Anatomical features of the canine C2-C3 spinal cord vascular environment

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OBJECTIVE

Interarcuate branch (IAB) is a vascular structure, particularly developed in C2-3 intervertebral space, forming a dorsal bridge that connects ventral venous plexi in the vertebral canal. While precisely described in the human, the precise anatomical features of IABs have not been reported in the veterinary literature. The purpose of this study is to describe the features and relations of IABs in the C2-3 vertebral canal.

ANIMALS

10 dogs were enrolled; 5 dogs for necropsy and 5 dogs for histology.

PROCEDURES

The ventral venous plexi in the cervical spine of 5 dogs were injected with latex and underwent vertebral canal dissection for visual assessment of the IAB. Two out of 5 dogs were injected with the addition of barium sulfate and underwent a CT scan. The C2-3 regions of 5 small-breed dogs were harvested for histological examinations.

RESULTS

IABs arose from the ventral venous plexus at the level of the intervertebral vein; they originated from 2 separate branches located caudally and cranially to the intervertebral foramen, forming a ventrodorsal triangle surrounding the spinal nerve root. No dorsal anastomosis was observed on the CT scan nor at dissection but were observed histologically. A cervical fibrous sheath was observed all around the vertebral canal.

CLINICAL RELEVANCE

IABs are voluminous venous structures at the C2-3 intervertebral space in dogs and found within a split of the cervical fibrous sheath, which is adherent to the interarcuate ligament and the ligamentum flavum. This anatomical description is paramount when planning an approach to the C2-3 intervertebral space.

The venous system of the canine spine is a complex network of interconnected venous structures. The main component of the internal vertebral venous system is the ventral internal vertebral venous plexus. Basivertebral veins extend through the vertebral bodies. Intervertebral veins exit the vertebral canal through the intervertebral foramen, and interarcuate branches (IABs) extend dorsally along the inner aspect of the vertebral arch.¹⁻³ All of these veins arise from the internal ventral plexus, but IABs exclusively remain in the vertebral canal.

The ventral internal vertebral venous plexus is in direct communication with the cranial venous sinuses located in the head. These vascular structures are uniquely characterized by a lack of valves. Thus, blood may flow cranially or caudally depending on pressure relations. This feature may have major implications during surgery, especially

in dogs with assisted ventilation.⁴ A dorsal or lateral surgical approach to the cervical spine and, in particular, to the C2-3 intervertebral space is performed in dogs to address spinal affections, such as disk herniation, spinal cord neoplasia, or subarachnoid diverticula (SAD).⁵⁻¹³ More specifically, 55% of SAD occurs in the cervical spine, with the C2-3 intervertebral space being the most common location.^{14,15} Hemorrhage is the most frequent intraoperative complication when approaching the cervical spine dorsally or laterally.^{5,7,16-18} This complication is commonly attributed to the disruption of the vessels in the intervertebral foramina (intervertebral artery and vein) or the internal venous plexus. Nevertheless, left and right IAB run ventrolaterally to dorsally along vertebral arch and may be encountered during a dorsal or lateral surgical approach.^{1,2} Several authors suggest that IABs

may lead to serious hemorrhage if damaged and should be identified and ligated.⁶⁻⁸

The precise location of IABs with respect to the intervertebral space is not described in dogs. IABs have been briefly mentioned as part of the interarcuate ligament on the basis of anatomical and surgical findings as well as macroscopic evaluation.^{6-8,19} The relation of IABs to adjacent structures (cervical fibrous sheath, ligamentum flavum, and dura mater) is unclear and of crucial concern when considering a surgical approach for this anatomical location.

The cervical fibrous sheath is another little-known anatomical structure of the spine. The cervical fibrous sheath was first described by Fick²⁰ in 1904 and has seldom been reported in human medicine since. According to Wiltse,²¹ the cervical fibrous sheath is "a fibrovascular sheath lying external to the dura lining the vertebral canal, leaving a potential space between it and the dura, which is called the epidural space." To the author's knowledge, the cervical fibrous sheath has never been described in veterinary literature.²¹

The aim of this study is to describe the anatomical location of IABs at the level of the C2-3 intervertebral space in dogs and their relation to surrounding structures.

Materials and Methods

Vertebral venous system latex injection study

The cervical region (C1 through C7), including juxta-vertebral muscles, of 5 medium-sized dogs euthanized for reasons unrelated to the study were harvested from fresh cadavers. The ventral venous plexuses were identified in the C7 caudal aspect, catheterized, and slowly injected with red latex until the latex came out of the cranial aspect of the venous plexus. The ventral venous plexus was then ligated, and injection was continued until the latex appeared in soft tissues surrounding the spine. Two of the 5 samples were injected with a mixture of red latex and barium sulfate (volume ratio, 3:1) inspired by the study of Renard et al.²² After fixation (12 hours of storage at -10 °C), the samples were defrosted at room temperature for 24 hours. A CT scan (16 cross-sectional acquisitions each 0.6 mm thick) of the whole spine was performed for the latex and barium sulfate-injected samples. Helicoidal slices were acquired, images were processed, and results were obtained using a software (Horos version 3.3.5; Horos Project) and treated by the authors. The position, anatomical relation, and size of IAB were recorded on CT images. Thereafter, C2-3 dorsal laminectomy was performed layer by layer on each of the 5 spinal columns. After the laminectomy, IABs were delicately dissected. When opening the vertebral canal, the spinal cord in its dura matter was removed to assess the ventral aspect of the vertebral canal. The position, anatomical relation, and size of IAB were assessed. The size of IABs was measured on its widest craniocaudal dimension. Then, the ratio between this data and the length of the dorsal por-

tion of the vertebral body of the caudal vertebra was calculated for each dog.

Histological study

The C2-C3 vertebrae of 5 small- to medium-sized dogs euthanized for reasons unrelated to this

Figure 1—Midsagittal reconstructed 3-D images of the C2-5 portion of the of a 10-year-old 32-kg female German Shepherd Dog (top image) and 7-year-old 24-kg male Shar Pei (bottom image). The images were reconstructed from CT sequences that were obtained following injection of the ventral venous plexus (arrow) with a mixture of red latex and barium sulfate (volume ratio, 3:1) to identify the interarcuate branches (IABs; arrowheads) of the intervertebral vein.

Figure 2—Representative transverse CT images of the C2-3 intervertebral space of a 10-year-old 32-kg female German Shepherd Dog obtained following injection of a mixture of red latex and barium sulfate (volume ratio, 3:1) into the ventral venous plexus to enhance visualization of the IABs. The images have a slice thickness of 0.6 mm. The IABs arose from both the right and left sides of the ventral venous plexus at the level of the intervertebral vein and traveled dorsolaterally toward the nerve root. Notice that there does not appear to be any dorsal communication between the right and left IABs in these images.

Figure 3—Representative photograph (A) and schematic illustration (B) of the ventral surface of the vertebral canal of a medium-sized dog following injection of red latex into the ventral venous plexus and completion of a C2-3 dorsal laminectomy and removal of the spinal cord. The IABs arise from the intervertebral vein, lie within a split in the fibrous sheath lining the vertebral canal, and form a ventrodorsal triangle around the intervertebral foramen and spinal nerve root. The Heidemann spatula is inserted beneath the intervertebral vein in the area where it transitions to the IAB. The forceps are grasping remnants of peridural fat and the fibrous sheath lining the vertebral canal. The red latex appears as gray shading in the schematic illustration. C—Schematic illustration of a parasagittal plane of the C2-3 vertebral segment of a dog that depicts the intervertebral vein and triangle formed by the IABs (blue lines) at the level of the caudal and cranial articular processes of C2 and C3, respectively. The spinal cord is not depicted in this illustration.

study were harvested from fresh cadavers. Care was taken not to damage the structures of the vertebral canal. Juxta-vertebral muscles were removed, and the sample underwent standard preparation for histological evaluation.²³ Portions that were cranial and caudal to the C2-3 intervertebral space were removed to keep the area of interest at an appropriate size to fit in the cassettes before casting them in paraffin wax. Transversal slices were cut in 100- μ m intervals, stained with H&E, and coverslipped.

The slides were microscopically reviewed by board-certified pathologist (TM) to identify IABs and their relations to the adjacent structures.

Results

The 5 dogs included in the dissection study had a mean body weight of 27.6 ± 3.0 kg. The dogs included 2 German Shepherd Dogs, 1 Shar Pei, 1 Irish Setter, and 1 mixed-breed dog. The 2 dogs included in the CT study were a German Shepherd Dog and Shar Pei. The 5 dogs included in the histological study had a mean body weight of 13.0 ± 1.6 kg. The dogs included 2 Cocker Spaniels, 2 Beagles, and 1 Miniature Pinscher.

CT scan

The IABs were visualized on each of the C2-3, C3-4, and C4-5 intervertebral spaces for the 2 samples prepared for a CT scan on both the right and left sides (**Figure 1**). IABs exhibited flat-shaped venous structures.

The IABs originated from the ventral venous plexus at the level of the intervertebral vein. From the ventral venous plexus, they form 2 branches located caudal and cranial to the intervertebral foramen and then merged dorsally to the nerve root. The CT scan failed to show dorsal communication between the right and left branches (**Figure 2**). This pattern was similar for each of the C2-3, C3-4, and C4-5 intervertebral spaces in the 2 samples studied.

Dissection

The venous plexuses injected with latex were properly visualized. Sizes and positions of the IABs were visualized in the CT reconstruction. All of the visualized IABs of the C2-3 intervertebral space had a cranial and caudal component that arose from the ventral plexus and then merged together dorsally to the intervertebral foramen (**Figure 3**).

For the C2-3 intervertebral space, the IAB mean size ratio of the craniocaudal length of IABs to the dorsal length of the caudal vertebra was $27.7 \pm 1.53\%$.

The IABs could not be manipulated freely from the surrounding tissues. A fibrous membrane was

identified in the vertebral canal between the inner cortex and the dura mater. The membrane could be easily separated from the internal aspect of the lamina cranially and caudally to the intervertebral space (**Figure 4**). However, the membrane merged with the interarcuate ligament and the ligamentum flavum at the level of the intervertebral space. The ventral plexus could not be elevated from this membrane during palpation with a Heidemann spatula, while IABs originating from the ventral venous plexus could be gently elevated with the probe. The passage of latex-injected IABs through the fibrous sheath was located at the origin of the intervertebral vein and IABs from the venous plexus. On the dorsal aspect of the vertebral canal, the latex molding was located externally to the fibrous sheath (Figure 3). The cranial and caudal origins of the IABs merging above the intervertebral foramen were located laterally to the fibrous sheath. IABs were observed dorsally to the intervertebral foramen, but no dorsal communication between the right and left sides was observed.

Histology

IABs were identified on histological slides, and their trajectory followed in a slight craniodorsal orientation. Because the slides were created in a transverse orientation, the path of the IABs was distributed on different slides. Artifacts were present on most of the slides owing to sample preparation features and the various tissues in the sample. However, the relations of the different structures were consistent in the different dogs studied. A description of the results is presented according to the locations described in the methods section.

The IABs emerged dorsolaterally to the ventral plexuses at the level of the intervertebral space and extended in a dorsal direction. Dorsal communication between right and left IABs was identified (**Figure 5**). This communication was small relative to the size of the lateral portion of the IAB.

A fibrous membrane was observed between the inner cortex of the vertebrae and the dura mater. In the

Figure 4—Representative photographs of the spinal cord of a medium-sized dog following completion of a C2-3 dorsal laminectomy and prior to removal of the spinal cord. The forceps are grasping the fibrous sheath lining the vertebral canal. The fibrous sheath is being retracted dorsally in the image on the left and medially in the image on the right. Notice that the fibrous sheath does not appear to be adhered to the underlying cortical bone.

ventral aspect of the vertebral canal, this membrane split in 2 layers that surrounded the right and left ventral plexuses on their ventral and dorsal aspects. These

Figure 5—Representative photomicrographs of transverse sections of the cervical vertebral column of a 12-year-old 10-kg male mixed breed obtained at the level of (A) and just caudal (B) and cranial (C) to the C2-3 intervertebral disk. A—The IABs (arrows) arise from the left and right sides of the intervertebral vein, traverse in a dorsolateral direction, and anastomose dorsally at the level of the intervertebral foramen (arrowheads). H&E stain; bar = 5 mm. B—A fibrous sheath lines the vertebral canal (arrows); the dura mater (arrowhead) and lumen of the ventral venous plexus (asterisk) are also visible. H&E stain; bar = 400 μ m. C—The fibrous sheath (arrowhead) is free from the bone; however, this may be an artifact caused during processing (eg, dehydration) of the specimen for histological examination. H&E stain; bar = 400 μ m.

2 layers merged medially and laterally to the plexuses (Figure 5). Going more dorsally in the vertebral canal, the membrane remains lateral to IABs. At a level of the articular processes, the IABs exit the peridural space as observed during dissection. In the dorsal aspect of the dorsal canal, a communication between the right and left IAB was observed and was located between the fibrous sheath and the ligamentum flavum.

Cranially and caudally to the intervertebral space, IABs were not present on the slides. The fibrous sheath followed the inner cortical bone. It was free from the bone (Figure 5), as observed during dissection.

No evidence of periosteum could be observed histologically on the inner cortex in any of the available samples.

Discussion

The results of our anatomical and histological study provide concordant information regarding the location of IABs, which has never been described with accuracy to date.

In dogs, the size of IABs is substantial and may interfere with any surgical approach in this anatomical area, as reported by Lipsitz and Bailey.⁸ IABs have been found to originate from the ventral venous plexus both cranially and caudally to the intervertebral foramen, forming a ventrodorsal triangle surrounding the spinal nerve root. The widest craniocaudal dimension is located dorsally. The data given in this study regarding the IABs size are poorly reliable given the limited number of cases and the bias related to the uncontrolled pressure during latex injection. However, IABs may reach approximately 30% of the length of the corresponding vertebra in their greatest dimension. These values are given for information purposes only and should not be considered as definitive. IAB dilation may have been overestimated in our study owing to latex injection, and extrapolating these results in a clinical context may be hazardous. Indeed, it has been shown that experimental spinal cord compression may lead to a collapse of the venous plexus.²³ Conversely, the use of mechanical ventilation in anesthetized dogs may lead to an increase of the size of these branches.⁴ Therefore, further *in vivo* studies addressing this issue are needed. Ultimately, the size of the IABs described here may not completely reflect the clinical reality, but it can be asserted that these structures should be identified when laterally or dorsally approaching the C2-3 intervertebral space.

Dorsal communication between the right and left IAB was observed on histologic slides, as described in the literature.^{1,2} This communication was located at the intervertebral space in the ligamentum flavum. These observations demonstrate how hemostasis is important during the surgical approach. Indeed, when performing a laminectomy or hemilaminectomy, precise knowledge of those vascular structures is critical to prevent hemorrhage and to provide their adequate visualization. In humans, posterior internal vertebral venous plexuses are described posterolat-

erally to the spinal cord in the peridural space.^{24,25} Posterior internal vertebral venous plexuses communicate with anterior internal vertebral venous plexuses through ladder-like transverse connecting veins that are equivalent to IABs in dogs.²⁵ Anecdotal references to dorsal internal vertebral plexuses have been reported in veterinary medicine, but such structures were not evident in our study.² The dorsal communication between the right and left IAB observed on the histologic slides was very small compared to the vertical component of the IABs. For IABs running in an oblique direction, their continuity and accurate diameters could not be properly evaluated on transverse cross sections. We collected data only regarding the comparison of their sizes. We failed to describe dorsal communication during the dissection study. We believe that IABs could not be identified during the dissection of the ligamentum flavum owing to their small size or because they were not correctly filled with latex. Barium sulfate was added to the latex in 2 of our samples to create radiopacity for CT evaluation. The volume ratio was determined before the study to create sufficient radiopacity to be observed on the CT, taking care not to overly thicken the latex. Nevertheless, the fluidity of the latex has been modified and may have led to a lack of filling of the smallest venous structures, such as the dorsal anastomosis of IABs.

In this study, we macroscopically located the laterodorsal part of IABs between the inner cortex and a fibrous membrane. Histologically, IABs were more accurately located in a split of this membrane. During initial dissection, this membrane was first identified as the periosteum, uncommonly fibrous and resistant, and easily separated from the bone. We finally identified this membrane as the cervical fibrous sheath described in humans.^{21,26} To the best of the author's knowledge, this anatomical structure has not been described as the cervical fibrous sheath in veterinary literature. In humans, the cranial dura mater has been described to split at the foramen magnum to yield 2 layers, namely the spinal cord dura mater and a "periosteal layer" that fuses with the periosteal lining of the vertebral canal, defining the epidural space between these 2 layers.²⁶ However, periosteal lining may not be present in the vertebral canal. Indeed, contradictory reports exist regarding the presence of periosteum in the vertebral canal in humans.²⁷ On one hand, periosteum has been reported to be present on every bone except for intraarticular surfaces and sesamoid bones.²⁸ On the other hand, Wiltse et al²¹ described the inner lining of the vertebral canal as a peridural sheath, which is a homolog of the periosteum but does not biologically act as the periosteum, and referred to it as the cervical fibrous sheath. This structure in humans was first described by Fick²⁰ in 1904, and very few reports have described or mentioned it since.^{21,26} Dommissse²⁹ described it as a double-layer membrane within which lies the anterior and posterior venous plexus (Batson plexus), while the transverse segmental venous channels are located in the epidural space.

In our study, we described a fibrous membrane surrounding the epidural space, within which the ventral venous plexus and the dorsal part of IABs are found. Beneath this membrane, rough periosteum-free bone has been reported macroscopically and microscopically. This structure fits with the description of a cervical fibrous sheath in the vertebral canal of dogs.

Ventrally, IABs were located above the cervical fibrous sheath and were found dorsolateral to the spinal cord between the fibrous sheath and the inner cortex of the lamina. The transitional zone where the intervertebral veins pass the fibrous sheath has been identified by passing a Heidemann spatula beneath the ventral venous plexus and following IABs to the transition zone located at the level of the intervertebral foramen. This anatomical feature exhibits paramount importance when performing a surgical approach in this area. Hemilaminectomy or dorsal laminectomy implies an opening of the vertebral canal, and the ventral limit would be dorsal or at the level of the intervertebral foramen.^{5,8,11} Our results suggest that drilling bone around the foramen (foraminotomy) should be performed with caution when reaching the inner vertebral cortical bone because IABs would be directly beneath it before the epidural space is reached.

This work has several limitations, and the size of dogs used in the study was different for the histological group and CT-scan group. Histological slides have been made with the technical possibility of the laboratory. Indeed, microtomes and histological cassettes provided in the laboratory were not large enough to obtain slides of the C2-3 intervertebral space in larger dogs, and direct comparison with the CT-scan group cannot be performed. We believe that if no dorsal communication have been identified in larger dogs with the latex-injected CT scan, no dorsal communication would have been identified in smaller dogs neither. Furthermore, latex is a relatively dense material which has been described in previous studies and cannot pass in small vessels (0.1 mm in fresh-frozen specimens).³⁰ Unfortunately, the use of other material such as a mixture of epoxy resin and polymeric agent (1,4,7,10-tetraazadecan) that is known to pass in smaller vessels (0.03 mm)^{30,31} could not have been used because of the necessity to make a mixture with barium and so, failed to identify dorsal communication of the IAB in our study.

IABs are voluminous venous structures in the C2-3 intervertebral space in dogs. IABs lie within a split of the cervical fibrous sheath, which is adherent to the interarcuate ligament and the ligamentum flavum. This anatomical description is paramount when planning a lateral or dorsal surgical approach to the C2-3 intervertebral space.

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References

1. Barone R. Veines. In: *Anatomie comparée des mammifères domestiques*. 2nd ed. Vigot; 2011:448–685.
2. Benzuidenhout A. Veins. In: *Miller's Anatomy of the Dog*. Elsevier Saunders; 2013:505–34.
3. Gómez M, Freeman L, Jones J, Lanz O, Arnold P. Computed tomographic anatomy of the canine cervical vertebral venous system. *Vet Radiol Ultrasound*. 2004;45(1):29–37.
4. Duke-Novakovski T, de Vries M, Seymour C. *BSAVA Manual of Canine and Feline Anaesthesia and Analgesia*. 3rd ed. British Small Animal Veterinary Association; 2016:464.
5. Rossmeisl JH Jr, Lanz OI, Inzana KD, Bergman RL. A modified lateral approach to the canine cervical spine: procedural description and clinical application in 16 dogs with lateralized compressive myelopathy or radiculopathy. *Vet Surg*. 2005;34(5):436–444.
6. Lipsitz D, Bailey CS. Clinical use of the lateral cervical approach for cervical spinal cord and nerve root disease: eight cases. *Progress Vet Neurol*. 1995;6(2):60–65.
7. Pettit GD, Whittaker RP. Hemilaminectomy for cervical disk protrusion in a dog. *J Am Vet Med Assoc*. 1963;143:379–383.
8. Lipsitz D, Bailey CS. Lateral approach for cervical spinal cord decompression. *Progress Vet Neurol*. 1992;3(1):39–44.
9. Tanaka H, Nakayama M, Takase K. Usefulness of hemilaminectomy for cervical intervertebral disk disease in small dogs. *J Vet Med Sci*. 2005;67(7):679–683.
10. Bagley RS. Spinal neoplasms in small animals. *Vet Clin North Am Small Anim Pract*. 2010;40(5):915–927.
11. Funkquist B. Decompression laminectomy for cervical disk protrusion in the dog. *Acta Vet Scand*. 1962;3:88–101.
12. Gnirs K, Ruel Y, Blot S, et al. Spinal subarachnoid cysts in 13 dogs. *Vet Radiol Ultrasound*. 2003;44(4):402–408.
13. Rylander H, Lipsitz D, Berry WL, et al. Retrospective analysis of spinal arachnoid cysts in 14 dogs. *J Vet Intern Med*. 2002;16(6):690–696.
14. Lowrie ML, Platt SR, Garosi LS. Extramedullary spinal cysts in dogs: spinal cysts in dogs. *Vet Surg*. 2014;43(6):650–662.
15. Mauler DA, De Decker S, De Risio L, et al. Signalment, clinical presentation, and diagnostic findings in 122 dogs with spinal arachnoid diverticula. *J Vet Intern Med*. 2014;28(1):175–181.
16. Smith TJ, Fitzpatrick N. Surgical removal of a microchip from a puppy's spinal canal. *Vet Comp Orthop Traumatol*. 2009;22(1):63–65.
17. Schmied O, Golini L, Steffen F. Effectiveness of cervical hemilaminectomy in canine Hansen type I and type II disc disease: a retrospective study. *J Am Anim Hosp Assoc*. 2011;47(5):342–350.
18. Felts J, Prata R. Cervical disc disease in the dog: intraforaminal and lateral disc extrusions. *J Am Anim Hosp Assoc*. 1983;19(5):750–755.
19. Reinhard KR, Miller ME, Evans HE. The craniovertebral veins and sinuses of the dog. *Am J Anat*. 1962;111(1):67–87.
20. Fick R. Anatomie der gelenke. In: *Handbuch der Anatomie und Mechanik der Gelenke*. Verlag; 1904:10–45.
21. Wiltse LL, Fonseca AS, Amster J, Dimartino P, Ravessoud FA. Relationship of the dura, Hofmann's ligaments, Batson's plexus, and a fibrovascular membrane lying on the posterior surface of the vertebral bodies and attaching to the deep layer of the posterior longitudinal ligament. An anatomical, radiologic, and clinical study. *Spine (Phila Pa 1976)*. 1993;18(8):1030–1043.
22. Renard Y, Hossu G, Chen B, Krebs M, Labrousse M, Perez M. A guide for effective anatomical vascularization studies: useful ex vivo methods for both CT and MRI imaging before dissection. *J Anat*. 2018;232(1):15–25.
23. Kang QK, LaBreck JC, Gruber HE, An YH. Histological

- techniques for decalcified bone and cartilage. In: An YH, Martin KL, eds. *Handbook of Histology Methods for Bone and Cartilage*. Humana Press; 2003:209–219.
24. Gómez M, Lanz O, Jones J, Broadstone R, Inzana K, Freeman L. Effects of artificially induced spinal cord compression on the canine cervical internal vertebral venous plexus: comparative evaluation of computed tomographic venography and digital subtraction venography. *Arch Med Vet*. 2008;40(2):161–168.
 25. Chaynes P, Verdié JC, Moscovici J, Zadeh J, Vaysse P, Becue J. Microsurgical anatomy of the internal vertebral venous plexuses. *Surg Radiol Anat*. 1998;20(1):47–51.
 26. Stringer MD, Restieaux M, Fisher AL, Crosado B. The vertebral venous plexuses: the internal veins are muscular and external veins have valves. *Clin Anat*. 2012;25(5):609–618.
 27. Dwek JR. The periosteum: what is it, where is it, and what mimics it in its absence? *Skeletal Radiol*. 2010;39(4):319–323.
 28. Zadeh J, Lazorthes G, Roux P, Laveran A. The spinal periosteal layer and the fibrous sheath of the cervical spinal canal. Article in French. *Bull Assoc Anat (Nancy)*. 1989;73(220):45–47.
 29. Dommissé GF. *The Arteries and Veins of the Human Spinal Cord from Birth*. Livingstone; 1975.
 30. Doomernik DE, Kruse RR, Reijnen MMPJ, Kozicz TL, Koo-loos JGM. A comparative study of vascular injection fluids in fresh-frozen and embalmed human cadaver forearms. *J Anat*. 2016;229(4):582–590.
 31. Van Der Zwan A, Hillen B. Araldite F as injection material for quantitative morphology of cerebral vascularization. *Anat Rec*. 1990;228(2):230–236.