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THE VENOUS DRAINAGE OF THE CERVICAL VERTEBRAE OF THE OX (*BOS TAURUS* L.)

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ABSTRACT

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The venous drainage of the cervical vertebrae of the ox was studied in 16 animals (Friesland, Jersey and Guernsey cross-breeds), ranging from near full-term foetuses to adults. The extra- and intraosseous veins of the cervical vertebrae are described and illustrated. The nutrient vessels are derived from the vertebral, deep cervical, occipital and internal jugular veins. In addition to the dorsal and ventral external venous plexuses, a lateral external venous plexus is described. The intraosseous veins correspond in the main to the arteries. They are described and illustrated with reference to the available literature. In both young and adult animals anastomoses between epi- and metaphysial vessels are reported. The role of the internal ventral vertebral venous system as a collateral pathway is stressed and comments are made on its possible functional role.

Résumé

L'IRRIGATION VEINEUSE DES VERTÈBRES CERVICALES CHEZ LE BOEUF (BOS TAURUS *L.*)

On a étudié l'irrigation veineuse des vertèbres cervicales du boeuf chez 16 *spécimens (races croisées de Friesland, Jersey et Guernsey), depuis des foetus presque à terme jusqu'à des animaux adultes. Les veines extra- et intraosseuses des vertèbres cervicales sont décrites et figurées. Les vaisseaux nourriciers dérivent des veines vertébrale, cervicale profonde, occipitale et jugulaire interne. Outre les plexus veineux externes dorsaux et ventraux, on décrit un plexus veineux externe latéral. Les veines intraosseuses correspondent en gros aux artères. Elles sont décrites et figurées, avec renvoi aux publications disponibles. Tant chez les animaux jeunes que chez les adultes on note l'existence d'anastomoses entre les vaisseaux épi- et métaphysiaux. On souligne le rôle du système veineux v rtébral interne du côté ventral en tant que voie collatérale et sa fonction possible est commentée.*

INTRODUCTION

The anatomy of the extra- and intraosseous venous pathways of the vertebral column of the ox has never been described in detail, though studies have been made on other animals and on man. Renewed interest in the veins of the vertebral column was aroused when Batson (1940) demonstrated their importance in the spread of tumours and infection in man.

In reviewing the literature, attention will be focused on the source of supply to the vertebrae, the anatomy and functional role of the ventral internal venous vertebral plexus, the mode of entry into the vertebrae and the distribution of the vessels within the bone, and age differences.

The venous drainage of the vertebral column of the pig was described by Wissdorf (1970) who noted that, in the cervical region, the V. vertebralis is the major vessel of supply with additional contributions from the deep cervical and occipital veins. The Pl. venosus vertebralis internus ventralis is described as 2 vessels running parallel on the floor of the vertebral canal, supplying basivertebral veins to the vertebral bodies and connecting through the intervertebral foramina with the vertebral veins. He also described dorsal and ventral external vertebral plexuses.

A number of workers have made a study of the venous drainage of the vertebrae of the dog. Beron (1964) described a ventral vertebral plexus and a dorsal venous arch which is formed at the intervertebral foramina and constitutes a dorsal internal venous vetebral plexus. The vertebral vein and its connections are described, as well as dorsal and ventral external venous vertebral plexuses. No details of the intraosseous venous distribution are given except that basivertebral veins drain the vertebral body. Dräger (1937), Worthman (1956) and Reinhardt, Miller & Evans (1962) described the ventral internal venous vertebral plexus in the dog and its connections with the occipital, vertebral and deep cervical veins. Worthman (1956) mentioned anastomoses between the basivertebral veins and the extravertebral branches of the vertebral veins, and also described external plexuses. Wieboldt (1966) described the extravertebral veins of the vertebral column of the dog and cat, without referring to the nutrient vessels. Crock (1960) gave a thorough account of the intraosseous venous distribution of the vertebra of the dog, using radiography and clearing techniques. He observed that there are definite age differences in the distribution of these veins.

Von Willer (1923) described venous canals passing through the vertebral bodies of cats and rabbits and connecting the external and internal surfaces and noted that the ventral internal venous vertebral plexus resembled a ladder. Amato & Bombelli (1959) studied the normal vascular supply to the vertebral column of the growing rabbit. They observed that the veins do not follow the pattern of the arteries. The external and internal plexuses are described and the basivertebral veins are mentioned as anastomosing with the external plexus. Metaphysial and epiphysial vessels unite in the adult only. Nickel, Schummer & Seiferle (1975) gave a general description of the ventral internal venous plexus in domesticated animals, without any special reference to the ox, and listed the principal veins draining the plexus. Wiley & Trueta (1959) who used radiographic and clearing techniques to study the venous drainage of the vertebral column of man and the rabbit, found a similar arrangement in the cervical, thoracic and lumbar regions. The pattern in the vertebral body is described as tree-like, with minute tributaries draining from the metaphysis into the large central channel which opens into the ventral internal venous vertebral plexus. Connections are described between the central basivertebral vessel and external extraosseous branches.

In man the extraosseous supply is described in standard textbooks, for example, Schaeffer (1953) and Warwick & Williams (1973). According to these descriptions dorsal and ventral and internal venous vertebral plexuses are present and anastomose freely

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with the vertebral veins. In old age the basivertebral veins become enlarged. Dommisse (1973) described the vast extent of the internal venous plexuses and their extensive connections with extravertebral veins. He demonstrated experimentally in the baboon the importance of the venous plexus of Batson as an alternative route for the venous drainage of the brain. His findings support those of Batson (1940, 1957) and Herlihy (1947).

The intrinsic venous circulation of the vertebral body in man was described by Wagoner & Pendergrass (1932). They noted connections between basivertebral and extraosseous veins and stated that the venous channels within the vertebral body were lined by R.E. cells and constituted 40% of its volume. The authors postulated that they must therefore have an important antibacterial function.

No descriptions are available of the venous drainage of the vertebral column of ruminants. The external veins of the cervical vertebrae and their connections were described by Rauhut (1962) in the goat and sheep, and by Seidler (1966) in the ox. Rauhut described the ventral internal venous vertebral plexus as *circelli venosi* and mentioned that the delicate nutrient veins that arise from them supply the vertebral bodies. She described the vertebral vein as continuing an intravertebral course cranial to C3 although, according to Seidler (1966), it continues to the atlas. Le Roux (1959) described the course of the internal jugular vein in the ox and its possible connection with the occipital vein as well as anastomoses between the deep cervical and occipital veins dorsal to the axis.

This study was aimed at establishing the source of the blood vessels supplying the cervical vertebrae, their mode of entry and their distribution within the osseous tissue.

Materials and Methods

The 16 animals, all either Friesland, Jersey or Guernsey cross-breeds, used for this study, comprised 2 adults, one 15-month-old specimen, 9 calves aged 3–8 months, 2 new-born calves and 2 foetuses.

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

The following techniques, as described by Smuts (1977), were used to study the course and distribution of both the extraosseous and intraosseous nutrient vessels:

1. *Revultex injection and subsequent dissection:* venous system injected in 4 specimens; both arterial and venous systems injected in 2.
2. *Maggot digestion of revultex-injected specimens:* venous system injected in 1 specimen; both systems injected in 3.
3. *India ink injection and clearing of bone:* 1 specimen.
4. *Injection of contrast media for angiography and subsequent clearing of bone:* venous system injected in 3 specimens; both systems injected in 1.

Results

A. *The extraosseous nutrient veins*

Four blood vessels contribute to the venous supply of the cervical vertebrae. In order of importance they are: V. vertebralis (Fig. 1, a), V. cervicalis profunda (Fig. 1, b), V. occipitalis (Fig. 1, o) and V. jugularis interna (Fig. 1, c). Tributaries of these vessels anastomose freely, forming plexuses dorsally on the laminae and spinous processes, laterally along the laminae and transverse processes, and ventrally along the surface of the vertebral bodies. A striking feature of the venous pattern is the occurrence of 2 prominent longitudinal anastomoses between the dorsal rami of the vertebral vein at the level of the articular (Fig. 1, b^{II}) and the transverse (Fig. 1, b^{III}) processes respectively. These 2 vessels represent the dorsal vertebral ramus (Seidler, 1966) and lateral vertebral ramus of the deep cervical vein. Cranially they connect with the occipital vein. The ventral vessel is reinforced by branches from the internal jugular vein caudal and cranial to C4 (Fig. 1, x,x^{I}). The internal venous pattern is characterized by the Plexus venosus vertebralis internus (Figs. 3 & 4), which largely overlies the *circelli arteriosi.*

The costocervical vein (Fig. 1, d) arises from the cranial vena cava at the level of the 2nd intercostal space, constituting the common trunk for the vertebral, dorsal scapular and deep cervical veins. At the mediocranial border of the 1st rib the dorsal scapular vein (Fig. 1, Sc) is given off and shortly afterwards the costocervical vein bifurcates to form the vertebral (Fig. 1, a) and deep cervical (Fig. 1, b) veins. The latter runs dorsalwards behind the transverse process of C7 while the vertebral vein runs towards the transverse foramen of C6.

For practical reasons it is more convenient to describe the vessels of lesser importance first.

(a) *V. cervicalis profunda* (Fig. 1, b): The deep cervical vein lies caudally to the homologous artery. It courses dorsalwards behind the transverse process of C7 to the level of the caudal articular process, where it bifurcates in the majority of cases. Flanking the homologous artery, it now runs craniodorsalwards along the deep face of the M. semispinalis capitis as the Ramus ascendens (Seidler, 1966). It terminates (Fig. 1, k^{III}) by anastomosing with the vessel in the common opening of the lateral vertebral and alar foramina of the atlas. At the level of the axis it connects with a dorsal ramus (Fig. 1, g) of the vertebral vein and with the dorsal vertebral branch (Fig. 1, b^{II}). These anastomoses are associated with an extensive arterial network within the substance of the caudal oblique capital muscle.

Near the origin of the deep cervical vein, from 1–3 nutrient vessels arise which enter the dorsolateral aspect of the vertebral body of C7 along the epiphysial line. Several anastomoses occur between the deep cervical and vertebral veins in their angle of divergence (Seidler, 1966). In this way a plexus is formed on the deep face of the vertebral artery and the ventral ramus of spinal nerve No. 7. The plexus extends dorsocaudally along the ventral and ventrocaudal aspects of the transverse process of C7, providing the latter with 2 or 3 nutrient vessels. In about half the specimens, a vessel enters the caudal surface of the pedicle of C7, while 5 or 6 slender vessels fan out cranialwards within the periosteum covering the internal surface of the vertebral archl Two or 3 of these vessels anastomose along the dorsa.

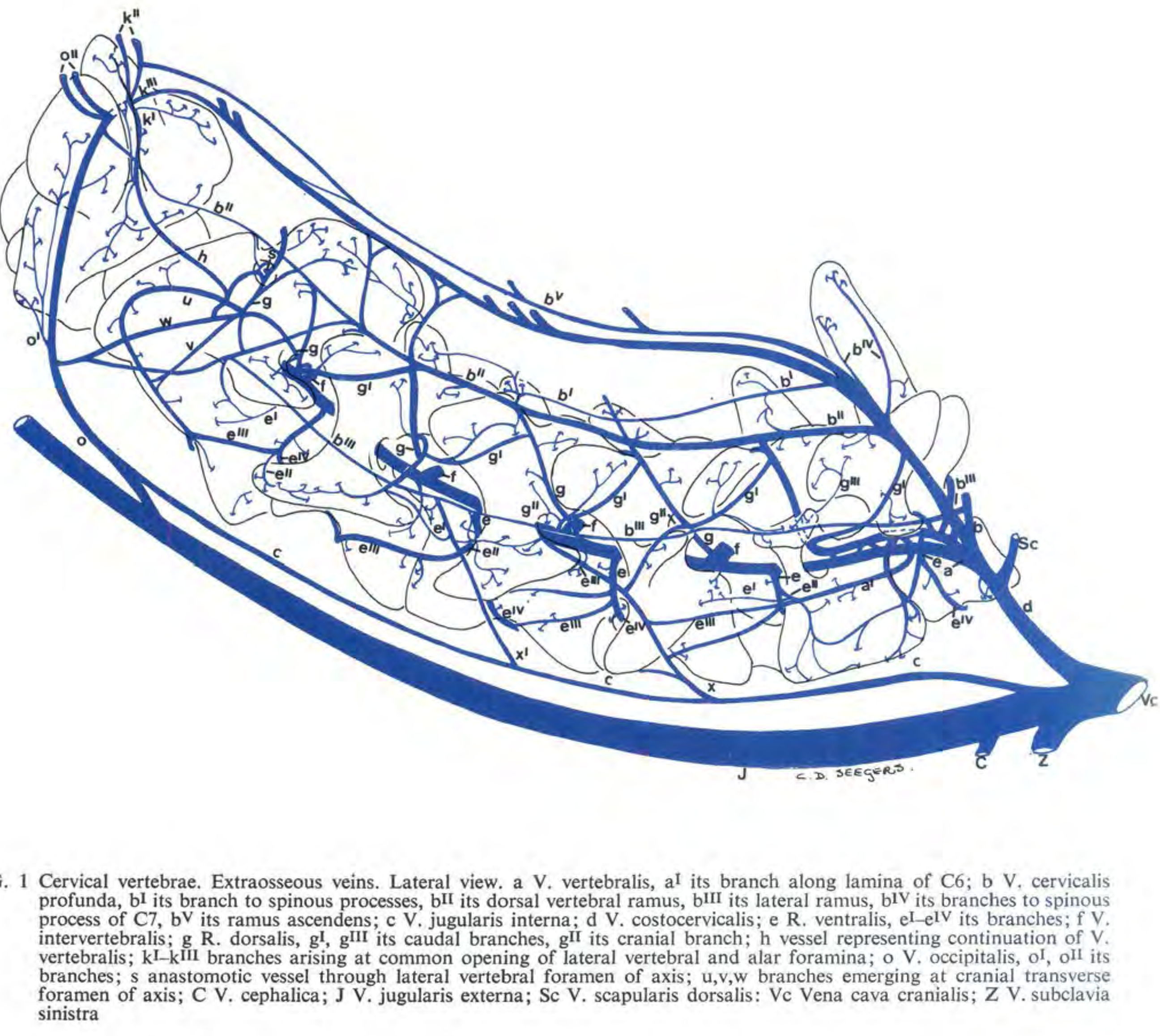

FIG. 1 Cervical vertebrae. Extraosseous veins. Lateral view. a V. vertebralis, a^{I} its branch along lamina of C6; b V. cervicalis profunda, b^{I} its branch to spinous processes, b^{II} its dorsal vertebral ramus, b^{III} its lateral ramus, b^{IV} its branches to spinous process of C7, b^{V} its ramus ascendens; c V. jugularis interna; d V. costocervicalis; e R. ventralis, e^{I}–e^{IV} its branches; f V. intervertebralis; g R. dorsalis, g^{I}, g^{III} its caudal branches, g^{II} its cranial branch; h vessel representing continuation of V. vertebralis; k^{I}–k^{III} branches arising at common opening of lateral vertebral and alar foramina; o V. occipitalis, o^{I}, o^{II} its branches; s anastomotic vessel through lateral vertebral foramen of axis; u,v,w branches emerging at cranial transverse foramen of axis; C V. cephalica; J V. jugularis externa; Sc V. scapularis dorsalis: Vc Vena cava cranialis; Z V. subclavia sinistra

midline of the lamina, while 5 or 6 very slender nutrient vessels arise from their dorsal face to enter the middle third of the laminar surface.

The following branches now arise from the deep cervical vein:

(i) From a muscular branch near its origin a vessel (Fig. 1, b^{III}) proceeds cranialwards along the dorsolateral edges of the transverse processes from C6–C2. This is the Ramus vertebralis lateralis (*vide supra*). Anastomoses are formed along the transverse processes with the dorsal rami (Fig. 1, g^{I}) of the vertebral vein. In this way a *lateral external venous plexus* is formed.

(ii) On a level with the caudal articular process of C7, a branch (Fig. 1, g^{I}) arises which supplies the dorsal surface of the transverse process of this vertebra and anastomoses with the first dorsal ramus of the vertebral vein. A large nutrient vessel which enters a foramen in the lateral fossa of the lamina is also given off.

(iii) At the level of the ridge connecting the articular processes of C7, 2 branches (Fig. 1, b^{IV}) arise which supply the spinous process of C7. One of these provides a number of small nutrient vessels to the caudal surface of the base and particularly to the free extremity, while the other supplies 2 or 3 vessels to the lateral surface of the proximal third of the process.

(iv) Also arising at this level is the Ramus vertebralis dorsalis (Fig. 1, b^{II}). It runs along the dorsolateral edges of the articular processes and anastomoses with the dorsal rami of the vertebral vein. Cranially, it joins a vein emerging from the common opening of the lateral vertebral and alar foramina of the atlas. This longitudinal vessel supplies a few fine nutrient vessels to the dorsal surface of the articular processes and laminae. Anastomoses are formed with interarcuate rami penetrating the Ligg. flava, as well as with the next branch.

(v) On a level with the middle of the spinous process of C7, a branch (Fig. 1, b^{I}) arises which supplies nutrient vessels to the free extremities of the spinous processes from C6–C3. It anastomoses along the dorsal surface of the laminae with the ramifications of the dorsal vertebral branch and the interarcuate rami, in this way forming a *dorsal external venous plexus*.

(b) *V. jugularis interna* (Fig. 1, c): The left and right internal jugular veins arise from a short common trunk formed in the angle of bifurcation of the 2 external jugular veins (Seidler, 1966). They run cranialwards along the ventral surface of the M. longus colli accompanied by the common carotid arteries. In 2 specimens they joined the occipital vein; in 2 cases they ended within the musculature at the level of C3; and in 1 case they proceeded cranialwards to form the cranial thyroid vein. The internal jugular vein contributes to the external venous supply of the vertebrae by means of 2 slender branches. The caudal one (Fig. 1, x) arises ventral to C5 and runs towards the dorsal tubercle of the transverse process of C4 under cover of the ventral scalenus muscle. It supplies a branch to the medioventral surface of the transverse process of C5 where it anastomoses with a ventral ramus (Fig. 1, e) of the vertebral vein. The cranial ramus (Fig. 1, x^{I}) reaches the lateral aspect of the 3rd transverse process. Both the cranial and caudal branches join the lateral vertebral branch (Fig. 1, b^{III}) of the deep cervical vein and thus contribute to the *lateral external venous plexus*.

(c) *V. vertebralis:* The vertebral vein (Fig. 1, a) results from the division of the costocervical vein (Fig. 1, d) at the craniomedial border of the 1st rib. It leaves the latter vessel at an acute angle, runs towards the transverse foramen of C6 which it enters and courses cranialwards in the transverse canal. At the 2nd intervertebral space it enters the vertebral canal through the intervertebral foramen and joins the ventral internal venous vertebral plexus. Its continuation, a vessel much reduced in size, traverses the transverse canal of the axis and terminates at the cranial transverse foramen by dividing into several branches. In specimens lacking the axial transverse canal, the vein runs along the lateral surface of the pedicle to its termination. At the origin of the vertebral vein and in its angle of divergence from the deep cervical vein a well-developed plexus is formed which simulates a double vertebral vein (Seidler, 1966). Along its course and at each segment the vertebral vein consistently gives rise to a ventral ramus, a dorsal ramus and an intervertebral vein.

(i) *R. ventralis:* A typical ventral ramus (Fig. 1, e) arises at the edge of the cranial transverse foramen of a vertebra. Its course resembles that of the homologous artery which lies superficially and cranially to it. It runs ventralwards on the vertebral body, supplying a number of nutrient vessels to the bone along the cranial epiphysial line of the succeeding vertebra. The ramus ventralis then terminates by bifurcating into a cranial (Fig. 1, e^{III}) and a caudal branch (Fig. 1, e^{IV}) which anastomose along the mid-ventral line with the corresponding vessels of the opposite side to form a diamond-shaped pattern. In some specimens the cranial terminal branch is not included in the formation of this pattern but, instead, ramifies along the caudal epiphysis of the preceding vertebral body. In such cases the pattern is completed by the lateral branch of the ventral ramus (*vide infra*).

Near its origin the ventral ramus gives off a lateral vein, whose caudal branch (Fig. 1, e^{II}) ramifies on the lateral surface of the succeeding transverse process; the cranial branch (Fig. 1, e^{I}) supplies nutrient vessels to the ventrocaudal aspect of the preceding transverse process. In the cranial segments of the series this branch tends to arise separately from a dorsal branch of the vertebral vein. When the cranial terminal branch of the Ramus ventralis is not included in the formation of the diamond-shaped pattern, this branch continues medially along the ventral tubercle of the transverse process. It supplies the base with nutrient vessels and completes the pattern on the ventral aspect of the vertebral body. In most cases a small vessel arises from the vertebral vein near the caudal transverse foramen. It supplies a few nutrient branches to the vertebral body and to the base of the transverse process.

Caudally, at the level of C7, the 1st ventral ramus arises either from the plexus involving the vertebral vein or from the costocervical trunk. Its distribution corresponds in the main to that of a typical ramus ventralis. Nutrient vessels are supplied to the body of C7 and to the epiphyses of the contiguous 6th and 7th vertebrae. In addition, the vertebral vein detaches a slender branch (Fig. 1, a^{I}) which runs cranialwards along the dorsolateral aspect of the lamina of C6. It anastomoses with the preceding ventral ramus and with the internal jugular vein and supplies a few nutrient vessels to the lamina. The caudal and caudolateral aspects of the lamina of C6 are supplied by a small vessel originating from the vertebral vein at the level of the intervertebral vein.

At the 2nd intervertebral space the branches of the Ramus ventralis supply nutrient vessels to the vertebral bodies and transverse processes of C2 and C3. They also connect with a vessel joining the dorsal and lateral vertebral branches of the deep cervical vein to the occipital vein and with a vessel (Fig. 1, h) issuing from the cranial transverse foramen of the axis.

At the termination of the vertebral vein, at the cranial transverse foramen of the axis, a typical ventral ramus is absent. Instead, several vessels emerge here and take over the distribution of the ventral ramus. They form a variable network of anastomoses with nearby vessels. One branch (Fig. 1, u) runs cranioventrally along the articular process of the axis, curves caudally, and continues along the ventral spine. It gives off 6–8 nutrient vessels along its course and anastomoses with a slender vessel (Fig. 1, v) descending from the cranial transverse foramen. Another constant vessel (Fig. 1, w) descending from the foramen, connects with the occipital vein ventrally to the atlantoaxial articulation. It anastomoses with the nearby dorsal ramus and sends a fairly large branch (Fig. 1, h) cranialwards over the atlantoaxial joint capsule and the dorsolateral aspect of the atlantal wing, to the common opening of the lateral vertebral and alar foramina. Numerous large nutrient veins enter the edges and the wing of the atlas along the course of this vessel.

(ii) *R. dorsalis:* The dorsal rami (Fig. 1, g) arise from the vertebral vein near the caudal transverse foramina of the vertebrae. Related caudally to the accompanying arteries, they pursue a craniodorsal course across the vertebral laminae towards the articular processes of preceding vertebrae. At this level they join the dorsal vertebral branch (Fig. 1, b^{II}) of the deep cervical vein. Delicate nutrient vessels are supplied to the dorsal surface of the laminae. In this region the dorsal rami also anastomose with a branch (Fig. 1, b^{I}) of the deep cervical vein which supplies the 3rd–the 6th cervical spinous processes and with interarcuate vessels emerging from the ventral internal venous vertebral plexus.

The mode of branching of the dorsal ramus corresponds largely to that of the ventral ramus, i.e. cranial (Fig. 1, g^{II}) and caudal (Fig. 1, g^{I}) branches are given off. The former supplies the dorsal aspect of the transverse process and anastomoses with the lateral vertebral branch (Fig. 1, b^{III}) of the deep cervical vein. The pedicle and lamina of the preceding vertebra receive nutrient vessels from this source. The caudal branch accompanies the dorsal ramus of the spinal nerve and anastomoses with the succeeding dorsal ramus below the level of the articular process. Periosteal and nutrient vessels to the lamina and articular process arise from it. The cranial and caudal branches may arise separately from the dorsal ramus.

Caudally, the 1st Ramus dorsalis (Fig. 1, g) originates from the plexus in the angle of divergence between the vertebral and deep cervical veins. At the transverse foramen of C6 it sends an anastomotic branch (Fig. 1, g^{I}) across the lamina of C7 to the deep cervical vein. The dorsal ramus then runs craniodorsally across the lamina of C6 and joins the dorsal vertebral branch (Fig. 1, b^{II}) of the deep cervical vein and the plexus on the dorsal surface of the vertebra. It is related caudally to the homologous artery. Typically it also gives rise to cranial (Fig. 1, g^{II}) and caudal (Fig. 1, g^{III}) branches. The former supplies the dorsal tubercle of the transverse process and anastomoses with the preceding dorsal ramus and with the lateral vertebral ramus (Fig. 1, b^{III}) of the deep cervical vein. The caudal branch provides nutrient vessels to the lateral aspect of the cranial articular process of C7.

At the 2nd intervertebral space, the dorsal ramus anastomoses with the succeeding dorsal ramus, with the dorsal and lateral vertebral branches of the deep cervical vein and with vessels issuing from the cranial transverse and lateral vertebral foramina of the axis. Nutrient vessels are supplied to the dorsal aspect of the axial transverse process and to the lamina. From the anastomotic branch with the succeeding dorsal ramus nutrient vessels enter the cranial articular process of C3.

The last typical dorsal ramus arises from the end of the vertebral vein at the cranial transverse foramen of the axis. It runs dorsalwards towards the spinous process where numerous nutrient vessels enter the bone. Connections are established with the dorsal vertebral branch (Fig. 1, b^{II}) of the deep cervical vein at the base of the transverse process. A branch (Fig. 1, s) joins the ventral internal venous vertebral plexus through the lateral vertebral foramen of the axis.

(iii) *V. intervertebralis:* At each segment from the 2nd–the 6th, the vertebral vein detaches an intervertebral vein (Fig. 1 & 2, f). It enters the intervertebral foramen and joins the ventral internal venous vertebral plexus. It may arise directly from the vertebral vein or, more frequently, in common with the dorsal ramus. The intervertebral vein is often double or may divide into 2–4 interconnecting branches to form a small plexus (Fig. 2). Caudally, at the 6th interspace, it runs along the caudal vertebral incisure of C6 before joining the ventral internal vertebral plexus. The vein is also connected to the plexus in the angle of divergence of the vertebral and deep cervical veins.

Plexus venosus vertebralis internus ventralis

This plexus (Fig. 3) represents the caudal continuation of the basal part of the sinuses of the dura mater. It covers the dorsal surface of the vertebral bodies and the medial surface of the pedicles for the entire length of the cervical vertebral column. The plexus partly overlies the *circelli arteriosi* and consists of 2 large parallel vessels interconnected across the vertebral bodies by means of 2 or 3 transverse anastomoses (Fig. 3, 4 & 6, y). They may be absent at the level of C4 and C5, where a fringe-like series of small branches (Fig. 3 & 4, y^{I}) enters the bone on either side of the median plane. One or 2 basivertebral veins accompanied by an artery enter the dorsal face of the vertebral body through the basivertebral foramina. In addition, a number of smaller nutrient vessels may also enter the vertebral body in the immediate vicinity. A connection occurs between the plexus and the vertebral vein through the vertebral opening of the transverse canal in the pedicle.

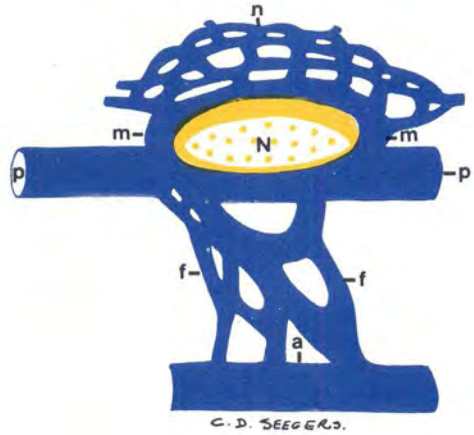

FIG. 2 Venous tunnel formed by Pl. venosus vertebralis internus ventralis (p), Rr. interarcuales (m) and interarcuate plexus (n), surrounding emerging spinal nerve (N). V. intervertebralis (f) forms a plexus between V. vertebralis (a) and internal plexus (p)

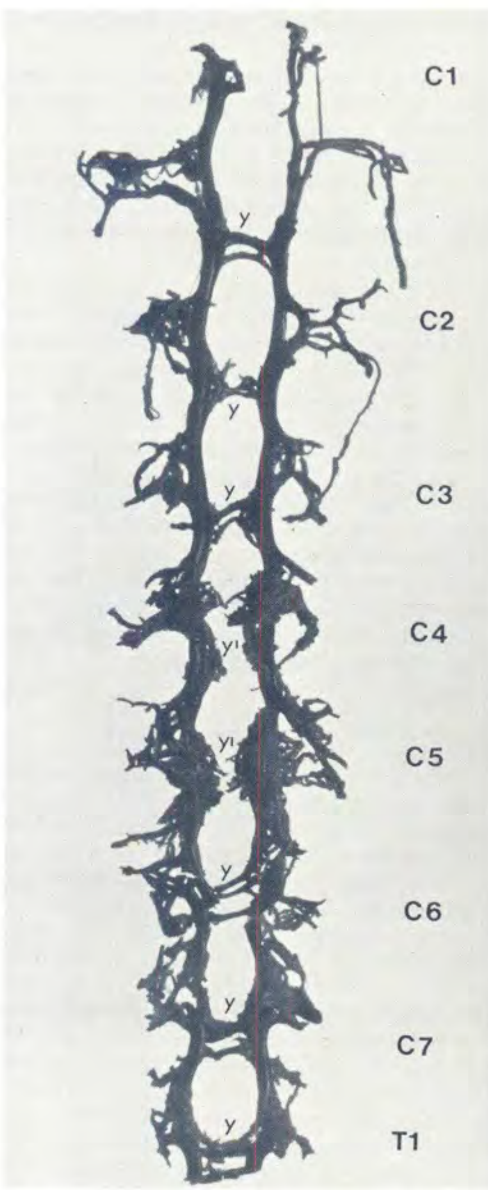

FIG. 3 Plexus venous vertebralis internus ventralis, dorsal view. Photograph of injected specimen

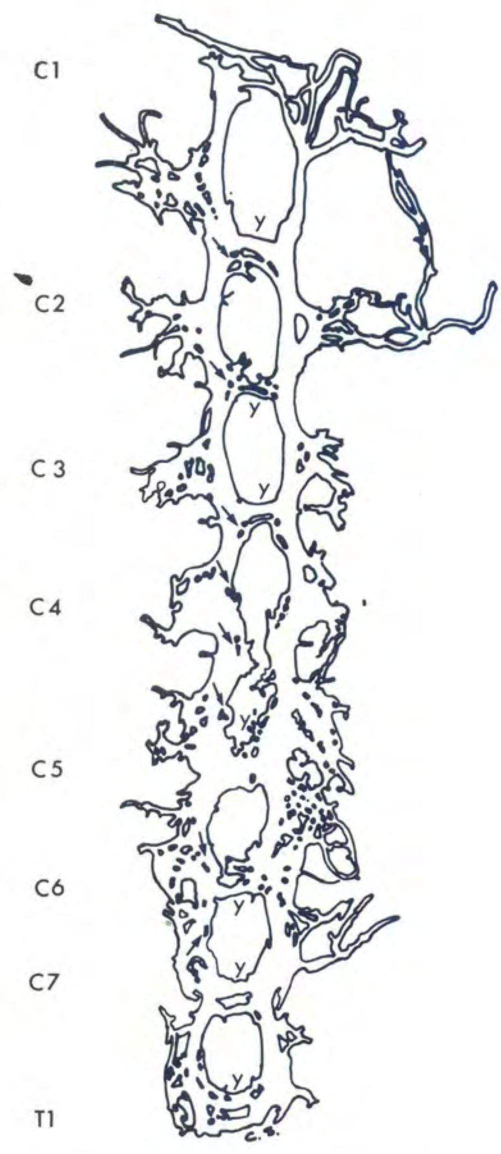

FIG. 4 Plexus venous vertebralis internus ventralis. Ventral view of specimen in Fig. 3, copied from a photograph. Note the openings of basivertebral veins (arrow) and nutrient veins to the laminae

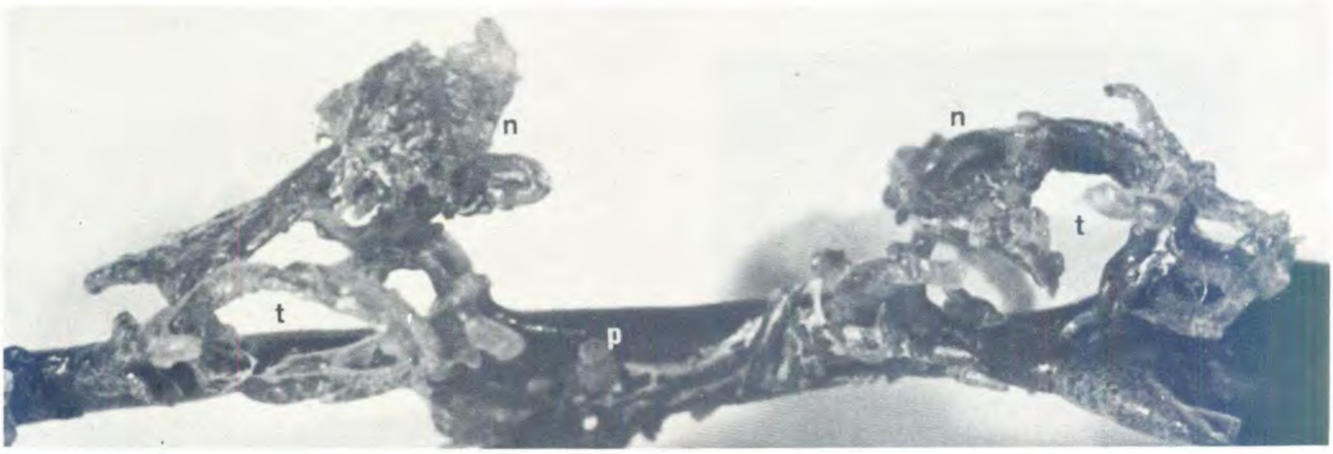

FIG. 5 Plexus venosus vertebralis internus ventralis. Lateral view of a segment of Fig. 3, enlarged 4×. t venous tunnel formed for the emerging spinal nerve; n interarcuate plexus

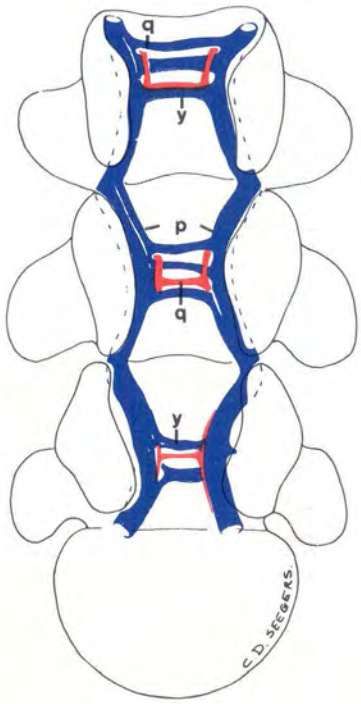

FIG. 6 Interwoven relationship between pl. venosus vertebralis internus ventralis and circelli arteriosi at transverse anastomoses

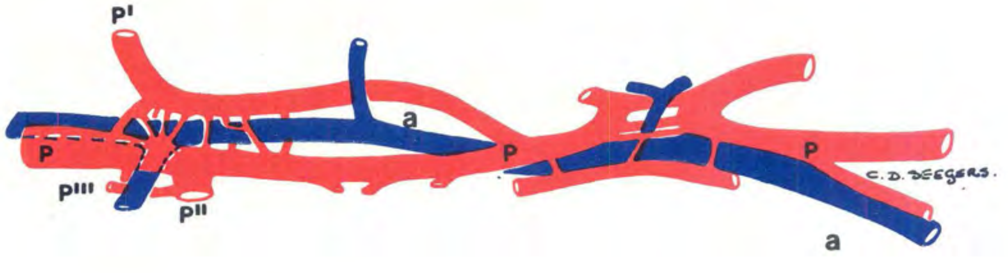

FIG. 7 Relationship between pl. venosus vertebralis internus ventralis (p) and A. vertebralis (A) at the level of the atlas and axis; pI–pIII branches of p at level of atlas

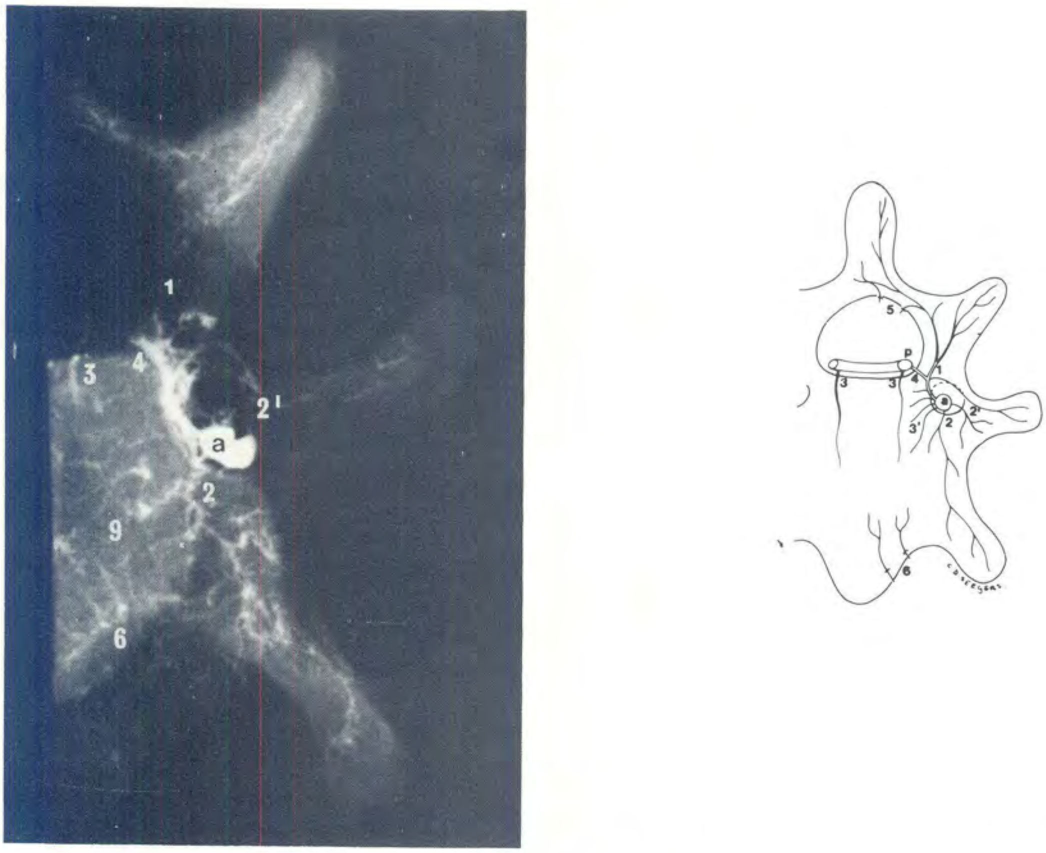

FIG. 8 C5, cranial view. Roentgenograph and schematic drawing, illustrating the intraosseous vein of the vertebral arch (1), vein of the transverse process (2), additional supply to dorsal tubercle (2'), basivertebral vein (3) with additional branches (3') to the body arising from the vertebral vein (a), extraosseous periosteal vessels (5, 6), intraosseous venous plexus (9) and ventral internal venous plexus (p)

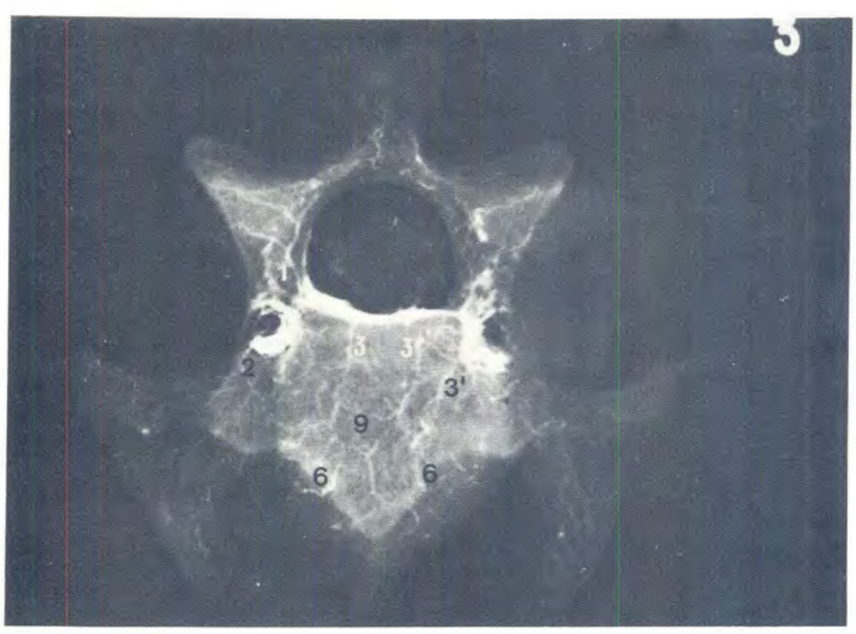

FIG. 9 C3, cranial view. Roentgenograph. Paired basivertebral veins (3) are reinforced by branches (3') from V. vertebralis; 1 vein of the vertebral arch; 2 vein of the transverse process; 6 extraosseous vessels; 9 intraosseous venous plexus

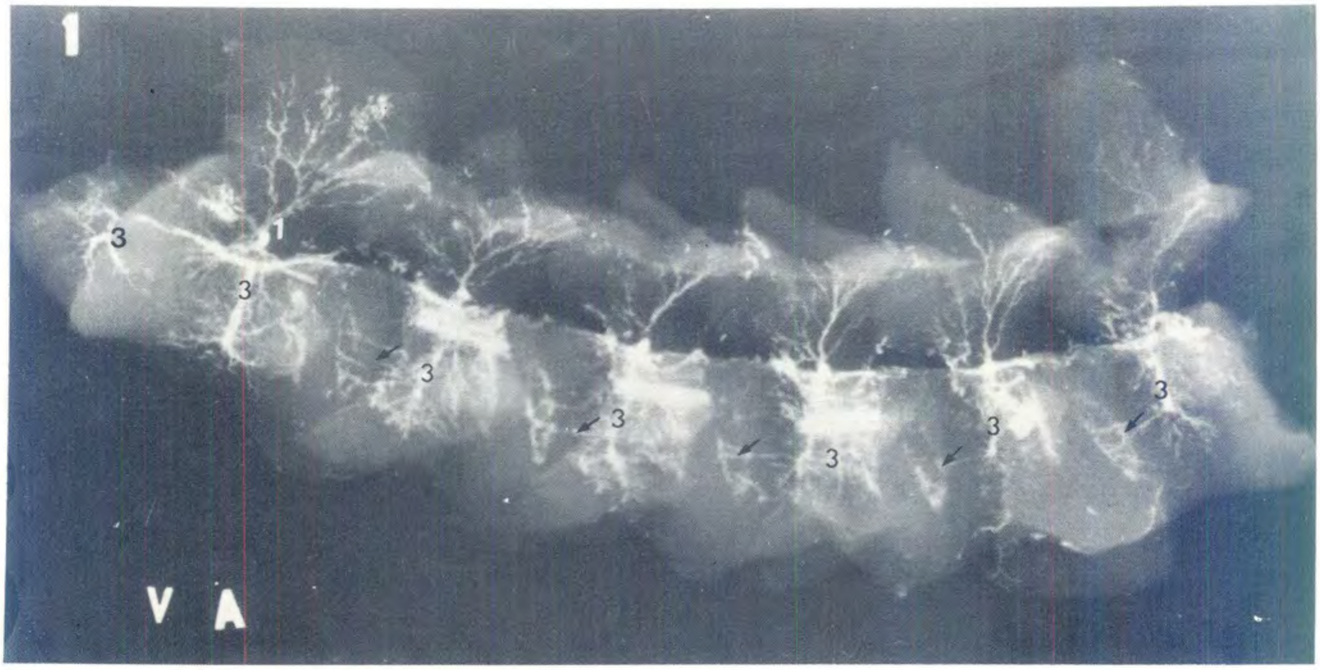

FIG. 10 C2–C7 of new-born. Roentgenograph: arterial and venous systems injected. Note branches of basivertebral vessels which traverse the growth plates (arrows) to anastomose with epiphysial vessels. Basivertebral vessels (3) and vessels of the vertebral arch (1) are clearly visible

FIG. 11 Roentgenograph of laminae and spinous processes of C6 and C7: 1 vein of the vertebral arch; 1I its continuation in the spinous process

FIG. 12 Axis: photograph of cleared bone of 5-year-old animal injected with coloured Micropaque. 1 vein of the vertebral arch; 1II additional vessels to vertebral arch; Photographed through clearing fluid

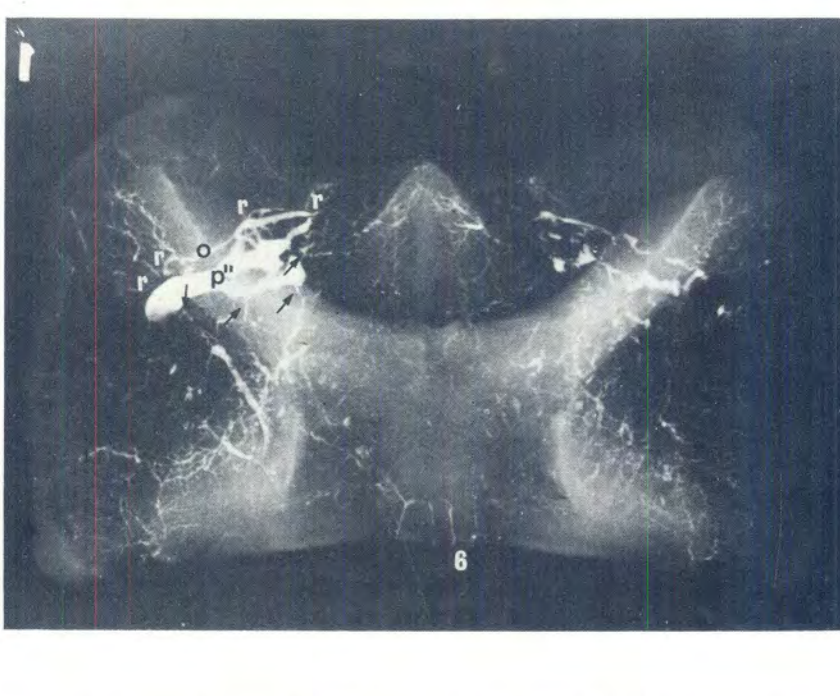

FIG. 13 Atlas. Roentgenograph, ventral view. pII vein of the vertebroalar canal—its branches are arrowed; o V. occipitalis, r its branches; 6 extraosseous nutrient veins

Cleared specimens, photographed through clearing fluid

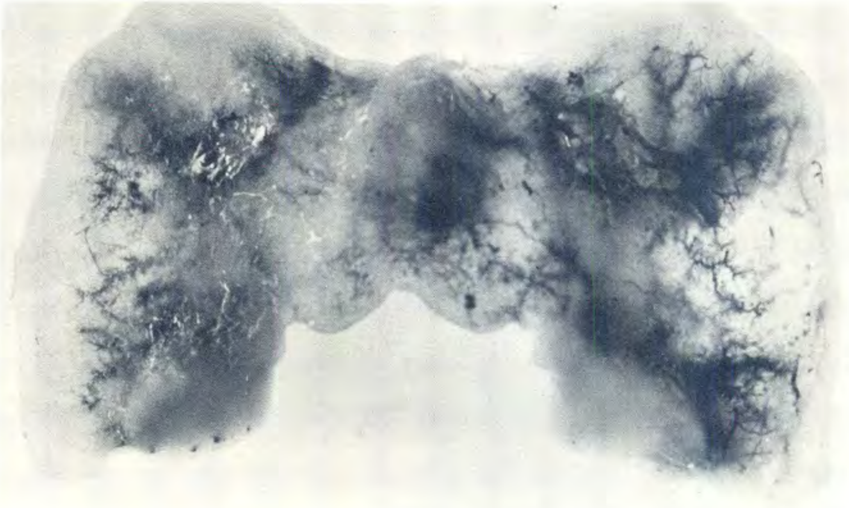

FIG. 14 Atlas, dorsal view. Ventral arch removed

FIG. 15 C7, spinous process (magn. 2 ×)

FIG. 16 C6, lateral view

FIG. 17 C4, laminae and spinous process, dorsal view

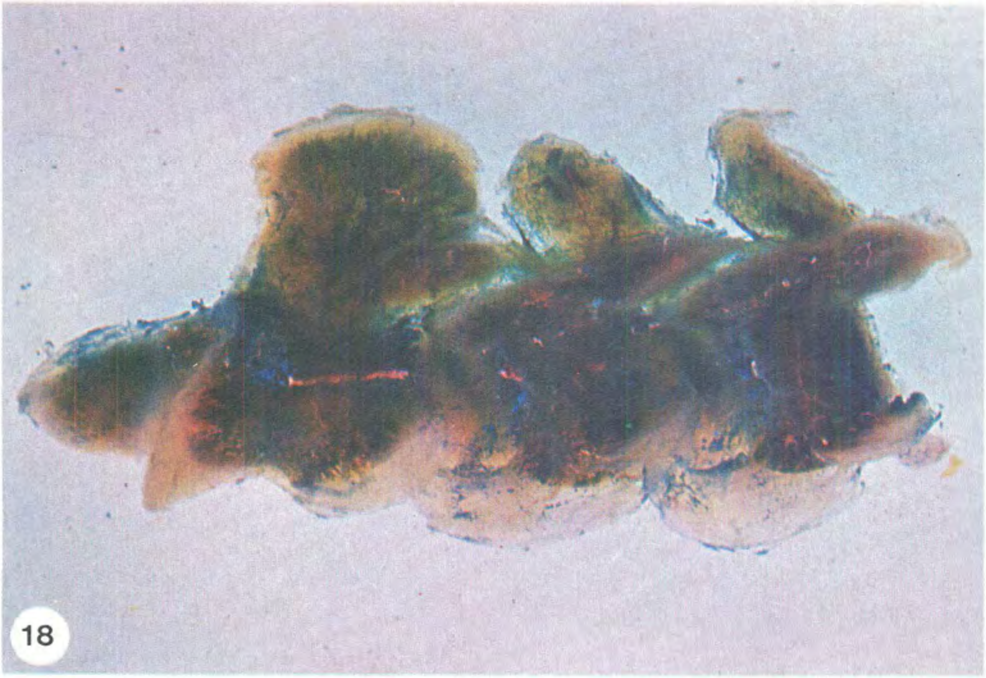

FIG. 18 C2–C4 of new-born calf, lateral view. Arterial and venous systems injected. Vertebrae cleared and photographed through clearing fluid

Opposite each intervertebral foramen 2 interacute rami (Fig. 2, m) arise from the dorsal surface of the plexus, flanking the emerging spinal nerve (Fig. 2, N). They anastomose along the dorsal surface of the nerve and form a dense, platelike meshwork (Fig. 2, n) within the Lig. flavum. Ventrally, it is continuous with the network formed by the intervertebral vein (Fig. 2, f). In this way a venous tunnel (Fig. 5, t) is formed around the spinal nerve as it emerges through the intervertebral foramen. The platelike plexus (Fig. 2, n) within the Lig. flavum is continued for a short distance cranially and caudally within the periosteum of the pedicles and laminae. A few nutrient vessels arise from this plexus to supply the bone. A longitudinal anastomosis along the internal surface of the pedicle may connect preceding and succeeding networks. Dorsally there are tenuous transverse connections within the Lig. flavum between networks of the left and right sides, and a few vessels penetrate the ligament to anastomose with the external dorsal plexus. An interesting feature is the interwoven relationship between the circelli arteriosi and the plexus, evident at all the transverse anastomoses (Fig. 6). It is particularly striking at the 2 cranial segments (Fig. 7), where the vertebral artery (Fig. 7, A) runs in the vertebral canal. Here the plexus (Fig. 7, p) is enlarged, forming an extensive and complicated interconnected system with the artery (Fig. 7, A) interwoven into it. At the lateral vertebral foramen of the atlas the vertebral artery and its branches are completely enveloped by the plexus. At the level of the dens, the medial vessels (Fig. 7, p^{I}) from each side anastomose and detach a number of nutrient veins. The lateral vessel, which represents the main continuation of the plexus, sends a large branch (Fig. 7, p^{II}) through the vertebroalar canal which connects with the occipital vein in the alar foramen. Another small branch (Fig. 7, p^{III}) accompanies the R. descendens of the vertebral artery through the lateral vertebral foramen of the atlas. It anastomoses with the occipital vein in the common opening of the lateral vertebral and alar foramina; in the majority of cases it also connects with the vein in the vertebroalar canal through an intermediate foramen in the floor of the common opening.

Several vessels appear dorsally at the common opening of the lateral vertebral and alar foramina of the atlas. These arise from a parent trunk lying in the common opening and resulting from the confluence of a branch of the occipital vein. The occipital vein enters the alar foramen, plus branches of the internal ventral venous vertebral plexus which issues through the lateral vertebral and vertebroalar foramina. The following vessels appear at the common opening:

(i) One or 2 vessels (Fig. 1, k^{II}), running cranially in the M. capitis dorsalis minor, supply nutrient branches to the craniodorsal aspect of the articular process of the atlas.

(ii) A nutrient branch supplying the dorsal tubercle of the atlas (Fig. 1 between o^{II} and k^{II}).

(iii) An anastomotic branch (Fig. 1, k^{III}) to the deep cervical vein.

(iv) A branch (Fig. 1, k^{I}) running caudally along the wing of the atlas and connecting with the vessels at the cranial transverse foramen of the axis (*vide supra*).

(d) *V. occipitalis* (Fig. 1, o): The occipital vein arises from the external jugular vein on the level of the axis. Ventral to the atlantoaxial articulation the lateral vertebral branch of the deep cervical vein joins it. When the occipital vein reaches the ventral tubercle of the atlas, 1 or 2 branches (Fig. 1, o^{I}) arise which provide nutrient vessels to the tubercle and the craniolateral aspect of the cranial articular process as well as to the atlantal fossa.

Before reaching the opening of the vertebroalar canal, the occipital vein gives off 1 or 2 branches (Fig. 1, o^{II}) which run within the M. rectus capitus lateralis towards the head. Over the dorsolateral edge of the wing it receives the dorsal vertebral branch (Fig. 1, b^{II}) of the deep cervical vein. The terminal branches of the occipital vein enter the alar and vertebroalar canals and connect with the ventral internal venous vertebral plexus.

B. *The intraosseous nutrient veins*

Basically, the pattern of the intraosseous veins corresponds to that of the arterial side. Three main nutrient vessels are present, namely, the vein of the vertebral arch, directed dorsally and supplying the arch and its processes; the vein of the transverse process, which is detached lateralwards into the transverse process and the basivertebral vein, which is destined to supply the vertebral body. The vertebrae in the middle of the series display this pattern best and will be considered together. Differences in the remaining vertebrae will be described individually.

Cervical vertebrae 3–5

(i) *The vein of the vertebral arch* (Fig. 8 & 9/1) supplies the vertebral arch, spinous and articular processes. In addition extraosseous vessels enter the bone from the roof of the vertebral canal (Fig. 8/5) and from the external (Fig. 8 & 9/6) surface. The vein of the vertebral arch is a large vessel that arises from the vertebral vein, enters a canal in the arch and runs dorsally towards the spinous process. Along its course it gives off a cranial and a caudal branch to the pedicle. This in turn anastomoses with extraosseous veins and sends a large anastomotic branch (Fig. 8/4) through the vertebral opening of the transverse canal to the ventral interna venous plexus. The next branch is directed laterally within the arch where it breaks up into numerous small vessels distributed to the cranial and caudal articular processes.

Further along its course the vein of the vertebral arch runs close to the vertebral canal from which it receives delicate branches. It terminates by dividing into 2 or 3 branches which ramify and form a diffuse network in the spinous process. Caudally, at the base of the spinous process, extraosseous vessels enter and join the plexus in the bone.

(ii) *The vein of the transverse process* (Fig. 8 & 9/2) may be represented by several branches of the vertebral vein. In C5, (Fig. 8), where the dorsal tubercle is placed further dorsally in relation to the transverse canal, the vessel of supply (Fig. 8/2^{1}) arises from the vein of the vertebral arch. Prominent extraosseous veins enter through the fossa between the dorsal and ventral tubercles and anastomose with the network within the bone.

(iii) The vertebral body is richly supplied by the ventral internal venous plexus, the vertebral vein and extraosseous vessels.

The basivertebral veins (Fig. 8 & 9/3), single or double, run ventrally into the bone from the ventral internal venous plexus. Branches are given off and anastomoses established with extraosseous vessels entering the lateroventral surface of the body. Additional nutrient vessels (Fig. 8 & 9/3[I]) are received from the vertebral vein. Apart from the large basivertebral veins the ventral internal venous plexus also gives off several smaller vessels to the vertebral body. Some of these vessels enter into the formation of the plexus in the body and anastomose with the vertebral vein.

The chief branches of each central basivertebral vessel run towards the metaphyses. In both adults and new-born animals (Fig. 10) they anastomose with epiphysial veins which are derived partly from the ventral internal venous plexus and partly enter from the circumference. Within the cranial epiphysis 2 or 3 large vessels run cranialwards into the convex cranial extremity. Their branches spread out along the inner surface of the covering cartilage.

Cervical vertebra No. 6

The origin and distribution of the nutrient vessels correspond largely to those of the 3 preceding vertebrae. The vein of the vertebral arch may be reinforced by a vessel entering the cranial aspect of the pedicle. The large ventral lamina of the transverse process is supplied by branches of the vertebral vein. They are supplemented by several prominent extraosseous vessels entering the lateral and medial aspects of the lamina. The ramifications from both sources form a network in the lamina.

Cervical vertebra No. 7

The distribution of the nutrient vessels is similar to that of the previous 6 vertebrae. Owing to the absence of a transverse canal or foramen, the origin of the vein of the vertebral arch is modified as follows: one or 2 vessels, arising from the dorsal ramus of the vertebral vein enter the pedicle from the cranial aspect and anastomose with a large vein entering the lateral aspect of the lamina. In approximately half the specimens this vein also anastomoses with a branch of the deep cervical vein entering the caudal aspect of the pedicle. In this way a transpedicular vessel is formed, giving rise to a typical vein of the vertebral arch as well as to the vein of the transverse process.

Axis

(i) *The vein of the vertebral arch* (Fig. 12/1) leaves the vertebral vein in the transverse canal, supplies a branch to the pedicle and lamina and heads towards the caudal articular and the spinous process. The terminal branches are dispersed here to form a plexus which anastomoses with extraosseous vessels entering from the external surface and from the vertebral canal. The cranial part of the arch and the spinous process receive additional vessels (Fig. 12/1[II]) from the anastomotic branch between the vertebral vein and the ventral internal venous plexus. This branch traverses the vertebral opening of the transverse canal.

(ii) *The vein of the transverse process* courses lateralwards from its origin on the vertebral vein and supplies the substance of the process. Anastomoses are formed with a few extraosseous vessels.

The dens is well supplied by basivertebral veins (Fig. 10/3) arising from the transverse anastomosis of the ventral internal venous plexus on its dorsal surface. The vessels ramify throughout the substance of the dens and anastomose with the plexus in the cranial articular process.

(iii) The vertebral body is supplied mainly by nutrient vessels from the ventral internal venous plexus. The large *basivertebral vein* (Fig. 10/3) (usually single) runs towards the centre of the vertebral body, furnishing branches to the cranial, caudal and ventral parts of the body and to the cranial articular process. Ventrally the branches anastomose with large extraosseous vessels. The cranial and caudal vessels give off numerous slender tributaries in a bottle-brush fashion.

The cranial articular process receives additional supply from the vertebral vein. The branch arises from the vertebral vein as the latter leaves the transverse canal.

The metaphysial vessels connect with epiphysial vessels arising from the ventral internal venous plexus and with a number of large extraosseous nutrient veins entering from the lateral and lateroventral surface of the body.

Atlas

Two vessels are mainly responsible for the venous supply of the atlas. They are the vein of the vertebroalar canal (Fig. 13/p[II]) and the occipital vein (Fig. 13/o). The latter, despite its smaller size, provides branches (Fig. 13/r) to the cranial part of the dorsal tubercle, dorsal and ventral arches, the wing and the cranial articular process. The larger vein of the vertebroalar canal supplies the bone of the atlas from the level of the vertebroalar canal caudalwards. Four-five branches (Fig. 13, arrows) are given off and distributed to the caudal part of the dorsal tubercle, the ventral tubercle and the intervening part of the wing. One of these vessels anastomoses through a large opening with an extraosseous vein. These vessels have extensive featherlike ramifications which are interconnected. Six–eight prominent extraosseous vessels (Fig. 13/6) enter the ventral tubercle and run dorsalwards into the ventral arch where they join a vessel running transversely through the arch from left to right. This vessel connects with branches issuing from the vein of the vertebroalar canal on both sides. It is reinforced by a few large veins entering from the vertebral canal. Extensive anastomoses are formed with extraosseous vessels and with a number of slender nutrient veins penetrating the internal aspect of the dorsal arch.

An extensive, finely-meshed, radially-arranged network of veins occupies the substance of the spongy bone. The thin (2–5 mm) surface layer of compact bone appears devoid of vessels, except where intraosseous vessels enter to anastomose with the vessels of the spongy bone.

DISCUSSION

The extraosseous veins contributing to the supply of the cervical vertebrae are the vertebral, deep cervical, occipital and internal jugular veins. They are interconnected to form a *dorsal external venous plexus* along the spinous processes and laminae, a *lateral external venous plexus* along the transverse processes and a *ventral external venous plexus* along the vertebral bodies.

The large Plexus venosus vertebralis internus ventralis is the most striking feature of the vertebral venous system and is the most important source of supply to the vertebral body and the vertebral arch. The interwoven relationship between the plexus and the *circelli arteriosi* deserves consideration.

It could be postulated that overdistension of the plexus may impede the flow of blood in the basivertebral vessels, and in the vertebral arteries along the cranial segments of the canal.

It could also be postulated that the plexus plays a role in the pressure and temperature regulatory mechanisms along the intervertebral course of the vertebral artery in the same way that these mechanisms behave at the rete mirabile level.

The presence of the plexus as a venous cushion, underlying the spinal nerves, is obviously protective.

The size and interconnections of the plexus with extra- and intraosseous vessels underline the findings of previous workers (Batson, 1940, 1957; Herlihy, 1947; Bowsher, 1954; Schröder & Krahmer, 1966 and Dommisse, 1973) regarding its functional importance as a collateral venous pathway and as a possible conveyer of infection to the vertebrae.

The intraosseous venous distribution is similar to that of the arterial side (Smuts, 1977), but the vessels are larger and their ramifications more extensive.

When the röntgenographs and cleared vertebrae of young and old specimens are compared, the basivertebral veins of new-born animals seem to be relatively larger than they are in the adult. On the other hand the extraosseous vessels entering from the external surface show a relative increase in size during growth. In both young and adult specimens, frequent anastomoses occur between epi- and metaphysial intraosseous veins.

The relationship of arteries and veins within the vertebra

Arteries may enter and veins leave the vertebra either through the same nutrient foramen or separately. Most of the large openings along the lateroventral aspect of the vertebral body are pathways for veins only. The foramen in the lateral face of the lamina of C7, the prominent opening on the dorsal aspect of the wing of the atlas as well as the vertebroalar canal carry veins.

The basivertebral foramina house both arteries and veins and there seems to be no consistency about their relative positioning.

The intraosseous venous and arterial routes are fundamentally similar. In röntgenographs of new-born calves the veins clearly overshadow the arteries. In adult vertebrae also the veins are larger and more extensive than the accompanying arteries. In cleared specimens the arteries are seen to be surrounded by the venous plexus.

There are differences in the way the 2 systems branch: arteries form a delicate, wide-meshed network throughout the spongy bone, while the venous ramifications are pennate and not clearly circumscribed. This could be due to the nature of these venous channels. In man they have been found to be true sinusoids, lined by R.E. cells (Wagoner & Pendergrass, 1932).

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