Microangioarchitecture of the feline spinal cord

Three-dimensional observation of blood vessel corrosion casts by scanning electron microscopy

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The microangioarchitecture of corrosion casts of the cat spinal cord was studied by scanning electron microscopy. On the ventral surface of the spinal cord, the anterior spinal artery and the anterior spinal vein ran parallel along the anterior median fissure. Many central arteries branching from the anterior spinal artery coursed in a wavelike manner in the anterior median fissure. The number of central arteries was lowest in the thoracic spinal cord. Central arteries at some spinal cord levels revealed well-developed anastomoses with other central arteries in the anterior median fissure. These well-developed anastomotic central arteries were frequently observed in the thoracic spinal cord, in which the number of central arteries was lowest. On the dorsal surface of the spinal cord, the posterior spinal vein ran longitudinally at the midline and was drained by circumferential veins and posterior central veins. This vein formed a characteristic anastomotic plexus. Small arterioles (20 μm in diameter) in the spinal parenchyma revealed a ring-like compression at the branching site.

KEY WORDS: angioarchitecture • scanning electron microscopy • spinal cord • vasculature • cat
ml of low-viscosity polyester resin* was injected for 1 minute through the same catheter for perfusion fixation. The viscosity of the polyester resin was low just before injection. Two hours later, the spinal cord was removed and dissected into segments 8 mm in length. Some segments were cut midsagittally at the anterior median fissure. The spinal cord blocks were submerged in a 20% NaOH solution for 2 days to corrode the spinal cord tissues surrounding the plastic casts. The small tissue plaques on the plastic casts were then removed by ultrasonic cleansing for 2 days. The cleaned casts were freeze-dried for 1 day to preserve their fine structure, then mounted and sputtered with gold in an Ioncoater.† The casts were examined under a scanning electron microscope at 15 kV.

Results

Differentiation of Arteries and Veins

Differentiation between arteries and veins under SEM has been described previously. On the surface of the arterial cast, many ovoid impressions (10 × 5 μm in size) formed by the endothelial cell nuclei were observed, while venous casts only occasionally showed small round impressions (5 × 5 μm in size) (Fig. 1a). The configurations of the actual endothelial cell nuclei of the vessels under a scanning electron microscope were ovoid in the arteries (Fig. 1b) and round in the veins (Fig. 1c). These ovoid and round impressions were conspicuous in the pial vessels. Small intraparenchymal arterioles (as small as 30 μm in diameter) also showed ovoid nuclear impressions. In contrast, intraparenchymal venules (50 μm in diameter) rarely revealed such impressions.

Microangioarchitecture

Ventral Surface of the Spinal Cord. The anterior spinal artery (80 to 200 μm in diameter) and anterior spinal vein (90 to 220 μm in diameter) ran along the anterior median fissure on the ventral surface (Fig. 2). The anterior spinal artery was largest (180 to 200 μm in diameter) in the lumbar region, next largest (130 to 150 μm) at the cervical level, and smallest (80 to 100 μm) in the thoracic region. It gave off many central arteries toward the anterior median fissure and a small number of circumferential arteries toward the lateral part of the spinal cord. Circumferential arteries arising from the inferolateral part of the anterior spinal artery coursed through the ventrolateral surface of the spinal cord and perforated the spinal cord.

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Fig. 1. Scanning electron micrographs showing a corrosion cast of the pial vessels. a: Nuclear indentations are conspicuous in the pial vessels. On the surface of the arterial casts, many ovoid impressions (arrows) are observed, while the venous casts show round impressions (arrowheads). A = pial artery; V = pial vein. Bar indicates 50 μm. b and c: Inner surfaces of an actual spinal cord artery (b) and vein (c). Arrowheads show nuclei of endothelial cells. Bar indicates 5 μm.
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An anterior spinal vein ran parallel to the anterior spinal artery on the ventral surface. In some cases, duplicate anterior spinal veins coursed on either side of the anterior spinal artery. Branches from the circumferential veins and central veins running parallel to the artery drained into the anterior spinal vein.

**Dorsal Surface of the Spinal Cord.** A posterior spinal artery was seen running longitudinally along the posterior lateral sulcus; this was smaller in diameter (90 μm) than the anterior spinal artery (which was 80 to 200 μm). This artery gave off many branches on the dorsal surface of the cord, perforated the white matter, and supplied the peripheral portion of the dorsal spinal cord. The posterior spinal vein, drained by circumferential veins and posterior central veins, ran longitudinally on the dorsal surface of the spinal cord in the midline. This vein was usually larger than the anterior spinal vein. At the median part of the dorsal spinal cord, a well-developed posterior spinal vein formed a characteristic anastomotic plexus (Fig. 3). The posterior spinal vein was largest in diameter in the lumbar region, next largest at the cervical level, and smallest in the thoracic region.

**Midsagittal Section.** In the specimen cut midsagittally, many central arteries and veins were observed running toward the central canal. Central arteries ran circuitously in the anterior median fissure, while central veins ran straight (Fig. 4a). At some levels of the spinal cord (especially in the thoracic segment), the central artery revealed well-developed anastomoses with other central arteries in the anterior median fissure (Fig. 4b). The anastomotic central arteries were most frequently observed in the thoracic spinal cord. The number of central arteries and veins was counted in the spinal cord at three different levels. The total number of blood vessels in the anterior median fissure was greatest in the cervical level and lowest in the thoracic region. There were fewest arteries in the thoracic levels, while the number of veins was almost equal in all three spinal

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**Fig. 2.** Scanning electron micrograph showing the ventral surface of the spinal cord. The anterior spinal artery (ASA) and anterior spinal vein (ASV) run along the anterior median fissure on the ventral surface. RA = radicular artery; RV = radicular vein; CfA = circumferential artery; CfV = circumferential vein. Bar indicates 500 μm.

**Fig. 3.** Scanning electron micrograph showing the dorsal surface of the spinal cord. The posterior spinal vein (PSV) runs longitudinally on the dorsal surface of the spinal cord in the midline. A well-developed PSV forms a characteristic anastomotic plexus. The posterior spinal artery (arrowheads) is also observed. Bar indicates 500 μm.
FIG. 4. Scanning electron micrographs of a midsagittal section of the spinal cord. a: Many central arteries and veins run toward the central canal. Central arteries (A) run circuitously in the anterior median fissure, while central veins (V) run straight. Bar indicates 500 μm. b: Anastomosed central arteries (CA, arrowheads) in the anterior median fissure. CV = central vein; ASV = anterior spinal vein. Bar indicates 500 μm.

FIG. 5. Scanning electron micrographs of the midsagittal section at the cervical (a), thoracic (b), and lumbar (c) levels. The number of central arteries and veins is largest at the cervical level and smallest at the thoracic region. Bar indicates 500 μm.

levels (Figs. 5 and 6). The central arteries in the anterior median fissure perforated the spinal cord, after which they changed direction rostrally, caudally, or laterally.

Transverse Section. The vascularity of the gray matter was much more abundant than that of the white matter (Fig. 7). The angioarchitecture in the white matter basically showed a radial pattern of perforating arterioles and venules arising from circumferential ar-
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**FIG. 6.** Graph showing the number of central arteries (crosshatched bars) and veins (open bars) per 1 mm of anterior spinal artery and vein, respectively. The number of central arteries arising at the thoracic level is lowest; in contrast, the number of veins given off is almost equal in all three regions.

arterioles and venules. Capillary networks were less dense in the white matter than in the gray matter. The vessels in the gray matter showed a plexus pattern of dense arterioles, capillaries, and venules. Under high magnification, small arterioles (20 μm in diameter) in the spinal parenchyma showed a ring-like compression at branching sites. These ring-like compressions were observed in both capillaries and venules (Fig. 8).

**Discussion**

Scanning electron microscopic observation of vascular corrosion casts allowed differentiation between arteries and veins by their specific surface impressions (arteries showed ovoid impressions of endothelial cell nuclei and veins had round impressions). This technique provides a three-dimensional image of the vascular bed so that the entire course of the blood vessels and detailed anastomotic features can be thoroughly observed.

Detailed examination of vascular corrosion casts in the present study showed well-developed anastomoses in the spinal blood vessels. In the arterial system, central arteries anastomosed with other central arteries running in the anterior median fissure. In addition to arterial anastomoses, the spinal vein also has many anastomoses on the dorsal surface of the spinal cord. These facts suggest that the reason cerebral thrombosis is much more common than spinal cord thrombosis may be related to the greater development of vascular anastomoses in the spinal cord than in the brain.

In the present study, the number of central arteries was counted in the different spinal levels, and the thoracic spinal cord was found to contain the smallest number of central arteries. It is well established that the thoracic spinal cord is most vulnerable to ischemic disturbance. Several reasons have been proposed: 1) the direction of the blood stream in the anterior spinal artery is variable in the thoracic segment; 2) the size of the anterior spinal artery is small; and 3) aminergic and cholinergic innervation of blood vessels is most scattered. From the present study, the scarcity of central arteries in the thoracic spinal cord should be added as one more reason for this vulnerability.

Although the number of central arteries was smallest in the thoracic spinal cord, arterial anastomoses were most developed in the thoracic spinal cord. These arterial anastomoses in the thoracic segment may serve to protect this vulnerable region from ischemia. Highly developed anastomotic venous channels were observed on the dorsal surface of the spinal cord. From the viewpoint of the venous circulation, these well-developed...
FIG. 8. Scanning electron micrograph showing a small arteriole in the spinal parenchyma with a ring-like compression (arrows). Bar indicates 50 μm.

anastomotic venous channels may serve to render the dorsal part of the spinal cord less vulnerable to venous congestion due to compression, because dorsal compression does not always produce dorsal spinal cord symptoms.

As reported by Anderson and Anderson, 1 as well as by the present authors, 13 a ring-like compression on the arterial cast was observed in the brain. We suggest that this ring-like compression on the cast may represent a “vascular sphincter” in the arterioles. In the present study, we found ring-like compressions in spinal cord blood vessels such as arterioles, capillaries, and venules. Moreover, amnergic innervation of the spinal arterioles, capillaries, and venules was also observed under catecholamine histofluorescence. 11,12 We, therefore, suggest that there may be constriction not only of the cerebral but also of the small spinal blood vessels.

References


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