Evaluation of the internal vertebral venous plexus, vertebral canal, dural sac, and vertebral body via nonselective computed tomographic venography in the cervical vertebral column in healthy dogs

Marcelo A. Gómez, DVM; Jeryl C. Jones, DVM, PhD; Richard V. Broadstone, DVM, PhD; Karen D. Inzana, DVM, PhD; Larry E. Freeman, DVM, MS

Objective—To evaluate nonselective computed tomographic (CT) venography for evaluating the cervical internal vertebral venous plexus (IVVP), define the diameter and area dimensions of the IVVP, and determine the relationship between dimensions of the cervical IVVP and other vertebral components in medium-sized dogs.

Animals—6 healthy dogs that weighed 18 to 27 kg.

Procedure—Helical CT scans were performed from C1 to C7 before and after IV injection of contrast medium (480 mg of iodine/kg) and a continuous infusion (240 mg of iodine/kg). Image data were transferred to a CT workstation, and measurements were performed on displayed transverse images. Diameter and area measurements of the vertebral canal, IVVP, and vertebral body were obtained at C3 to C7.

Results—Opacification of vertebral venous structures was achieved in all dogs with no adverse reactions. Sagittal diameters of the IVVP for C3 to C7 ranged from 0.6 to 3.2 mm. Transverse diameters ranged from 2.32 to 5.74 mm. The IVVP area represented 12.4% of the mean vertebral canal transverse area and 30.61% of the mean vertebral epidural space area. Area measurements of the IVVP were significantly correlated with vertebral canal area and dural sac area.

Conclusions and Clinical Relevance—Results indicated that nonselective CT venography is a safe, sensitive method for performing morphometric assessments of the cervical IVVP in dogs. Findings support the theory that there may be a physiologic or developmental relationship between cervical vertebral canal components. (Am J Vet Res 2005;66:2039–2045)

The canine vertebral venous plexus is a large valveless collateral venous network that is composed of the internal vertebral venous plexus (IVVP) [epidural veins or vertebral venous sinuses], the external vertebral venous plexus, and the basivertebral veins. The IVVP is clinically important in dogs because it has been associated with pathologic conditions such as spontaneous epidural hematoma, arteriovenous malformation, fibrocartilaginous embolism, and lumbosacral stenosis. In a prospective cohort study of canine lumbosacral stenosis, 5 of 13 dogs had congestion of the IVVP and intervertebral veins at surgery. Epidual venous congestion has also been identified in dogs with experimental compression of the cauda equina. In humans, enlargement of the IVVP has been implicated as a direct cause of spinal cord or nerve root compression (lumbar radiculopathy). Under compression, veins of the vertebral plexus collapse easily because of the laxity of their walls and low internal pressure. Absence of valves in the vertebral venous plexus and flow deviation create localized venous dilatation and stasis cranial to and around the compression. Venous congestion may be responsible for acute intraneural edema and nerve function alteration.

The normal appearance of the cervical IVVP has been described in human and canine postmortem specimens by use of IV contrast-enhanced computed tomography (CT). Computed tomography with IV contrast enhancement has also been used in humans and dogs for detection of extradural compressive lesions, including disk herniations. Kaiser et al postulate that epidural venous stasis in humans is a CT sign of clinically important narrowing of the vertebral canal. These authors also recommend that CT be performed before and after IV injection of contrast medium to differentiate a protruded disk from prominent epidural veins.

Ratios and measurements between cervical spinal cord diameter and vertebral body diameter have been reported from myelographic studies in clinically normal small- and large-breed dogs. However, radiographic measurements are subject to errors because of rotation, superimposition, and projection. The ratio of the sagittal diameter of the human cervical vertebral canal to the corresponding diameter of the vertebral body has been calculated by use of CT and described as a reliable variable for assessing stenosis. Computed tomographic morphometry has also been used to detect stenosis of the canine lumbosacral vertebral canal. Calculating ratios of lumbosacral vertebral canal diameter and area versus vertebral body diameter...
Materials and Methods

Dogs—This prospective, nonterminal study was performed in 6 clinically normal research dogs. Weights of dogs ranged from 18 to 27 kg, with a mean weight of 21.5 kg. Breeds represented included Labrador Retriever, German Shepherd Dog, and mixed breed. There were 2 male and 4 female dogs. All dogs were examined by a board-certified veterinary neurologist (KDI) and determined to be free of any signs of spinal cord disease. All procedures were approved by the Virginia Tech Institutional Animal Care and Use Committee.

Anesthetic protocol—Food was withheld for 12 hours prior to anesthesia. Each dog was premedicated with butorphanol (0.2 mg/kg, IM), diazepam (0.2 mg/kg, IM), and atropine sulfate (0.02 mg/kg, IM). After placement of an indwelling 20-gauge cephalic vein catheter, anesthesia was induced by titrating 2% thiopental, IV, at a dose just sufficient to allow tracheal intubation (mean dose, 9.6 ± 1.3 mg/kg). Anesthesia was maintained with isoﬂurane (1.1% to 1.2% end-tidal concentration in 100% O2 [30 to 40 mL/kg]) delivered by a calibrated precision vaporizer using a closed system with a CO2 absorber system. Saline (0.9% NaCl) solution was administered IV at a rate of 10 mL/kg/h. A 20-gauge catheter was placed in a lingual artery for direct arterial blood pressure measurement. Tidal volume and respiratory rate were controlled to maintain an end-expired CO2 concentration of 28 to 32 mm Hg by use of a volume-controlled ventilator. The PO2 in end-expired gas was measured by use of an infrared analyzer. Heart rate, respiratory rate,

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TIVVIP = Transverse diameter of the left internal vertebral venous plexus (IVVP). TIVVPm = Transverse diameter of the right IVVP. TVC = Transverse diameter of the vertebral canal. TDS = Transverse diameter of the dural sac. SIVVP = Sagittal diameter of the left IVVP. SVIPr = Sagittal diameter of the right IVVP. SVC = Sagittal diameter of the vertebral canal. SDS = Sagittal diameter of the vertebral body. AIVVPc = Area of the left IVVP. AIVVPm = Area of the right IVVP. AVC = Area of the vertebral canal. AVB = Area of the vertebral body.
direct arterial pressure, end-tidal CO₂ concentrations, and oxygen saturation were recorded every 5 minutes during the entire procedure.

Nonselective CT venography protocol—All dogs were scanned with the same helical CT scanner. Dogs were positioned in sternal recumbency with their necks extended. Thoracic limbs were pulled caudally, and slight traction force was maintained by use of duct tape. Pre- and postcontrast CT scans were obtained with 3-mm slice thickness, 2-mm slice interval, and a table pitch of 1.25. The scanned region began at the external occipital protuberance and ended at the spinous process of the first thoracic vertebra (T1). The CT gantry was angled to generate slices that were as perpendicular to the vertebral canal as possible. For postcontrast images, iodinated contrast medium was administered IV via a 20-gauge catheter in the right lateral saphenous vein. A manual bolus of 30 to 40 HU. In 1 dog, a second dose of contrast medium was necessary because the first injection failed to opacify the vessels. This problem was caused by an error in settings on the infusion pump. None of the dogs had adverse reactions during or after the procedure. All dogs recovered routinely from anesthesia and were clinically normal at 24 and 48 hours after CT examination.

CT morphometry—The sagittal diameter of the IVVP for C3 to C7 ranged from 0.6 to 3.2 mm (mean, 1.84 mm). The largest sagittal diameter was at C6 (mean ± SD, 2.32 ± 0.44 mm), corresponding to the location of the C7 spinal cord segment (Table 1). Transverse diameter ranged from 2.32 to 5.74 mm (mean, 4.0 mm). Maximum transverse diameter was at C5 (left IVVP, 4.19 ± 0.04 mm; right IVVP, 4.80 ± 0.75 mm). Mean transverse area for the IVVP was 13.38 mm² (approx 6.69 mm² for each left and right component). This represented approximately 12.4% of the vertebral canal transverse area (mean, 107.9 mm²), 20.84% of the dural sac area (mean, 64.18 mm²), and 30.61% of the cervical vertebral epidural space area (area of the vertebral canal minus area of the dural sac, 43.7 mm²). Maximum areas of the IVVP were at C6 at the location of the cervical intumescence. Vertebral vein measurements were not obtainable, primarily because of a silhouette effect with vertebral arteries (Figure 2).

Maximum mean midsagittal diameter of the dural sac was at C6, and the lowest was at C4. For the transverse diameter, minimum values were at C3 and max-
mum values were at C6. Mean area of the dural sac from C3 to C7 was 64.18 ± 10.48 mm². The largest area was at C6.

Maximum mean midsagittal diameter of the vertebral canal was at C6, and the minimum was at C3. Maximum transverse diameter was at C7 (Figure 3); the minimum transverse diameter was at C3. Mean vertebral canal area from C3 to C7 was 107.87 ± 24.44 mm². The vertebral canal area was largest at C7. Maximum mean midsagittal diameter for the vertebral body was at C7, and the minimum value was at C3. Transverse diameters of the vertebral body were subjectively considered similar to transverse diameters of the vertebral canal at all cervical vertebral levels. The largest area of the vertebral bodies was at C7, and the smallest area was at C3.

When vertebral segments were analyzed individually, no significant correlations were found between dimensions of the IVVP and dimensions of other vertebral components (Table 2). When all segments (C3 to C7) were analyzed as a group, area measurements of the venous structures were significantly correlated with vertebral canal area and dural sac area. Significant correlations were also identified between the following dimensions: transverse diameter of the dural sac and midsagittal diameter of the vertebral canal; midsagittal diameter of the IVVP, midsagittal diameter of vertebral canal, and area of the vertebral canal; transverse diameter of the dural sac and transverse diameter of the vertebral body; midsagittal diameter of the dural sac and midsagittal diameter of the vertebral body; and area of the vertebral canal and area of the dural sac. Calculation of the ratio between midsagittal diameter of the dural sac and the vertebral canal revealed values of 0.73 and 0.78 for the cervical segments. The calculated ratios between sagittal diameter of the vertebral canal and sagittal diameter of the vertebral body ranged from 0.8 to 1.22.

**Discussion**

Our CT venography protocol achieved IVVP CT density values of 210 to 300 HU. A value of 240 HU has been reported²⁶,²⁷ to be optimal for vessel enhancement and measurements. No adverse effects after administration of contrast medium were detected in any dog. Morphologic features and location of the veins were consistent with those in dog cadavers.¹³ In that study,¹³ selective CT venography was performed with a single manual injection into the external jugular vein after occluding the ipsilateral internal jugular vein and the contralateral internal and external jugular veins. In the present study, nonselective CT venography was performed by use of an injection into the lateral saphenous vein. A manual bolus injection of contrast medium was followed by a continuous infusion.

Several factors may affect the accuracy of measurements in CT morphometric studies. Variations in window-level and window-width selections can influence the measurements because of a blooming artifact.²⁸ In that artifact, there is variation in the attenuation outside the real border of the vessel, which alters the apparent size of its lumen.²⁹ Also, the diameter and area of objects located in the transverse plane can be altered if they are not perpendicular to the scan plane.³⁰ In those instances, oblique slices can result in falsely

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*Indicates r > 0.7 and P < 0.001.
See Table 1 for remainder of key.
 elongated images. Operator factors can also influence variability in the accuracy of measurements, even when there is 1 observer performing the measurements. In a morphometric study of the lumbosacral portion of the vertebral column, Jones et al determined that the accuracy of transverse area measurements was lower than that of diameter measurements. This was considered most likely attributable to operator error related to hand tracing of irregular regions of interest. Imprecision of the device used for manual measuring can also affect the measurements. In 1 report, it was proposed that when the cursor or electronic caliper is positioned at the edges of the object being measured, there is often an unstable jittering of the instrument that can limit precise outlining of the object.

The range of sagittal dimensions of the cervical IVVP in our dogs (0.6 to 3.2 mm) was similar to that reported for humans. On the basis of images obtained via sagittal T1-weighted magnetic resonance imaging after administration of contrast medium, human cervical sagittal IVVP diameter ranged from 1 to 3 mm. In humans, no normal veins were identified with diameter >4 mm or <1 mm. However, the relative size of the IVVP measured in our dogs was greater than the relative size of the IVVP reported in humans. Our observations also indicated that diameter of the IVVP changed gradually between adjacent segments. No abrupt changes in linear dimensions were found. Maximum cross-sectional areas of the IVVP were identified at the caudal cervical region (C5 to C7). These results were consistent with findings from anatomic studies in dogs made by Crock. The amount of epidural space occupied by the venous plexus was approximately 30% in the cranial cervical region and almost 40% in the caudal cervical region (C5). It is possible that this relative increase in size of caudal cervical venous structures is related to protection and drainage of the cervical intumescence. It is also probable that the increased size of veins in this region is associated with the increased size of vertebral bodies.

Engorgement of the IVVP can occur because of congenital or acquired causes. In humans, localized congestion of the IVVP can cause sciatica symptoms and may resemble a prolapsed intervertebral disk when viewed by use of magnetic resonance imaging. Human patients with obstruction of the inferior vena cava because of caval thrombosis and gestation had enlargement of the IVVP and clinical signs of radicular compression. Spinal epidural varices is a rare condition in humans that can cause neurologic symptoms because of dilation of the IVVP. However, increased diameter of the IVVP can be asymptomatic in other conditions, such as congestive heart failure, hepatic failure, obesity, pregnancy, and positioning with abdominal compression.

In humans, measurement of the area and sagittal dimensions of the IVVP is useful for diagnosis of spinal diseases with CSF leakage such as spontaneous intracranial hypotension syndrome. The Monro-Kellie hypothesis established that cerebral CSF volume fluctuates inversely with cerebral blood volume. Therefore, a decrease in CSF volume leads to compensatory vasodilation in the brain and meninges. Because these vessels are closely associated with intraspinal vessels, venous dilation should also affect the cervical IVVP.

In the dogs reported here, lower midsagittal diameters of the vertebral canal occurred at C3 and higher values occurred at C6. This finding is consistent with previous radiographic studies in dogs. However, vertebral canal midsagittal diameter was typically 1 or 2 mm smaller than values obtained in previous radiographic studies. This difference could be the result of the smaller size of our dogs, absence of magnification of CT measurements, compared with radiographs, or both.

Midsagittal diameter measurements of the vertebral canal were nearly constant in this group of dogs from C3 to C4 and were increased from C5 to C7. In humans, vertebral canal quantitative data are controversial. Some studies found smaller sagittal dimensions in the superior cervical region, and other studies found smaller sagittal dimensions in the inferior cervical region. In our dogs, maximum transverse diameter and area of the cervical vertebral canal occurred at C7 also supports results of other CT studies in dogs. Transverse diameters of the vertebral canal were greater than midsagittal diameters in all cervical segments. In CT images, the epidural space was visible only in the lateral portions of the canal in most cervical vertebrae. In humans, this finding is believed to be the reason horizontal displacement of caudal cervical neural structures is more likely to occur than displacement in the sagittal plane. In our dogs, a relative increase in transverse diameter of the caudal cervical vertebral canal was also associated with an increase in size of vertebral veins. It is possible that this potential space helps protect the spinal cord at the vertebral level where segmental motion of the vertebral column is generally the greatest.

The dural sac in the dogs was more circular in shape in cranial cervical vertebrae and more oval in shape in the caudal cervical vertebrae, a finding also reported in previous studies. Epidural space areas were calculated by subtracting dural sac area from vertebral canal area. Mean epidural space areas represented approximately 30% of the vertebral canal area for the C3 to C7 vertebral segment in dogs. Epidural space areas were lower in the cranial cervical region (C3) than in the caudal cervical region (C6 to C7). This finding suggests that an epidural mass of similar size should be more compressive to neural and vascular tissues in the cranial cervical region than it would be in the caudal cervical region. We estimated the sagittal diameter of the epidural space by subtracting dural sac sagittal diameter from vertebral canal sagittal diameter. Cervical epidural space values in dogs ranged from 1.9 to 3.11 mm, with the greatest value at C6. Smaller values were found from C3 to C5 and were similar to the values for space available for the spinal cord in humans. The space available for the spinal cord is considered to be an effective indicator of cervical spinal stenosis in human patients.

Calculation of the ratio between midsagittal diameter of the dural sac and the vertebral canal revealed...
values of 0.73 and 0.78 for the cervical segments. These values are greater than ratios of spinal cord and vertebral canal diameter reported by Fourie and Kirberger. Discrepancies are likely attributable to the fact that the dural sac includes both the spinal cord and spinal subarachnoid space.

In our dogs, the calculated ratios between sagittal diameter of the vertebral canal and sagittal diameter of the vertebral body ranged from 0.8 to 1.22. In humans, this ratio is termed the Torg ratio and is used for determining spinal stenosis. Torg ratios < 0.8 or 0.7 are considered to be indicative of spinal stenosis. However, 1 CT study detected a low positive predictive value for this ratio regarding human cervical spinal stenosis. In a radiographic study that included Doberman Pinschers, Drost et al. found that the ratios between mid-sagittal diameter of the vertebral canal and mid-sagittal diameter of the vertebral body were significantly different at C5 and C7 in dogs with caudal cervical stenosis versus unaffected dogs. However, their measurements were performed at the cranial endplate of the vertebrae, whereas ours were performed at the mid-vertebral region. Drost et al. concluded that spondylosis deformans in the cranioventral portion of the vertebral bodies could affect the accuracy of those measurements.

Values for the midsagittal, transverse, and area dimensions of the vertebral bodies in our study increased from C3 to C7. In humans, midsagittal diameters of the vertebral bodies do not differ between C3 and C6 and slightly increase at C7. In humans, many patients with cervical stenotic myelopathy have larger cervical vertebral bodies than normal individuals. Previous studies revealed that an increase in size of the vertebral bodies can result in proportionally larger osteophytes or protruded disks. This may be caused by a higher area for mechanical stress or biomechanical forces affecting the vertebral bone mass.

Two limitations of our study were the small sample size and low breed variation. Small sample size may have resulted in lack of correlation observed among the vertebral variables, when all vertebral segments were analyzed individually. To overcome the problem of small sample size, significance for the correlation analysis was set with a high r value (> 0.7) and a low P value (< 0.001). Further studies that include specific breeds are necessary to determine whether our results are observed in other dog populations. The high correlation between sagittal and transverse diameters of the vertebral canal and its components (dural sac and IVVP) supports the theory that the morphologic features of the bony boundaries of the spinal canal may be related to the development of the neural and vascular structures of the canal.

Findings from our study indicate that nonselective CT venography is an effective and safe technique for morphometric evaluation of the cervical IVVP in dogs. Findings also support the theory that there may be a physiologic or developmental relationship between cervical vertebral canal components. Future research is needed to determine how these relationships change in dogs with developmental or acquired cervical spinal disease.

References


