii) The *arcus ventralis*, formed by nutrient branches (Fig. 14/5) of the vertebral artery penetrating the ventral arch from the floor of the vertebral canal. On either side of the midline 3–5 of these slender vessels radiate towards the ventral tubercle and the external surface of the arch, where they anastomose with periosteal vessels (Fig. 14/6).

The entire arterial sytem is interconnected in the adult vertebra, forming a delicate meshwork of vessels (Fig. 14/9) within the substance of the bon:.

Discussion

The *extraosseous arterial supply* to the cervical vertebrae of the ox is extensive. Externally the ramifications of the vertebral, deep cervical, occipital and common carotid arteries form an extensive plexus in the overlying musculature and periosteum. They serve to perpetuate an effective collateral supply to each individual vertebra and to maintain the vital ha mopoietic processes taking place in these vertebrae. Nutrient vessels enter from the external and internal (transverse and vertebral canal) surfaces. Extraosseous nutrient arteries enter mainly along the lateroventral surfaces of the vertebral bodies and along the epiphysial lines. Minor contributions supply the laminae, transverse and articular processes. Notable nutrient arteries enter the pedicles of the caudal cervical vertebrae.

The chief *intraosseous arteries* arise from the *circelli arteriosi* in the vertebral canal and from the vertebral artery along its course in the transverse canal. Except perhaps for the atlas, a strikingly uniform pattern has evolved for the cervical series, viz:

1. The artery of the vertebral arch.
2. The artery of the transverse process.
3. The basivertebral arteries.

Crock (1960) reported that in dogs the vertebral arch of the adult has a richer blood supply than the vertebral body but this was not found to be the case in the ox.

Intraosseous branching is either rosette-like (basivertebral arteries) or arborescent, resulting in a loose network of vessels forming an *intraosseous arterial* plexus. The latter anastomoses freely with extraosseous nutrient vessels entering the surface and again stresses the effective collateral supply, also to the bone substance. This agrees with descriptions for the dog (Crock, 1960) and pig (Wissdorf, 1970).

The only age difference noted was the gradual increase in size of the nutrient arteries entering the external surface of the vertebra in the growing animal. No evidence could be found that the "interspinal" contribution diminished with age (Crock, 1960). Contrary to the findings of Amato & Bombelli (1939) and Crock (1960), anastomoses between the epi- and metaphysial vessels were present in very young animals.

The blood supply to the vertebral disc consists of a few very delicate vessels penetrating the anulus fibrosus. No supply to the nucleus pulposus could be determined in this study.

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