Computed tomography (CT) and magnetic resonance imaging (MRI) are now routinely used in the diagnostic investigation of spinal diseases. This review discusses the fundamentals of CT and MRI, the technical aspects of both modalities, and the CT and MR imaging features of the most common spinal diseases.

Both CT and MRI offer significant advantages over survey radiographs and myelography. Whereas very few veterinary studies have been published demonstrating the benefits of CT or MRI over regular myelography, a wealth of data exists from studies on humans. The few comparative veterinary studies confirm the findings seen in humans. The overall diagnostic sensitivity of MRI is superior to CT, and as such MRI can be used to image the vast majority of spinal disorders, with few exceptions (e.g., spinal trauma caused by gun shot). Routine survey radiographs are always recommended before proceeding with advanced imaging because the area of interest may be more specifically localized, thus reducing scanning time, and severe spinal/osseous lesions, such as hemivertebrae or discospondylitis, may be identified without the need of advanced imaging studies. However, depending on the clinical status and treatment plan, advanced imaging may still be needed.

**FUNDAMENTALS OF COMPUTED TOMOGRAPHY**

Whereas conventional radiography produces summed images of an object, CT scanners rotate to divide an object and organize it into spatially consecutive, parallel image sections. Detectors that are aligned behind the patient opposite to the x-ray source measure the amount of x-ray attenuation. The CT computer not only collects but also stores this x-ray attenuation data and generates a matrix of values, depicted in various shades of gray. The major advantage of CT over radiographs is the improved spatial resolution.
In conventional CT, also known as single-slice CT, a series of equally spaced images are acquired sequentially through a specific region. The x-ray attenuation data is obtained on a slice-by-slice basis with the CT table advancing by predetermined set distances after each slice data acquisition. These units are no longer being manufactured but they are still used in many veterinary clinical settings.

With helical CT scanners, electrical slip ring contacts allow the gantry assembly to rotate continuously. By moving the table, and hence the position of the patient, during the scan, the data are acquired in a helical geometry around the patient. The advantage of this technology is that it significantly reduces scanning time. Multidetector technology permits CT scanners to acquire multiple slices or sections simultaneously and greatly increases the speed of CT image acquisition. The ability to obtain submillimeter slice thicknesses is also a characteristic feature of multidetector helical systems.

FUNDAMENTALS OF MAGNETIC RESONANCE IMAGING

Each nucleus with an odd number of protons and/or odd number of neutrons has a spin. Because protons carry an electric charge, the spin creates a magnetic field that has direction and finite strength. In the body, the "magnetic moments" of the protons point in all directions and cancel each other out. When the body is placed in a strong magnetic field, the magnetic moments of the protons will align parallel to the field direction (Z-axis).

This alignment, or magnetization, is then disrupted by radiofrequency pulses. As the nuclei recover their alignment by relaxation processes, they produce radio signals that are proportional to the magnitude of the initial alignment. Tissue contrast (ie, differences in signal) develops as a result of the different rates at which nuclei realign with the magnetic field.

The positions of the nuclei are localized during this process by the application of spatially-dependent magnetic fields called gradients. The signal is then read after a predetermined period of time has elapsed from the initial radiofrequency excitation. The signal is transformed by the computer into an image using a mathematical process known as Fourier transform.

Field strengths vary in the clinical MR units and range from 0.2 to 7.0 Tesla. Higher field strengths are available in research settings. In general, the higher the field strength, the higher the signal to noise ratio (SNR) and the faster the imaging times, to a limit. The field strength systems over 0.7 Tesla require more extensive shielding against external radiofrequency interference. Maintenance costs for these units are considerable.

CT VERSUS MRI

In general, CT provides superior spatial resolution and is better suited for imaging bone. Slice thicknesses as thin as 1 to 1.5 mm are possible in almost all available CT units. Thinner slice acquisitions (submillimeter) are possible with newer, multidetector systems. For CT this is a distinct advantage over MRI, for which such thin slice acquisitions are not currently possible because of decreases in SNR as slice thicknesses decrease. To some extent, high SNR is a factor of magnet field strength and the number of excitations (NEX) repeatedly collected over a sample volume of tissue. Although increasing NEX increases SNR, it also increases scan time. Other advantages of CT over MRI are decreased cost, fewer maintenance requirements and associated expense, and rapidity of imaging. Imaging patients under sedation is now possible with some of the newer scanners because of their rapid scan times. Because equipment costs and scanning times are less, client costs for CT are typically less than
MRI. CT can be used to successfully guide needle aspirations or biopsies once a lesion is localized, but this is not generally done with MRI guidance because of prolonged imaging times and the inability to use metal implements for tissue sampling.

MR provides superior contrast resolution and is better suited for imaging soft tissues, such as the spinal cord, nerve roots, and intervertebral discs. Images can be acquired in multiple planes whereas CT images can only be acquired in one plane (typically transverse). Although CT images can be reformatted into any plane desirable, including 3-dimensional, the image detail is slightly reduced on reformatted as compared with acquired images. The quality and conspicuity of the reformatted images is a factor of acquisition slice thickness; the thinner the slices acquired, the better the detail on reformatted images. Whereas myelography is still often used in conjunction with CT of the spine, this is not necessary with MRI because of the ability to alter tissue contrast by applying different acquisition sequences. Thus, the associated morbidity often accompanying myelography is avoided.

**CT IMAGING TECHNIQUES**

**Positioning**

- Dorsal recumbency (standard positioning for all spinal segments)
- Ventral recumbency for the cervical spine
  - To avoid overextension of the neck in cases of atlantoaxial instability
  - Useful for subtle intervertebral disc protrusions.

**Plane of Acquisition**

- Transverse
  - Reformatted into sagittal and dorsal planar images.

**Algorithm**

Selection of the appropriate image algorithm before initiation of scanning is paramount and dependent on the tissue of interest. In most cases both bone and the soft tissues of spine, to include the spinal cord, intervertebral discs, and paralumbar musculature, will need to be assessed.

**Technique**

The choice of mA and kVp is determined by considering patient size and area imaged, patient exposure dose, SNR, and time, dictated by the necessity for tube cooling when using a higher mA. Most CT units are equipped with standard image protocols based on patient size that require little modification before scanning.

**Field of View**

Field of view (FOV) is specific to the spinal column and dependent on patient size.

**Pitch (Specific to Helical Scanners)**

Pitch is defined as the ratio of table speed per gantry (detector) rotation around the patient and slice thickness.

**Slice Thickness**

Slice thickness is specific to the region of the spinal column imaged and patient size. In general, the following parameters are recommended:

- 1 to 2 mm through intervertebral disc or localized lesion other than disc
- 3 to 5 mm through spinal column.
Initial images typically are acquired through a segment of spinal column based on
neurolocalization of a lesion. This area may be scanned using larger slice thicknesses.
Once an isolated lesion is identified, thinner slice acquisitions through the lesion may
be acquired for greater lesion conspicuity. If looking specifically for intervertebral disc
disease, the plane of imaging should be parallel to the intervertebral disc. Otherwise,
transverse imaging perpendicular to the spinal column is advised. The desired imaging
plane may be obtained by tilting the CT gantry.

**MRI TECHNIQUES**

**Positioning**

The same general principles of positioning apply as described for CT; however,
straight spinal alignment is more important for MRI to allow direct comparison of
multiple sites on sagittal images. The spinal segment(s) to be imaged must be in close
contact with the radiofrequency coil for satisfactory SNR. As table surface coils
designed for spinal imaging are used in most instances, patients are typically posi-
tioned in dorsal recumbency.

**Plane of Acquisition**

- Sagittal: Often used as the survey series to localize a specific site of pathology as
a long segment of the spine can be imaged. The T2-weighted sequence is
preferred for initial assessment for intervertebral disc disease, infection, or
neoplasia.
- Dorsal
- Transverse: Typically limited to a specific site of pathology as imaging of
extended lengths of spine in this plane is time intensive.

**Image Sequences and Slice**

- T2-weighted: Fluid, such as cerebrospinal fluid (CSF) or edema, will be
hyperintense.
- T1-weighted: Fluid, such as CSF or edema, will be hypointense.
- FLAIR (fluid-attenuated inversion recovery): Pure fluid, such as normal CSF, will
be hypointense whereas edema or abnormal fluids will be increased in intensity.
- STIR (short tau inversion recovery) or fat saturation: The typically hyperintense fat
(on both T1- and T2-weighted sequences) will be of low signal intensity. If
a sequence is T2-weighted, CSF can be more readily differentiated from epidural
fat. If a sequence is T1-weighted, a contrast-enhancing lesion can be more
readily differentiated from fat.
- Gradient echo (GRE): A fast sequence that is very sensitive to inhomogeneities in
the magnetic field though less sensitive to motion artifact because of its speed of
acquisition. It is often used to detect areas of hemorrhage, as excessive iron
concentrations in hemorrhagic areas of the spinal cord will cause field
inhomogeneity.

**Recommended Standard Planes, Slice Thicknesses, and Sequences**

- 2-mm thick T2-weighted sagittal images followed by 2-mm thick T1-weighted
sagittal images. A 0.5-mm gap between slices, to avoid image cross-talk and
resultant decreased signal to noise, or interleaved (no gap) acquisition is typical.
- 2- to 3-mm transverse images through the lesion identified on the sagittal
images.
- 2-mm dorsal images for lateralized lesions identified on the prior sequences.
T1-weighted images after intravenous gadolinium injection may be obtained in all 3 image planes according to the lesion characteristics.

Field of View

FOV is defined as the vertical or horizontal distance across an image. It should be set specific to the spinal column, which is dependent on patient size. By decreasing FOV to a specific area, the SNR decreases and thus increases in sampling (NEX) or increases in slice width are necessary to maintain adequate spatial and contrast resolution. By increasing NEX, scan time is also increased.

Saturation Bands

As MRI is extremely sensitive to motion artifact secondary to respiration and blood flow, saturation bands may be placed over the abdomen and thorax to suppress the effects of motion from these areas during scanning.

Number of Excitements

NEX refers to the number of repeat signal samplings acquired in any given sequence. In general, the more times an area is sampled, the greater the SNR (improved tissue contrast). The downside is that the greater the NEX, the longer the overall imaging time. NEX values between 2 and 4 are typically required for field strengths over 1 Tesla.

CONTRAST IMAGING

Subarachnoid Nonionic Iodinated Contrast (CT only)

Indications include identification of nonmineralized extradural and intradural-extramedullary lesions. These indications may include intervertebral disc herniation, neoplasia, hematoma, granuloma/abscess, cyst (arachnoid or synovial), scar tissue, and empyema.

Intravenous Iodinated (CT) or Gadolinium Diethylenetriaminepentaacetic Acid (MRI) Contrast

Indications include identification of vascular lesions like those secondary to neoplasia, infectious/noninfectious inflammatory lesions other than related to intervertebral disc herniation, and vascular malformations.

CT AND MRI ARTIFACTS

A variety of artifacts are associated with both modalities, and it is beyond the scope of this article to discuss them. Both modalities are extremely sensitive to motion artifacts, MRI more so than CT. Many of the potential motion artifacts in CT can be overcome by the rapidity of imaging. Artifacts associated with metal implants or foreign bodies are also common to both modalities. In MRI, potentially deleterious effects to patients with pacemakers or small metallic shavings in or adjacent to critical sites are possible. Small shavings may move within the tissues, with the potential to penetrate, for instance, the spinal cord. For this reason, MRI of patients with gunshot injuries should be avoided.

NORMAL ANATOMY

The anatomic features of the spinal region being studied must be taken into consideration when interpreting advanced imaging studies. Each region of the vertebral
column (cervical, thoracic, lumbar, and sacral) has specific anatomic features. A larger degree of anatomic variation is seen in the cervical vertebrae compared with other vertebral regions. Not only are the cervical vertebrae different, but also the shape and relationship of the spinal cord to the vertebral canal varies according to the location within the cervical column (Fig. 1). The anatomic features of the cervical spine and lumbosacral spine have been reported in detail using CT, MRI, or both.

Due to the exquisite sensitivity of MRI it is important to assess the imaging findings in the light of the patient’s clinical signs and examination findings. The presence of asymptomatic spinal abnormalities is widely recognized in human medicine. The presence of multiple spinal abnormalities is commonly seen in aged dogs and cats. Clinically silent spinal cord compression, intervertebral disc degeneration, intervertebral disc protrusion, nerve root compression, intervertebral foraminal stenosis, and vertebral canal stenosis have all been reported without concurrent clinical signs in dogs. Similarly, no correlation exists between the severity of spinal cord or nerve root compression and the severity of clinical signs.

Fig. 1. Transverse T2-weighted MR images at the level of the C2-3 (A), C5-6 (B), and C7-T1 (C) intervertebral disks of a clinically normal Doberman Pinscher. Note the different shapes of the spinal cord at each cervical level. The normal spinal cord at C7-T1 has a trapezoid shape. (From da Costa RC, Parent JM, Partlow G, et al. Morphologic and morphometric magnetic resonance imaging features of Doberman Pinscher dogs with and without clinical signs of cervical spondylomyelopathy. Am J Vet Res 2006;67:1601–12; with permission.)
CONGENITAL SPINAL DISEASES

Atlantoaxial malformation and Chiari-like malformations are seen primarily in toy breed dogs and may be associated with severe clinical signs. Anatomic abnormalities associated with atlantoaxial malformation include odontoid process (dens) malformation, hypoplasia or aplasia, and/or weak or poorly developed supporting ligamentous structures of the odontoid process. The result may be subluxation or luxation of the atlantoaxial articulation, usually resulting in ventroflexion and a widened angle or space between the dorsal lamina of the atlas and spinous process of the axis (Fig. 2). If the odontoid process is intact and normally or partially formed it may deviate dorsally within the spinal canal, resulting in severe compression of the spinal cord, exacerbated by increased ventroflexion of the cranial cervical spine (Fig. 3). Anatomic malformations associated with Chiari-like malformation include occipital hypoplasia and brainstem crowding. Atlanto-occipital overlapping with or without medullary kinking may be present (see Fig. 2B). Syringohydromyelia may or may not be seen. CT is an excellent means of evaluating the size and shape of the odontoid process and in assessing for cranial over-riding of the atlas. MRI is sensitive for detecting secondary trauma to the spinal cord (hemorrhage, edema) secondary to instability at the articulations. MRI is also better suited for assessment of syrinx formation within the spinal cord (Fig. 4). Due to the naturally small size of the supporting ligamentous structures of the atlantoaxial articulation, these structures are typically not seen with either modality, even when normally formed.

Fig. 2. Atlantoaxial subluxation. (A) Lateral radiograph showing increased distance between the dorsal lamina of the atlas and the spinous process of the axis (arrows). The odontoid process is normally formed but dorsally displaced. (B) Sagittal T2-weighted MR image in the same dog. The odontoid process is a hypointense structure ventral to the spinal cord (long arrow). A curvilinear hypointensity caudal to the cerebellum (asterisk) represents caudal occipital overlapping with medullary kinking (short arrows). (C) Transverse T1-weighted MR image through the odontoid process (asterisk) and the atlanto-occipital articulation in the same dog. The normally oval spinal cord has a “kidney-bean” shape secondary to ventral compression by the dorsally deviated odontoid process.
Fig. 3. Atlantoaxial subluxation. Sagittal T1-weighted MR image showing dorsal deviation of the odontoid process (asterisk) with resultant, severe spinal cord compression.

Fig. 4. Sagittal (A) and transverse (B) T2-weighted MR images through the cranial cervical spine of a dog with syringohydromyelia. A fusiform region of hyperintensity is present in the central spinal cord at the level of C3 and cranial C4 (A). There is a large, circular region of hyperintensity representing fluid in the central spinal cord secondary to syringohydromyelia (B).
Hemivertebrae are quite commonly recognized in brachycephalic, screwtail breeds. Besides the tail, the mid to caudal thoracic spine is often affected to varying degrees.\textsuperscript{12,13} Hemivertebra results from abnormal, uneven growth between the two halves of one or more vertebrae during development, with often incomplete fusion between the halves. Because of the abnormal vertebral conformation, secondary spinal canal stenosis and spinal cord compression may occur. Also, inherent instability at the articulations at these sites is common, as articular process and vertebral end-plate conformation are compromised. One of the greatest challenges in imaging these patients is that most patients have associated, varying degrees of kyphosis, lordosis, and scoliosis. Achieving well-positioned planar images is difficult. CT is preferred for better definition of bone, particularly if a surgical stabilization process is being considered. If neurologic deficits are present, MRI is preferred for spinal cord imaging (Fig. 5). Other congenital vertebral anomalies include block vertebra, butterfly vertebra, transitional vertebra, and spina bifida (see the article by Westworth and Sturges elsewhere in this issue for further exploration of this topic). On rare occasions, herniation of the meninges (meningocele) or meninges and spinal cord (meningomyelocele) may be seen with spina bifida. Dermoid sinuses result from a congenital communication between the skin and spinal cord and may be seen in Rhodesian Ridgeback dogs, and occasionally in other breeds. MRI is the preferred imaging modality for assessment of meningoceles, myelomeningoceles, and dermoid cysts.

\textit{Spinal arachnoid cysts} consist of outpouchings of the arachnoid matter or focal dilations in the subarachnoid space that are filled with cerebrospinal fluid.\textsuperscript{14} The use of the term “cyst” to describe these lesions is a misnomer, as these outpouchings are not lined by epithelium. These lesions are most commonly located in the dorsolateral area of the cervical spine, but may be seen ventrally and in other regions of the spine column; they may be bilaterally paired, having a bilobed appearance (Fig. 6).\textsuperscript{15} There is still discussion as to whether these “pseudocysts” are congenitally acquired or

![Fig. 5. Sagittal (A, B) T1-weighted and dorsal (C) T2-weighted MR images of the thoracolumbar spine of a French bulldog with severe lordosis and mild scoliosis secondary to T7, T8, and T9 hemivertebrae.](image-url)
possibly secondary to trauma or arachnoiditis-induced adhesions. Arachnoid adhesions resulting from chronic inflammation and microtrauma may be the instigating cause of pseudocyst development.\textsuperscript{16} It has also been postulated that the arachnoid adhesions, rather than the subarachnoid outpouchings, are the cause of spinal cord compression and the resultant neurologic deficits.\textsuperscript{16} As the Rottweiler breed is over-represented, a genetic or hereditary component is likely in at least some patients.\textsuperscript{14–16} An acquired arachnoid cyst has been reported in a cat.\textsuperscript{17} CT myelography and MRI are equally adept at identifying cyst-like lesions of the subarachnoid space.

\textbf{INFLAMMATORY SPINAL DISEASES}

\textit{Discospondylitis} has been, by convention, a radiographic diagnosis. Clinical signs often precede radiographic evidence of vertebral endplate lysis and medullary sclerosis, typically seen with more advanced disease. CT is much more sensitive than radiographs for identifying endplate osteolysis early in the course of disease (Fig. 7). MRI is much more sensitive for detecting soft-tissue inflammation of the disc that usually precedes bony changes. Also, early marrow changes in the affected vertebra (increased hyperintensity on T2-weighted images and contrast enhancement on T1-weighted images) may be seen with MRI prior to overt osteolysis. As such, MRI may be preferred to CT to screen for early cases of discospondylitis where bony changes are not observed radiographically.\textsuperscript{18,19}

\textit{Myelitis and neuritis} are best evaluated with pre- and post-intravenous contrast MRI (Figs. 8 and 9). Imaging features are very similar to, and are difficult to distinguish from, neoplasia. Cerebrospinal fluid analysis, surgical biopsy, and the patient’s overall clinical picture may be necessary to confirm infectious or noninfectious inflammatory processes.

\textit{Epidural empyema} is defined as the accumulation of purulent material within the spinal canal and may be the result of a penetrating wound, grass awn migration, or
systemic sepsis with discospondylitis that erodes into the spinal canal. Patients are typically pyrexic and have a rapid course of progressive myelopathy. Neurologic signs are secondary to the combined effects of regional tissue inflammation and spinal cord compression by an epidural mass effect. MRI is the preferred imaging test, again for its superior soft-tissue resolution.\textsuperscript{20,21}

\textbf{SPINAL NEOPLASIA}

Spinal neoplasia is an important differential diagnosis for dogs presenting with either chronic or acute neurologic signs. Several classification systems are used to categorize spinal neoplasms. A common classification categorizes the tumors according to
the location into extradural, intradural-extramedullary, and intramedullary. Extradural tumors such as osteosarcoma and fibrosarcoma are the most common.\textsuperscript{22}

Both CT and MRI are sensitive techniques for the diagnosis of spinal tumors. Due to the superior soft-tissue resolution, MRI is usually the preferred imaging method; however, CT is excellent for visualization of osseous lesions, which are commonly observed in spinal tumors. CT examination of spinal tumors will often require

Fig. 8. C6-7 left-sided neuritis. Pre- (A) and post-intravenous contrast (B) transverse T1-weighted MR images made at the level of C6-7. There is thickening and diffuse contrast enhancement of the left C6-7 nerve root (long arrow). A slight dorsal protrusion of the hypointense C6-7 intervertebral disc is additionally present (short arrow).

Fig. 9. Myelitis. Sagittal (A) and transverse (B, C) T1-weighted MR images after intravenous gadolinium injection showing the irregular areas of contrast enhancement in the spinal cord (arrows).
intravenous contrast injection to identify areas of contrast enhancement. Contrast injection into the subarachnoid space (myelography) may also be required.

A study comparing myelography and CT concluded that the lytic/proliferative osseous lesions were depicted more clearly on CT than on radiographs (Fig. 10). Lytic and proliferative regions observed on imaging need to be differentiated from infections such as discospondylitis or vertebral osteomyelitis. As a general rule, lytic and proliferative lesions located in the vertebra itself are typical of neoplasia, whereas

Fig. 10. Spinal neoplasia—multiple myeloma. (A) Lateral radiograph show multiple areas of osteolytic lesions (arrows). (B) Reformatted sagittal CT scan makes visualization of the lytic areas more evident and reveals other areas not previously identified (arrows). (C) Transverse CT image of L3 showing severe osteolysis (arrowhead). (D) Transverse CT image at the caudal aspect of L4 showing lysis of the dorsal lamina (arrow).
lytic/proliferative lesions centered at the disc space are caused by infections (disco-
spondylitis). In one study, myelography was more useful in differentiating between
intradural-extramedullary and intramedullary tumors than CT.23 This same observa-
tion was made when comparing myelography and MRI in another study.24 Careful
evaluation of the images in all 3 planes (transverse, sagittal, and dorsal) may assist
in defining the location of the tumor. Dorsal images are particularly useful. The MRI
findings of spinal meningiomas, the most common intradural tumor, have been well
described.25,26 Most meningiomas are iso- to hyperintense on T1-weighted images
and hyperintense on T2-weighted images.24–26 Homogeneous, strong contrast
enhancement and presence of dural tail are also consistently observed (Fig. 11).24–26

MRI findings for other spinal tumors have not been well described. Osseous tumors
have very variable signal intensity, ranging from iso- to hyper- or hypointense on both
T1- and T2-weighted images. Contrast enhancement is also variable. It is important to
use fat suppression techniques (eg, STIR) when observing hyperintense lesions on
T1- and T2-weighted images within osseous structures, as these changes may be
caused by fat infiltration. Intramedullary tumors have more consistent imaging
patterns. Due to the common presence of edema, hyperintensity on T2-weighted
images and hypointensity on T1-weighted images, in relation to the surrounding spinal
cord, is commonly observed. The pattern of enhancement is variable.

Primary or secondary nerve sheath tumors (NSTs) are the most common cause of
neurogenic lameness. Approximately 45% of the tumors are located in the nerve roots
proximal to the spinal cord while 55% are located in the plexus area or peripheral
nerves.27 This fact emphasizes the importance of using a larger FOV when imaging
patients suspected of having NSTs. The imaging features of NSTs have been
described using CT and MRI. The visualization of NSTs is facilitated using MRI. CT
findings commonly observed in dogs with NSTs are rim enhancement and a hypo-
dense center.28 On MRI, nerve sheath tumors are consistently hyperintense on

![Fig. 11. Meningioma. T1-weighted MR images after intravenous gadolinium injection. (A)
Dorsal and (B) transverse images show a large, mostly homogeneous, contrast-enhancing
mass at the level of C1 and C2 (arrow). (From da Costa RC. In: Daleck, de Nardi, Rodaski,
with permission.)](image-url)
T2-weighted images, hypointense on T1-weighted images, and show homogeneous or inhomogeneous contrast enhancement (Fig. 12). The tumor may appear as a diffuse brachial plexus nerve thickening or a circumscribed mass (Fig. 13). Biopsy is always needed to confirm the diagnosis of spinal tumors or NSTs, and to define the specific type of tumor. Depending on the location of the tumor, biopsy can be guided using CT or ultrasonography.

**INTERVERTEBRAL DISC DISEASE**

Intervertebral disc disease (IVDD) is the most common spinal disease of dogs, and should be a differential diagnosis in any dog older than 1 year with spinal pain and myelopathic signs. A definitive diagnosis of IVDD requires myelography, CT myelography, or MRI. Noncontrast CT has been used in the diagnosis of acute IVDD for several years. The normal spinal cord is surrounded by epidural fat, which can be seen on plain transverse CTs as an area of intermediate attenuation over the region of the intervertebral discs. Visualization of the spinal cord is more challenging over the vertebral bodies because of the lesser content of epidural fat. CT characteristics of acute intervertebral disc extrusion include hyperdense material within the vertebral canal, loss of epidural fat, and distortion of the spinal cord (Figs. 14 and 15). Chronic disc extrusions appear to be even more hyperattenuating, possibly because of progressive mineralization. Acute intervertebral disc herniations are often associated with epidural hemorrhage. Acute and subacute epidural hemorrhage can be seen as irregular linear hyperdense areas cranial and caudal to the herniated disc material. It is often difficult to distinguish between hemorrhage and extruded disc material because blood is often admixed with disc. If the extruded nucleus pulposus is not mineralized, identification of disc material is more difficult and has to be based on loss of epidural fat and displacement of the spinal cord. If surgery is planned, myelography should then be performed to precisely localize the site of extrusion.

It is important to reformat the transverse CT images for assessment of the cranial and caudal extent of disc herniation and to compare multiple sites of disc herniation.

![Fig. 12. Primary malignant nerve sheath tumor: distal location. (A) Transverse T2-weighted MR image reveals a large hyperintense mass at the level of the left axilla just lateral to the first rib (arrows). (B) Transverse T1-weighted MR image after intravenous gadolinium injection shows an inhomogeneously enhancing mass at the same level of A (arrows). Arrowhead indicates the spinal cord.](image-url)
Recently, multiplanar reformatting was proposed as a useful technique to increase diagnostic certainty.\textsuperscript{32}

Recent studies have compared myelography and CT in the diagnosis of IVDD in dogs. In one study with 182 dogs, noncontrast CT had a sensitivity of 81.8%, whereas myelography had a sensitivity of 83.6%.\textsuperscript{33} Another study found a sensitivity of 90% for CT and 88% for myelography.\textsuperscript{34} A study with 19 chondrodystrophic dogs found agreement with surgical findings in 94.7% of dogs using myelography, 100% using conventional CT, and 94.7% using helical CT.\textsuperscript{35} It is possible that the differences in results among studies are related to the fact that the last study had only chondrodystrophic dogs that are predisposed to chondroid disc degeneration and disc mineralization. All of these studies focused on acute intervertebral disc herniations. The diagnostic sensitivity of plain CT in nonmineralized chronic, type II disc protrusions is currently unknown, but it is likely significantly less than the reported values for acute disc herniation. In chronic cases, CT myelography would likely be necessary. Of importance is that a normal CT does not rule out IVDD.

MRI allows clear visualization of intervertebral disc disease. The normal nucleus pulposus of the intervertebral disc appears a hyperintense ellipsoid area on sagittal T2-weighted images. Intervertebral disc degeneration leads to a decrease in signal intensity, and the degenerated disc becomes isointense to hypointense relative to the surrounding annulus fibrosus. The degree of brightness of the T2 signal of the nucleus pulposus correlates with the proteoglycan concentration but not with water or collagen concentration.\textsuperscript{36} MRI allows detection of disc degeneration at earlier stages of the degenerative process, before mineralization.

\textbf{Fig. 13.} Primary malignant nerve sheath tumor: proximal location. (A) Dorsal T1-weighted MR image after intravenous gadolinium injection shows an oval contrast-enhancing mass that appears to be displacing the spinal cord medially at the level of C5-6 (arrow). (B) Transverse T1-weighted MR image at the level of C5-6 shows a large contrast-enhancing mass involving the nerve roots and infiltrating into the spinal cord (arrow). (From da Costa RC. In: Daleck, de Nardi, Rodaski, editors. Canine and feline oncology. São Paulo: Roca; 2009. p. 411–35 [in Portuguese]; with permission.)
Fig. 14. Cervical intervertebral disc disease. (A) Reformatted sagittal CT image shows a large hyperdense area in the vertebral canal dorsal to the intervertebral disc space of C5-6 (arrow). Calcification is also seen at the C4-5 intervertebral disc space. (B) Transverse CT image reveals the large extradural hyperdense mass compressing and displacing the spinal cord dorsally (arrow).

Fig. 15. Thoracolumbar intervertebral disc disease. Transverse CT image at the level of T12 shows a focal hyperdense mass compressing and displacing the spinal cord dorsolaterally (arrowhead).
occurs, which is when it can be visualized using CT and radiographs. It must be emphasized that disc degeneration per se does not lead to clinical signs, except in uncommon cases of discogenic spinal pain. MRI also allows visualization of the spinal cord, which facilitates comparison when multiple sites are affected (Figs. 16 and 17). The size of the spinal cord and vertebral canal varies according to different spinal locations, so the same degree of disc protrusion may lead to different degrees of spinal cord compression according to the spinal location. Sagittal and transverse images should be used concurrently to assess the severity and lateralization of spinal cord compression (see Fig. 16). It is common to observe lateralized disc extrusions causing nerve root compression, which may not be seen on mid-sagittal images. Parasagittal images allow visualization of lateralized disc herniations and nerve root compression. Hemorrhage associated with disc extrusion can cause a signal void on MR images. GRE can confirm the presence of hemorrhage.

Fig. 16. Multiple sites of cervical intervertebral disc disease. (A) Sagittal T2-weighted MR image shows a large ventral extradural compressive lesion at the level of C2-3 (arrow), with less severe disc protrusions at C5-6 and C6-7. Intervertebral disc degeneration is seen at all these sites. (B) Transverse T2-weighted MR image at the level of C2-3 with a broad spinal cord compression. (C) Transverse T2-weighted MR image at the level of C5-6 shows a centrally located disc protrusion with dilation of the central canal of the spinal cord. (D) Transverse T2-weighted MR image at the level of C6-7 shows ventral compression of the spinal cord and nerve root on the right side (arrow). The nerve root compression was causing lameness of the right thoracic limb.
MRI also allows assessment of the spinal cord parenchyma and detection of spinal cord signal changes. In cases with multiple sites of spinal cord compression, identification of hyperintensity on T2-weighted images indicates the site with the worst compression. The spinal cord hyperintensity seen on T2-weighted images correlates with the severity of clinical signs. The degree of severity of spinal cord compression, however, does not correlate with the severity of clinical signs. Three studies in dogs have indicated that the presence and extension of spinal cord signal changes have prognostic implications. A study suggested that areas of hyperintensity longer than 3 times the body of L2 were associated with poor prognosis, with only 20% of dogs with this signal change regaining ambulatory status. The presence of hyperintensity was a more reliable prognostic indicator than absence of nociception. Even in noncompressive intervertebral disc extrusions, the extent of spinal cord hyperintensity predicted the outcome.

Chronic disc extrusions may be associated with inflammatory reaction surrounding the extruded disc, leading to a ring enhancement pattern surrounding the disc. The image may be mistaken as a granulomatous or neoplastic lesion. It is important to be aware of this imaging feature of IVDD to avoid misdiagnosing it as other conditions. Intervertebral disc herniation can cause many different types of imaging patterns and should always be considered in the differential diagnosis for unusual MRI findings. In contrast to nonenhanced CT, normal MRI findings in all 3 imaging planes rule out the diagnosis of IVDD.

CERVICAL SPONDYLOMYELOPATHY

Cervical spondylomyelopathy (CSM) is characterized by static and dynamic spinal cord compressions. The disease is commonly caused by osseous compressions in young, giant breed dogs; and by disc protrusion in middle-aged to older large breed dogs. Both MRI and CT have been used in the diagnosis of CSM in dogs. When planning advanced imaging studies of the cases suspected of having CSM, it is important to plan the FOV to cover the entire cervical spine up to the third thoracic vertebrae. A recent study found compressions at T1-T2 and T2 associated with other cervical compressions in almost 10% of dogs.
Noncontrast CT findings in dogs with CSM reveals the shape of the cervical vertebral canal, osteoarthritic changes in the articular processes, and mineralized disc herniation within the vertebral canal. Foraminal stenosis and lateralized disc herniations can also be observed. Noncontrast CT seems to be more valuable in evaluating dogs with severe osseous changes causing marked vertebral canal stenosis. CT after intravenous contrast injection allowed delineation of the venous sinuses dorsal to the vertebral bodies and appeared to be helpful in identifying asymmetric spinal cord compressions. However, it is also less diagnostic than conventional myelography. At present, noncontrast CT cannot be used as single diagnostic test for the diagnosis of CSM in dogs.

CT myelography allows cross-sectional images of the spinal cord area and provides superior visualization of areas of spinal cord compression as compared with myelography. Asymmetric spinal cord compression is readily identified (Figs. 18 and 19). CT myelography also allows detection of areas of spinal cord atrophy, seen as regular or irregular widening of the subarachnoid space with an altered spinal cord shape. Spinal cord atrophy was seen in approximately 20% of dogs in a recent study. It is unknown whether this finding has prognostic implications. CT myelography also allows easier visualization of synovial cysts that may be seen with osteoarthritic changes in giant breed dogs. CT myelography offers advantages over conventional myelography by establishing the exact location, degree, and lateralization of the compression.

MRI has been considered the best imaging technique for humans with cervical spondylotic myelopathy for more than 20 years. CT myelography is still used in humans for equivocal cases where cervical radiculopathy secondary to foraminal stenosis is the main clinical problem. The main advantage of MRI over CT myelography is the ability to directly visualize the spinal cord. This visualization allows detection of spinal cord signal changes that are helpful to determine the primary spinal cord lesion in cases with multiple compressions. Two recent studies indicate that multiple spinal compressions are seen in 63% of dogs with CSM.

Fig. 18. Cervical spondylomyelopathy: osseous compression. Transverse CT-myelographic image at the level of C5-6 of a 1-year-old Great Dane showing bilateral spinal cord compression secondary to proliferative osteoarthritic lesions affecting both articular processes.
A recent study compared MRI and myelography for dogs with CSM. It was concluded that MRI allows identification of more sites of abnormalities than cervical myelography. Although myelography could identify the location of the lesion in most patients, MRI was more accurate in predicting the site, severity, and nature of the spinal cord compression. Spinal cord signal changes were seen in the majority of patients and provided assistance in precise lesion identification (Fig. 20). The reader is referred to the discussion of CSM by Westworth and Sturges elsewhere in this issue for more information about imaging of CSM.

**LUMBOSACRAL DISEASE**

Lumbosacral (LS) disease, also known as degenerative lumbosacral stenosis (DLSS) or cauda equina syndrome, is a common disease of large breed dogs associated with nerve root compression at L6-L7 or L7-S1 vertebrae. Dogs with lumbosacral disease often present with lameness, paresis, and caudal lumbar or lumbosacral pain.

The CT findings in dogs with LS disease have been extensively studied by Jones and colleagues. CT abnormalities observed are loss of epidural fat, increased soft-tissue opacity within the intervertebral foramen, bulging of the intervertebral disc, vertebral canal stenosis, and thickened articular processes. In noncontrast CT, the epidural fat surrounds the nerve roots and dural sac; however, with stenosis and compression, the epidural fat is lost and the compressive soft tissue becomes indistinguishable from adjacent nerves. The use of intravenous contrast for CT evaluation of the LS area increased the sensitivity for detection of ventral and lateral compressions. The use of subarachnoid contrast (myelography) associated with CT is not recommended for evaluation of the LS area because the contrast medium causes blooming and beam hardening artifacts, making interpretation difficult.

The degree of lumbosacral compression detected using MRI has no correlation with the severity of clinical signs. Fecal and urinary incontinence were observed in dogs.
with minimal LS compression, whereas other dogs had severe compression of the LS region and showed pain only without neurologic deficits. MRI usually reveals ventral compression caused by intervertebral disc degeneration and protrusion (Fig. 21). Intervertebral disc protrusion can be seen with loss of the normal bright hyperintense signal of the intervertebral disc. Dorsal compression caused by joint capsule thickening, osteophyte formation, and hypertrophy of the ligamentum flavum can also be observed. Foraminal stenosis is an important component of the complex of the DLSS, and the parasagittal and transverse images should be carefully examined. Transverse images allow assessment of the dorsoventral diameter of the foramina while the parasagittal images allow evaluation of the craniocaudal diameter of the foramina. Dynamic studies of the LS spine can be performed; however, criteria for testing and normal reference ranges have not been established and as such, interpretation of the results can be problematic.

CT and MRI findings for LS disease showed a high agreement between both modalities; however, the correlation between CT or MRI findings with surgical findings is low. MRI and CT findings also had no correlation with outcome. It is also important to bear in mind that clinically normal dogs can have imaging characteristics of LS diseases without clinical signs.

**SPINAL TRAUMA**

No published data exist regarding the use of MRI in the evaluation of spinal trauma in small animals. The authors’ experience indicates that MRI is a valuable tool in the evaluation of dogs with spinal trauma (Fig. 22). A study compared the diagnostic sensitivity of survey radiographs and CT in dogs with confirmed spinal fractures and luxations. Radiographs missed approximately 25% of the lesions detected on CT. CT is the gold standard test for evaluation of spinal trauma in humans, and should be used whenever possible in the evaluation of dogs and cats with spinal trauma.

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**Fig. 20.** Cervical spondylomyelopathy: disc-associated. Sagittal T2-weighted MR image showing ventral spinal cord compression at the level of C6-7 with spinal cord hyperintensity (arrow). The intervertebral discs C5-6, C6-7, and C7-T1 show the various stages of disc degeneration.
Fig. 21. Degenerative lumbosacral stenosis. (A) Sagittal T2-weighted MR image showing severe ventral compression at the level of L7-S1 (arrow). Milder compressions are also seen at L5-6 and L6-7, along with degeneration of the caudal lumbar intervertebral discs. (B) Transverse T2-weighted MR image at the level of the lumbosacral junction showing foraminal stenosis and nerve root compression secondary to asymmetric disc protrusion (arrowhead).

Fig. 22. Spinal trauma. (A) Lateral radiograph of the cervical spine of a dog hit by a car that was presented with nonambulatory tetraparesis. No abnormalities were detected on survey radiographs. (B) Sagittal T2-weighted MR image of the same dog showing an extensive area of hyperintensity within the spinal cord parenchyma between C2 and C3 (arrow) indicating spinal cord injury.
SUMMARY

CT and MRI are extremely valuable techniques that offer significant advantages over conventional radiographs and myelography. These techniques have allowed us to identify and characterize many spinal disorders. Our knowledge and ability to detect spinal disorders will continue to advance as these technologies evolve.

REFERENCES