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Introduction
For many small animals with suspected neurologic disease, conventional diagnostic radiography remains the preferred method of initial evaluation [1-13]. It is inexpensive, noninvasive, and readily available to most veterinary practitioners. However, radiographs significantly underestimate many abnormalities of the nervous system. The main limiting factors include superimposition of overlying structures, insufficient contrast resolution, and silhouetting by adjacent tissue or fluid of similar density. Contrast procedures such as myelography and alternate imaging techniques such as ultrasonography, computed tomography, and magnetic resonance imaging are much more sensitive for detecting pathology in the head and spine [14]. As alternate imaging techniques become increasingly available and less expensive, they are rapidly becoming the standard of care in veterinary neurology [8,9,15-25]. Neurodiagnostic techniques have been divided into the following categories:

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Conventional Diagnostic Radiography
Basic Principles and Techniques - Conventional diagnostic radiography is a technique in which images are exposed onto radiographic film using an x-ray tube [26-29]. Synonyms include plain, routine, or survey radiography. In conventional diagnostic radiography, x-rays are produced within the x-ray tube by the bombardment of a metal target with a stream of fast-moving electrons. Primary beam x-rays exit the tube, penetrate the patient and are differentially absorbed or transmitted by tissues. This differential absorption is affected primarily by x-ray beam energy and tissue properties such as relative tissue density, thickness, and atomic number. Scatter radiation is also produced during tissue interactions and does not contribute to the image. The scatter radiation is absorbed by a grid, which is positioned between the patient and the film cassette. X-rays that pass through the patient and the grid directly expose the radiographic film and also cause a flash of light from the intensifying screen within the film cassette. The light flash from the intensifying screen contributes to 95% of film exposure and thus reduces the radiation exposure needed for a diagnostic radiograph. Those tissues or structures within the patient that absorb most of the x-rays are termed radiopaque. Those that allow most of the x-rays to be transmitted are termed radiolucent. Five basic densities (from most radiolucent to most radiopaque) are recognized on x-ray film: gas, fat, soft tissue, mineral, and metal. Diagnostic sensitivity of radiographs is maximized by the use of good radiography equipment, film/screen combinations, technique charts, film processing techniques, and patient positioning [30,31]. Chemical restraint (heavy sedation or general anesthesia) is highly recommended to ensure accurate positioning. Radiolucent positioning sponges, tape, or gauze also help to achieve symmetrical positioning and minimize personnel exposure. The use of a small focal spot and large object-film distance (air gap) may be used to help magnify smaller structures of interest [32]. The areas of clinical concern should be centered in the x-ray beam in order to minimize geometric distortion and maximize spatial resolution.
The most commonly used radiographic views for the calvarium include lateral and dorsoventral projections [2,4,7,11,33,34]. To obtain true lateral positioning, padding is usually placed beneath the nose and neck. Dorsoventral views are obtained with the mandibles resting evenly on the cassette or table. The beam is centered on the midline between the eyes. Brachycephalic breeds may require more penetration than mesaticephalic or dolichocephalic breeds. Open-mouth and oblique projections are added as needed to improve visualization of the nasal cavity, frontal sinuses, tympanic bullae, calvarium, and foramen magnum. The open mouth ventrodorsal view is obtained with the patient placed in dorsal recumbency.

The mouth is held open with a speculum or gauze tied to the mandibular canine teeth. The x-ray tube is angled approximately 24 - 30 degrees caudally and the central beam is positioned in the midline at the level of the fourth maxillary premolar. The endotracheal tube is removed or pulled to the side with gauze. The open-mouth rostrocaudal projection is performed with the patient in dorsal recumbency and the mouth held open with a speculum or gauze (Fig 1). The hard palate is tipped cranially, 3 - 12 degrees from vertical. Higher degrees of angulation are needed for brachycephalic breeds. The central beam is positioned in the midline at the back of the throat. The endotracheal tube is removed or tied to the mandible in the center of the mouth. The frontal sinus view is obtained with the patient in dorsal recumbency and the neck slightly flexed so that the occipital condyles rest on the cassette or table. Once the patient is positioned, the beam is angled parallel to the nose. The calvarium and foramen magnum may be demonstrated in a 24 - 40 degree, closed mouth, rostrocaudal oblique projection. Lateral oblique and open-mouth, rostrocaudal projections are very helpful for visualizing the tympanic bullae. Lateral oblique views are obtained by positioning the patient in lateral recumbency, with the bulla of interest closest to the film. The bulla is projected ventrally by placing a wedge sponge beneath the mandible. Views of the opposite bulla are recommended for comparison purposes.

The most commonly used views for the spine are lateral and ventrodorsal projections [1,3,6,8,10,33]. For lateral views of the spine, rectangular foam or gauze pads are placed beneath the neck, a wedge sponge is placed beneath the nose and sternum, and a rectangular sponge is placed between the hindlegs. A weighted positioning sponge is used as needed to reduce curvature of the thoracolumbar spine. Forelimbs are pulled caudally for cervical spinal views and cranially for all thoracic spinal views. Hindlimbs are extended caudally for lateral views of the lumbar spine. For ventrodorsal views, sandbags or weighted positioning devices are placed on either side of the shoulders. The head is elevated slightly using a thin rectangular foam pad or roll cotton. The hindlimbs may be flexed in a frogleg position, with wedge sponges supporting the stifle joints. Hindlimbs may also be extended, with the stifle joints elevated slightly to minimize lumbar lordosis. The central x-ray beam should be placed in the center of each spinal region of interest in order to minimize geometric distortion. Recently, a concave radiographic table was developed that allows radiography of the entire canine spine without the associated anatomic distortion [5]. Suspected vertebral instability may be assessed using flexed and extended lateral views. The lateral oblique and open-mouth rostrocaudal views are helpful for improving visualization of the C2 odontoid process. The lateral oblique view is obtained by placing a wedge sponge beneath the caudal mandible and ventral neck regions. The odontoid process may be seen between the offset wings of the atlas. The open-mouth rostrocaudal view is obtained using positioning similar to that described for the tympanic bullae. The odontoid process is positioned in the space between the bulla.

The endotracheal tube may need to be removed. Horizontal beam radiography can be used to obtain orthogonal views in animals with suspected spinal fractures or luxations. The patient is taped securely in lateral recumbency on a body board or stretcher, then placed on a thick foam pad that has been positioned on the x-ray table. Lateral views are obtained using standard techniques, with an increase of approximately 10 percent kVp to compensate for the stretcher and foam pad. Ventrodorsal views of the region of interest are obtained by rotating the x-ray tube 90 degrees and centering the x-ray beam on the midline of the body. Image-intensified fluoroscopy may be used in conjunction with routine radiography to diagnose suspected atlanto-occipital or inter-vertebral instability [29]. It may also be used to guide placement of spinal contrast agents and to guide collection of tissue samples for cytology and culture/sensitivity [35].

Normal Findings

**Brain** - The brain is not normally visible in plain radiographs, due to superimposition of overlying bone. The calvarium (cranial vault), which houses the brain, consists of 14 bones joined by sutures [36,37]. The calvarium is smoothly marginated, with swirling convolutions on the dorsal and lateral surfaces. The cribiform plate is visible as a rostrally convex, curvilinear, bone opacity between the calvarium and the caudal nasal cavity. Open fontanelles may be visible in the dorsal calvarium in immature animals. Small breed dogs and cats have a more domed shape to the dorsal calvarium, and frontal sinuses may be poorly developed. The walls of the calvarium also appear thinner than those seen in large breed dogs.

**Spine** - The spinal cord and nerve roots are not normally visible in plain radiographs. The spinous process of C2 should be adjacent to or overlap the lamina of C1 (Fig 2). The cervical articular processes are superimposed over the intervertebral foramina and vertebral canal in the lateral view. The C6 transverse process is large and projects ventral to the vertebral body (Fig 3).
Slight enlargements of the C5-T2 and L2-5 spinal canal occur where the brachial and pelvic nerve roots arise. There are normally narrowed intervertebral disk spaces at C7-T1, T10-11, and T11-12. A mild loss of definition of the ventral margin of L4 may be due to the muscular attachments of the diaphragm [38]. The ventral portion of the L7-S1 intervertebral disk space is often wider than the dorsal portion. The lumbosacral angle varies widely among individuals and is easily changed with flexion or extension of the spine. The dorsal margins of the sacrum and L7 vertebra should remain aligned, with no step defect. The hemal arches of the caudal vertebrae are visible as triangular or linear opacities ventral to the vertebral bodies in the lateral view. Use of a long scale of contrast, presence of a relatively high percentage of scatter radiation, and patient obesity may create an apparent decrease in vertebral opacity [39]. An artifactual increase in vertebral opacity may be caused by underexposure or use of a short scale of contrast (kVp too low).

Clinical Applications

**Brain** - Because the brain is not visible in plain radiographs, diseases of the brain must be inferred from secondary changes in the skull. Calvarial enlargement, increased doming, or thinning of the bony wall are radiographic signs of congenital or acquired hydrocephalus [40] (Fig 4). There may also be decreased visualization of the normal convolutions. The severity of distortion depends on the rate of fluid accumulation, severity of ventricular enlargement, and the stage of ossification at the onset of disease. Enlargement of the foramen magnum is a characteristic of occipital dysplasia [41-43] (Fig 5).

One morphometric study of occipital dysplasia concluded that the malformation is likely to be an incidental finding, especially in the Pekingese dog [43]. Another study concluded that more severe forms of this malformation may be associated with hydrocephalus or partial herniation of the cerebellum through the foramen magnum [42]. Signs of this complication may include occipito-cervical pain, personality changes, scratching of one ear, protrusion of the tongue, dysphagia, ataxia, or convulsions. Neoplasms of the calvarium may cause invasion or compression of adjacent brain tissue. Lesions may be either osteolytic or osteoblastic. Most osteosarcomas of the cranial vault are osteoblastic, with regular well-defined borders and evenly distributed granular calcific densities [44]. Multilobular tumors of bone appear as lobulated, mixed soft tissue and bone opacity masses, which may or may not be locally invasive [45]. Synonyms include osteochondroma, osteochondrosarcoma, or chondroma rodens. In some cats, intracranial meningioma may be visible as a focal calcification or thickening of the calvarium [46] (Fig 6).
Middle ear disease may cause neurologic dysfunction if it extends medially to the inner ear and causes inflammation of the vestibulocochlear nerve. Radiographic characteristics of middle ear disease include an increase in opacity of the affected bulla and associated thickening of the ventral bulla wall [47] (Fig. 7).

In severe cases, the affected bulla may be expanded. With neoplastic disease there may also be lysis of the petrous temporal bone and invasion of the cranial vault. However, one study found that 25 percent of dogs with surgically confirmed middle ear disease had negative radiographs [48]. Skull fractures may be associated with brain compression due to displaced fragments, or hematomas. Fractures are visible as radiolucent lines within the calvarium, which may or may not be associated with normal suture lines [49]. A step defect is visible when there is malalignment of the fracture fragments. Intracranial gas may be seen if there is a communication with the skin surface, nasal cavity or paranasal sinuses.

Spine - Survey radiography can be helpful for identifying chronic disc degeneration and some sites of disc herniation, but it does not have a high enough diagnostic sensitivity for surgical planning [50,51]. In one study of 64 dogs with surgically confirmed intervertebral disc protrusion, accuracy for detecting sites of intervertebral disc protrusion from survey radiographs was in the range of 51 - 61%. In type I disk disease, radiographs may demonstrate a focal mineral opacity in the vertebral canal or intervertebral foramen, narrowing or wedging of the intervertebral disk space, narrowing of the articular process joint space, or a decreased size of the intervertebral foramen [10,20,50] (Fig 8a and Fig 8b). Some type I disc calcifications are asymptomatic and have been seen to undergo spontaneous resorption in sequential radiographs [52]. Radiographic signs of type II disk degeneration and protrusion include narrowing of the disk space, sclerosis of the vertebral endplates, spondylosis deformans, Schmorl’s nodes, vacuum phenomenon or articular process osteoarthritis [51] (Fig 9). Early spondylosis may appear as faint bone spurs on the margins of the endplates [53,54].
Later on, the bone spurs may form a solid bridge across the intervertebral disk space. When the spondylosis forms ventrally and laterally, it does not cause nerve compression. When the spondylosis forms dorsally or dorsolaterally, it may cause stenosis of the vertebral canal or intervertebral foramina. Schmorl’s nodes are intravertebral disc herniations that appear as discretely marginated lucencies surrounded by a rim of sclerosis in vertebral endplates [55]. Degenerative or developmental weakening of the vertebral endplate is believed to be a predisposing factor. Vacuum phenomenon is a focal gas opacity occurring within the intervertebral disc or articular process joint space [51]. It is believed to be caused when traction forces pull nitrogen gas through cartilage clefts. Radiographic signs of articular process osteoarthritis include periarticular osteophyte formation, narrowed joint spaces, malalignment, subchondral sclerosis, or facet hypertrophy.

Radiographic signs of atlanto-axial malformation/malarticulation include blunting or absence of the odontoid process, craniodorsal displacement of C2 relative to C1, and widening of the C1-2 interlaminar space [56] (Fig. 10).

Cervical vertebral malformation/malformation in large breed dogs is most often characterized radiographically by alteration in vertebral body shape, alteration in articular process shape, subluxation, and apparent stenosis of the vertebral canal [57-59]. Cervical spinal stenosis has been quantified from lateral radiographs in Doberman Pinschers and Great Danes using ratios of vertebral canal/vertebral body height or ratios of vertebral canal/vertebral body length [60]. Block vertebra are evident as absence of visualization of the articular process joint or intervertebral disk spaces [61,62]. Depending on the portion of the vertebra that fails to form, a hemivertebra may be wedge-shaped with the base oriented dorsally, ventrally, or medially (Fig 11). Neurologic dysfunction may occur when there is concurrent spinal stenosis, progressive spinal angulation with aging, or instability

Ribs may be absent or hypoplastic at T13. This should be noted to avoid miscounts of vertebral levels at surgery. Vertebral osteochondromas or multiple cartilaginous exostoses appear as smoothly-marginated, mixed soft tissue and bone opacity masses. They may cause neurologic dysfunction due to spinal canal encroachment. Spina bifida is visible as an absence of spinous processes, or as a triangular or linear lucency in the vertebral lamina. This problem may be associated with other vertebral and neural anomalies, especially in Bulldogs and Manx cats [63] transitional lumbar sacral vertebrae may appear as a caudal L7 vertebra with sacral characteristics (sacralization) or as sacral vertebrae with lumbar characteristics (lumbarization) [64]. Transitional lumbar sacral vertebrae, in combination with degenerative disk disease, are predisposing factors for cauda equina syndrome in German Shepherd dogs [65]. One theory is that abnormal sacroiliac articulations may cause premature disk degeneration

Hypervitaminosis A in the cat may be seen radiographically as irregular bone proliferation involving the ventral aspects of the caudal cervical and cranial thoracic vertebrae [66]. Feline mucopolysaccharidosis may cause partial fusion of cervical or lumbar vertebrae, irregularly shortened or misshapen vertebrae, widened intervertebral disk spaces, or an apparently widened spine [67]. Hyperparathyroidism is often characterized by a generalized decrease in bone density, with compression fractures of the vertebral bodies [68]. Vertebral neoplasms may be osteolytic, osteoblastic or both [23]. When there is extensive focal osteolysis, a compression fracture may be evident (Fig 12a and Fig 12b)
A paraspinal soft tissue mass may be visible adjacent to the affected vertebra. Focal enlargement of the spinal canal or intervertebral foramen can be found with slow-growing neoplasms of the nervous tissues. Focal vertebral osteolysis and osteoproliferation may also be seen with vertebral osteomyelitis [69]. Osteomyelitis may originate within the vertebral body (spondylitis), physis (physitis) or disc space (discospondylitis). Causes for vertebral osteomyelitis include migrating plant foreign bodies, aspergillosis, or bacterial infections. In spondylitis, the bony changes are most commonly centered within the vertebral body, and may involve several adjacent vertebrae. In physitis, the caudal vertebral physis appears widened and irregular. The caudal vertebral endplate may become sequestered and surrounded by an involucrum. In diskospondylitis, bone lysis and proliferation are most often seen in adjacent endplates [70,71] (Fig 13).

![Figure 13. Lateral spine radiograph of a dog with lumbosacral discospondylitis. There is widening of the intervertebral disk space with loss of definition of the caudal L7 and cranial sacral endplate margins. - To view this image in full size go to the IVIS website at www.ivis.org . -](image)

The severity of the bone lesions correlates with the time elapsed from the onset of clinical signs. After initiation of appropriate antibiotic therapy, complete resolution of clinical disease usually takes a minimum of 6 weeks. Complete radiographic recovery of diskospondylitis lesions (fusion or bridging of involved vertebrae) may take longer. These endplate lesions need to be differentiated from Schmorl’s nodes, which are more likely to be related to degenerative or developmental disease of the vertebral endplates [55]. Schmorl’s nodes would also be less likely to progress over time than diskospondylitis lesions. Fluoroscopically guided percutaneous aspirates of radiographically suspect discs may help differentiate infectious from non-infectious causes of endplate lysis [35].

Radiographic signs of vertebral trauma include changes in shape, opacity, margination, angulation or alignment [10,72]. Vertebral bodies may appear shortened or exhibit a triangular or trapezoidal shape. Fracture fragments may be visible as irregular bone opacities adjacent to the fracture site. Abrupt changes in spinal angulation may be associated with articular process luxation, compression fractures, or severe muscle spasms. Malalignment is visible as an abrupt change in the vertebral canal margin (step defect). Orthogonal views are very important, because malalignment may be apparent in only one plane (Fig. 14a and Fig. 14b).

![Figure 14a. Lateral spine radiographs of a dog with traumatic vertebral subluxation. The lateral view demonstrates severe dorsal displacement and caudal angulation of L6 relative to L5. This displacement is not apparent in the ventrodorsal radiograph. - To view this image in full size go to the IVIS website at www.ivis.org . -](image)

![Figure 14b. Ventrodorsal spine radiographs of a dog with traumatic vertebral subluxation. The lateral view demonstrates severe dorsal displacement and caudal angulation of L6 relative to L5. This displacement is not apparent in the ventrodorsal radiograph. - To view this image in full size go to the IVIS website at www.ivis.org . -](image)

It is often helpful to hold the radiograph at an angle to the viewbox and look along the vertebral column to detect more subtle malalignments [12]. Dynamic vertebral subluxation may be demonstrated by comparing views obtained during flexion versus those obtained during extension [73]. Dogs with dens dysgenesis or cervical vertebral malformation/malarticulation may be predisposed to vertebral subluxation or disc herniation following relatively minor trauma [56,58].

**Myelography**

*Basic Principles and Techniques* - Myelography is a radiographic examination that is performed after injection of an iodine-based contrast agent into the spinal subarachnoid space [26,74,75]. Commonly used myelographic contrast agents include iohexol and iopamidol. These non-ionic, isotonic contrast agents are preferred for myelography due to their lower incidence of adverse reactions [76]. Reversible asystole has been reported in one dog immediately following injection of iohexol injection, however the most common adverse reactions associated with myelography are temporary worsening of clinical signs and seizures [77-79]. Complications are less commonly seen in cats than dogs [80]. Neurologic abnormalities are more pronounced the day after myelography in dogs with caudal cervical spondylomyelopathy, meningitis, and extradural tumors [79]. Seizures are also more commonly seen post-myelography in large dogs, especially those with caudal cervical spondylomyelopathy [78,79]. The contrast agent is injected into the subarachnoid space via the cisterna magna or the lower lumbar spine at a
dose of 0.3 - 0.45 ml/kg. The risk of seizures is higher with cisterna magna injections, therefore we prefer lumbar injections at our hospital [78]. For both techniques, a 22 - 20 gauge spinal needle with stylet is used to minimize any damage caused by inadvertently piercing spinal cord tissue. For cisterna magna injection, the head is held in flexion and the needle is slowly introduced into the atlanto-occipital space. For lumbar injection, the hindlimbs are positioned in flexion and the needle is introduced into the L4-5 or L5-6 interlaminar space. The tip of the needle is most often positioned in the ventral portion of the lumbar subarachnoid space in order to minimize the risk of intramedullary injection. Because the needle penetrates the terminal portion of the spinal cord, care should be taken to minimize angular movement of the needle once it is in place. The bevel should be oriented cranially and the stylet removed to assess flow of CSF. Correct needle placement may be confirmed using a test injection of a small dose of contrast and image-intensified fluoroscopy (Fig. 15). A pre-injection radiograph may also be obtained to assess needle position. Contrast injection is performed through a pre-filled, flexible extension tube in order to minimize needle movement. Lateral radiographs are obtained following contrast injection, while the needle remains in place. The needle is then removed for ventrodorsal views. Oblique and dynamic views are obtained as needed to clarify a suspected compressive lesion.

Common myelographic artifacts include air bubbles, gravity filling defects, central canalogram, subdural injection, and epidural leakage. Air bubbles may cause oval or oblong filling defects in the subarachnoid space. Gravity may cause a regional decrease in subarachnoid filling. This is especially a problem in the cranial thoracic and thoracolumbar spine. It may be necessary to elevate the cranial and caudal portions of the spine to achieve filling in these regions [81]. The central spinal canal may be opacified (canalogram) due to iatrogenic injection of contrast agent into the central canal or due to a communication with the lumbar subarachnoid space. Contrast medium injected into the subdural space may cause an apparently widened dorsal column, with the ventral margin of the pooled contrast medium exhibiting a wavy or undulating shape [82]. The epidural space may also be inadvertently opacified when there is leakage of contrast outside the subarachnoid space (Fig. 16a and Fig. 16b).

Normal Findings
- The spinal cord ends caudal to L6 in cats and small breed dogs [36]. The cord ends cranial to L6 in large breed dogs. The spinal subarachnoid space begins at the foramen magnum, and ends at the filum terminale. It is continuous with the intracranial subarachnoid space. The normal myelogram is characterized by discrete, thin columns of contrast medium that are nearly parallel. Exceptions to this rule may be seen in caudal cervical and caudal lumbar regions. In these locations, the myelographic columns may diverge slightly at the levels of the cervical and lumbar intumescences. Normal cervical spinal diameters have been described for dogs [84]. Columns converge to a tapering point in the region of the conus medullaris. Small-breed dogs and cats have relatively large cords and relatively thin contrast columns [84]. The dorsal, ventral, and lateral columns should be of similar size at a given vertebral location. Exceptions to this rule may be seen in the cranial cervical, thoracolumbar and lumbosacral regions. The ventral subarachnoid space is normally narrower than the dorsal subarachnoid space at C2-3 [85]. The dorsal subarachnoid space is normally wider than the ventral in the thoracolumbar region. The ventral subarachnoid space is normally wider than the dorsal subarachnoid space in the lumbosacral region. The spinal cord may appear to be deviated dorsally in the caudal cervical and caudal lumbar regions, due to a relative increase in size of the ventral epidural space. The position of the dural end sac may be highly variable, depending on breed and the position of the hind legs [86,87]. Tortuous, curvilinear subarachnoid filling defects in the cranial cervical region are caused by the basivertebral artery and its branches. Caudally-oriented, linear filling defects in the lumbar subarachnoid space are caused by intradural nerve roots. Normal myelographic columns do not rule out spinal cord disease. Normal findings may be associated with spinal cord atrophy, fibrocartilaginous emboli, myelitis, or meningitis [88]. Lumbosacral stenosis may also be present with a normal myelogram [89].

Clinical Applications - Myelography is indicated when:

1. There is absence of a spinal lesion on routine radiographs,
2. The lesion seen on routine radiographs does not correlate with the clinical signs,
3. Multiple lesions are seen on routine radiographs,
4. More precise localization of a lesion is needed for surgical planning,
5. More information on extent of involvement is needed for establishing a prognosis, or
6. The diagnosis of a neurologic disorder is established by absence of myelographic evidence of spinal cord compression (e.g., degenerative myelopathy) [74,88,90].
Some people consider CSF evidence of infectious disease to be a contraindication for myelography. Myelographic patterns of compression are classified as extradural, intramedullary, or intradural/extramedullary. Extradural compression is characterized by thinning and convergence of contrast columns (Fig. 17). Differential diagnoses for extradural compression include intervertebral disk herniation, ligamentous hypertrophy, epidural hematoma/hemorrhage, epidural or vertebral neoplasm, spinal stenosis, or vertebral subluxation/luxation.

Intervertebral disk protrusion or herniation is one of the most common causes of extradural spinal cord compression, especially in chondrodystrophic dogs [50,91]. The myelographic contrast columns are deviated away from the site of disk herniation. Myelography is more sensitive than routine radiography for identifying the site(s) of disk protrusion [92,93]. When the disk protrusion is focal and either central or laterally positioned, the ventral contrast column may appear split [94,95]. Obtaining both right and left lateral views helps increase the probability of visualizing this abnormality [96]. Severe, chronic disk herniations may only exhibit mild deviation or narrowing of myelographic contrast columns. One possible reason for this is that chronic compression causes spinal cord atrophy, which in turn causes a relative increase in the size of the adjacent epidural space. It is the author's opinion that even mild narrowing of the myelographic contrast columns should be considered clinically significant when there is a localized decrease in spinal cord diameter.

In dogs with cervical vertebral malformation-malarticulation (wobbler) syndrome or cervical spondylomyelopathy, myelographic evidence of spinal cord compression may worsen with spinal extension and improve with spinal flexion or traction (Fig 18a and Fig 18b). Convergence of the contrast columns in both orthogonal views (hourglass appearance) may indicate concurrent spinal stenosis, hypertrophy of the ligamentum flavum or joint capsule proliferation.

Extradural neoplasms are more commonly centered at the mid-body of the vertebra. There may also be bone lysis on the side of the tumor or a paraspinal mass. Congenital spinal stenosis may cause segmental extradural compression in the canine thoracic or lumbosacral spine [61]. The dye columns may converge gradually or abruptly, depending on whether the stenosis is due to a uniformly small vertebral canal or to bulbous articular process joints. Because of the tapering shape of the caudal dural sac, myelography may underestimate lumbosacral canal stenosis in some dogs [97]. Spinal stenosis may occur as a separate entity or concurrently with vertebral anomalies such as hemivertebrae, or block vertebrae. Diskospondylitis may be associated with extradural compression in some dogs. In one recent study, the severity of myelographic compression did not correlate with severity of neurologic dysfunction [98].

Intramedullary compression is characterized by narrowing and divergence of contrast columns. Differential diagnoses include spinal cord edema, contusion, neoplasia, syringomyelia, hydromyelia, or granuloma. Acute type I disk herniation may cause a regional loss of myelographic filling due to spinal cord edema (swelling). Myelographic evidence of cord swelling was correlated with neurological outcome in a study of 46 dogs with intervertebral disk disease and absence of deep pain perception (DPP) [99]. Using a swelling L2 ratio of 5.0 as a cutoff for indication of neurological recovery yielded a sensitivity of 74% and a specificity of 61%. Overall neurological recovery rate was 43%. Intramedullary tumors may cause divergence and thinning of myelographic contrast columns in all views. Syringomyelia and hydromyelia may be distinguishable if there is a communication between the subarachnoid space and the central canal. Focal accumulations of contrast material will be visible within the spinal cord parenchyma. Other differentials for central spinal cord opacification include hematomyelia or myelomalacia [100]. Intradural/extramedullary compression is characterized by focal widening of the subarachnoid space, with or without an intraluminal filling defect. Intradural/extramedullary compression may be caused by subarachnoid cysts, intradural disk herniations, granulomas or neoplasms [101-103]. Myelography has been found Ultrasonography to be more sensitive than plain CT for identifying intradural/extramedullary tumors in dogs [104].

Ultrasonography

Basic Principles and Techniques - Ultrasonography is an imaging technique that uses high frequency sound waves to visualize internal structures [105,106]. The sound waves are propagated from specially constructed ceramic materials called piezoelectric crystals. Real-time, B-mode imaging refers to the use of pulsed ultrasonography to obtain moving images of structures in grey scale. Images are constructed from returning echoes and continuously updated on the computer monitor by digital computer reconstruction. The brightness of the imaged
structure is proportional to the strength of the returning echo. White structures are termed hyperechoic, grey structures are termed hypoechoic, and black structures are termed anechoic. The sound waves are both generated and received using a transducer or probe. Transducers are available in a variety of shapes and frequencies. The higher frequencies yield higher spatial resolution, but may not penetrate deeply enough in larger animals. Color flow Doppler ultrasonography and Doppler spectral analysis are used in conjunction with B-mode ultrasonography to evaluate blood flow. Color Doppler ultrasonography is performed first to determine the location of blood vessels. Blood flow is visible as areas of red, blue, yellow, or white on the ultrasound monitor. Electronic cursors may be placed within the lumen of vessels of interest to quantify blood flow velocity used Doppler spectral analysis. Velocity values are highest and the accuracy of the calculation is greatest when the angle of the ultrasound beam is parallel to the direction of blood flow.

Commonly encountered ultrasonographic artifacts include:

1. Refraction,
2. Reverberation,
3. Beam intensity, and
4. Beam thickness [105].

Refraction artifacts occur when there is a mismatch between ultrasound beam propagation speed and angle of inclination. These artifacts may cause surfaces in the far field to be erroneously placed within the center of the image. Reverberation artifacts are time-related and create repetitive images of structures. Beam intensity artifacts are created by either total reflection or total transmission of beam intensity. These cause either a shadow deep to the reflection (acoustic shadowing) or an increased intensity of echoes deep to the transmission (far enhancement). Beam thickness artifacts are created by the inclusion of both the wall and the lumen in the same image. This creates the false appearance of an intraluminal object. Beam thickness artifacts are caused by the false assumption by the receiver that the beam is infinitely thin.

The brain can be imaged through craniotomy defects, open fontanelles or some of the larger neural foramina [17,105,107]. Some animals have sufficiently thin bone in the temporal region to allow transcranial imaging without a craniotomy defect. For most small animals, transducer frequencies between 7 and 12 MHz usually provide diagnostic quality images. Imaging through the temporal bone may require the use of lower frequency probes, with some associated decrease in spatial resolution. Midline structures can be imaged using linear array, curvilinear, or sector transducers. Sector or curvilinear transducers are best for imaging peripheral structures. To image the brain through an open bregmatic (dorsal midline) fontanelle, the probe is placed over the fontanelle in an oblique transverse orientation. Images can be obtained in a rostrocaudal direction using a "windshield wiper" motion. The probe is then rotated 90 degrees to obtain parasagittal images. To image the brain intraoperatively, the probe head and ultrasonic gel are placed in gas-sterilized plastic wrap. Sterile elastic bandaging material is used to wrap the probe stem and cord. Sterile physiologic saline is used to fill the craniotomy defect and provide an acoustic window for viewing brain tissues.

The spinal cord can be imaged through laminectomy defects, intervertebral foramina, noncalcified intervertebral disks, or defects caused by spina bifida [17,105]. Articular processes may need to be removed to evaluate dorsal root ganglia or nerve roots within the lateral recesses or intervertebral foramina. The small size of the spinal cord requires the use of a high frequency transducer (7.5-12.0 MHz). For intraoperative ultrasonography of the spine, the probe and acoustic gel are placed in a sterile glove or plastic wrap, similar to the method described for intraoperative ultrasonography of the brain. Acoustic coupling is also performed by filling the surgical defect with sterile physiologic saline solution. Color flow Doppler ultrasonography and Doppler spectral analysis have been used to assess locations and flow velocities of spinal cord and nerve root blood vessels. The central spinal arterial system may be evaluated through a dorsolateral laminectomy defect [108]. The probe is oriented sagittally and angled 30 - 45 degrees from a plane perpendicular to the spinal cord. The dorsal root ganglion arteries may be evaluated through dorsolateral laminectomy and facetectomy defects [109]. The probe is oriented parasagittally, and angled caudolaterally.

**Normal Findings**

*Brain* - Normally visible brain structures include the falx cerebri, splenial sulci, cingulate gyrus, callosal sulci, lateral ventricles, third ventricle, caudate nucleus, thalamus, hippocampus, cerebellum, and osseous tentorium [17]. The gyri and sulci in neonatal brains are less well developed than those of mature brains. The hippocampus is less clearly seen in neonatal brains versus adult brains. In mid-transverse images of the brain, the paired splenial sulci and the longitudinal fissure appear as a hyperechoic (white) umbrella-like structure in the dorsal portion of the brain. The handle of the umbrella is made up of structures within the callosal sulcus. The corpus callosum appears as a hyperechoic horizontally oriented structure. In rostral transverse images, the superficial portions of the caudate nuclei appear as paired, oval, hyperechoic structures ventromedial to the lateral ventricles. The lateral ventricles are gull-wing shaped anechoic (black) structures. These may be difficult to see when there is insufficient CSF present. In one study, the mean height of the normal canine lateral ventricles, measured in transverse images at the level of the interthalamic adhesion, was 1.5 mm [110]. In the caudally oriented transverse images, the choroid plexus may be visible as a hyperechoic area in the floor of each lateral ventricle. Asymmetry between the lateral ventricles is common. The pyriform lobes are hyperechoic structures located ventrally on the floor of the cranium. In neonatal animals, the tentorium cerebelli, cerebellum, and medulla may be visible in the most caudal images. The tentorium cerebelli forms an inverted, hyperechoic, V-shaped structure. Deep to the tentorium, a stack of horizontal hyperechoic lines represents the vermis of the cerebellum. The cerebellar lobes appear as paired hyperechoic structures on either side of the vermis.

*Spine* - The spinal meninges are hyperechoic, the subarachnoid space is anechoic, and the spinal cord is homogeneously hyperechoic [108]. In some normal dogs, focal hyperechoic areas or linear echoes may also be seen within the spinal cord parenchyma. These may be caused by small intraparenchymal vessels. There is no differentiation between white and grey matter. Single or double linear echoes within the center of
the spinal cord are associated with the central canal. The epidural space ventral to the spinal cord contains lobular echoes, presumably related to fat and connective tissue. The bony vertebral margin appears as a very bright, smooth echo with deep acoustic shadowing.

Clinical Applications -

Brain - The most common application for brain ultrasonography is to determine the size of lateral ventricles in small breed dogs with suspected hydrocephalus [17,105]. Lateral ventricular enlargement is considered to be present when the mean height exceeds 0.35 cm [110] (Fig. 19). However, there is a poor correlation between ventricular size and severity of clinical signs. The second most common application is to evaluate the brain in animals with suspected intracranial neoplasia. Intraoperative ultrasonography may be used to guide surgical biopsy or excision of intracranial masses (Fig. 20).

Figure 19. Transverse ultrasonographic image of a dog with hydrocephalus. There is severe enlargement of both lateral ventricles. (Courtesy Dr. Martha Moon Larson, Virginia Tech). - To view this image in full size go to the IVIS website at www.ivis.org . -

![Figure 19](https://www.ivis.org)

Figure 20. Sagittal, intraoperative ultrasonographic image of a dog with cerebral meningioma. The mass is hyperechoic relative to normal brain parenchyma. The zone of decreased echogenicity surrounding the mass is caused by edema. (Courtesy Dr. Martha Moon Larson, Virginia Tech). - To view this image in full size go to the IVIS website at www.ivis.org . -

The size of a biopsied mass may be monitored after radiation or chemotherapy. The site of a surgically excised mass can be monitored over time to assess tumor regrowth. Most neoplasms appear hyperechoic [111]. A technique for ultrasound-guided biopsy has been developed for use in dogs [112]. In this technique, the ultrasound probe is used to mark the biopsy site, then a needle guide is attached to the probe. The needle guide is adjusted to allow the needle to intersect the marked biopsy location. An incision is made in the dura to allow introduction of the biopsy needle into the brain mass. Ultrasonography may also be used to guide drainage of intracranial abscesses [17]. The sonographic appearance of arachnoid cysts have been recently described in a study of 3 dogs [113]. Acoustical windows successfully used were: persistent bregmatic fontanelle, temporal window, foramen magnum. Cysts appeared as well defined, anechoic triangular areas lying between the caudal cerebral hemispheres, dorsal to the midbrain, and rostral to the cerebellum.

Spine - Common applications for ultrasonography of the spine include suspected retention of disk fragments, myelomalacia, intraparenchymal neoplasia, recurrent dural or spinal cyst [17]. Intraparenchymal hemorrhage appears as focal hyperechoic regions within the spinal cord. Retained intervertebral disk fragments appear as irregular hyperechoic foci, with or without acoustic shadowing, within the epidural space [111]. The adjacent spinal cord may appear compressed. Spinal or arachnoid cysts appear as discrete anechoic lesions [114]. Most spinal neoplasms appear hyperechoic. There may be associated swelling of the spinal cord, with disruption or loss of the central canal linear echoes. Serial examinations may be helpful for differentiating neoplasia from intraparenchymal hemorrhage.

Computed Tomography

Basic Principles and Techniques - Computed tomography (CT) is a digital imaging technique that uses x-ray energy and computer processing to make cross-sectional (transverse) images of structures [106,115,116]. The x-ray tube is housed within a ring-shaped structure called the gantry (Fig. 21).

Figure 21. Photograph of a CT scanner, demonstrating the patient table and gantry. - To view this image in full size go to the IVIS website at www.ivis.org . -

![Figure 21](https://www.ivis.org)

A motorized table advances the patient through the gantry for each slice. Slices are made when the x-ray tube rotates in a circle around the patient. The energy of transmitted x-rays is recorded opposite the patient by detectors. Detectors convert the x-ray energy to an electrical signal. Each slice is divided into a matrix of cubes (voxels). A computer converts the electrical signal associated with each cube of tissue into numerical (digital) data. These data are referred to as CT numbers. They are units of density relative to water and are expressed in Hounsfield units (HU). Mean CT numbers are calculated for each cube of tissue and displayed as greyscale picture elements (pixels) on the viewing monitor. White is assigned to pixels with higher CT numbers (e.g., bone). Varying shades of grey are assigned to pixels with intermediate CT numbers (e.g., soft tissues, fat and fluid). Black is assigned to pixels with lower CT numbers (e.g., lung, air-filled organs). The higher the number of pixels per unit volume of tissue, the higher the spatial resolution. The main advantages of CT over radiography are the ability to detect more subtle tissue density differences than radiography, elimination of superimposition, the ability to adjust image data as needed to improve visualization of structures. Operators can adjust the contrast (window width) and brightness (window level) of images as needed to better see tissues of interest. Bony structures are usually viewed at window widths greater than +500. Soft tissue structures are usually viewed at window widths less than +500.

CT scanners are classified in generations, with the numbers based primarily on technologic advancements in x-ray tube movement and
3rd generation scanners are configured such that the x-ray tube and arc of detectors rotate together around the patient for each slice. 4th generation scanners have an x-ray tube that rotates around a stationary ring of detectors. Spiral (helical) CT scanners are the newest technology. With spiral scanning, the table moves continuously while the x-ray tube is rotating around the patient. This allows acquisition of all the volume data at one time, so that slice thickness can be altered retrospectively as needed. In spiral scanning, the table speed can be adjusted (pitch). The slower the table speed, the more samples are obtained per unit of tissue and the higher the image resolution. Extremely fast examination times are also possible (e.g., 30 seconds for a brain scan), but yield slightly lower image resolution.

A motorized patient table supports the patient in the center of the ring-shaped gantry opening. The maximum weight limit for most tables is 300 - 400 pounds. The table is incrementally advanced by the CT computer. This controls the slice thickness and intervals. The gantry houses the x-ray tube and detectors. The gantry can be tilted as needed to adjust angulation of the slices through the anatomic region of interest. A collimator, positioned between the x-ray tube and the patient, adjusts the thickness of beam. The detectors are positioned opposite the x-ray tube, so that they can record the amount of x-ray energy passing through the patient. The operator console of the CT computer controls the technique settings (kVp, mAs), slice thickness/interval, size of the area to be scanned (field size), size of the area to be displayed (image size), and the number of scans per slice. The CT computer processor creates the image from the numerical data. It also may be used to reformat the data in a set of CT images in order to view structures in the sagittal, dorsal, or oblique planes. Advanced computer processing techniques also allow three-dimensional reconstructions and selective color displays. Images are most commonly stored on x-ray film, using either a multi-format or laser camera. Digital image data are temporarily stored on the computer hard drive, then archived on tape cartridges or optical discs.

The most common CT artifacts are streak and partial volume artifacts. Streak artifacts appear as white or black lines that go across the CT image. Most are caused by errors in computer interpretation. Common kinds of streak artifacts include patient motion, density change, beam-hardening, and field of view. Patient motion causes parallel, blurred, white streaks in images. The streaks are oriented parallel to the direction of motion. Density change artifacts appear as bright white, sharp lines that radiate outward from a high density object (e.g., EKG lead, gunshot, bone plates). Beam hardening artifacts appear as black, blurred streaks across soft tissues adjacent to dense bone. This is especially a problem in the caudal fossa of the cranial vault (Fig. 22). Beam hardening artifacts are caused when dense bone differentially absorbs the lower energy portion of x-ray beam (e.g., cerebellum/brainstem).

Field-of-view artifacts appear as parallel, sharply marginated, white lines across the whole image. They are usually caused by a body part or wire being positioned outside of the scanner’s field of view. Partial volume artifacts appear as false areas of increased or decreased opacity in the image. They are caused by a voxel/pixel translation problem. The displayed greyscale is determined from an average density of tissues within a given slice. If high density and low density tissues are adjacent to each other and included in the same slice, the computer averages their density and displays the greyscale accordingly. Partial volume artifacts can be differentiated by looking at adjacent slices or re-scanning the area of concern using thinner slices. Other image quality factors include patient positioning, targeting, slice thickness, and scan speed [117]. It is important to make sure the anatomic region of interest is oriented perpendicular to the slice plane. Oblique positioning may cause a false positive diagnosis of anatomic asymmetry. Targeting is performed by choosing an image size that is limited to the region of interest (e.g., spine and paraspinal region). This allows the computer to enlarge the image and assign smaller pixels per unit area. Patients are placed under routine general anesthesia so that accurate positioning can be maximized and motion artifacts minimized.

For head imaging, we prefer sternal recumbency. The head is positioned within an extension cradle and adjusted as needed with foam sponges. The nose is slightly elevated such that the hard palate is parallel to the table surface. The endotracheal tube is taped to the extension cradle to avoid changes in head position as the table moves. Saphenous vein catheterization is preferred, but access to a cephalic vein catheter may be facilitated by positioning the forelimbs caudally. Lateral and ventrodorsal digital radiographs (pilot, scout image) of the region of interest are obtained with the CT scanner. Positioning is adjusted as needed and radiographs repeated. Transverse slices are posted on the final radiographs, with the cribriform plate as the first slice and the foramen magnum as the last slice. We use slice thicknesses of 2 mm for cats and small dogs, 4 mm for medium dogs, and 5 - 8 mm for large dogs. Image sizes range from 120 to 240 mm. Survey scans are first examined, then the scan is repeated immediately following a rapid intravenous injection of iodinated contrast medium at a dose of 400 mg I/kg.

We also prefer sternal recumbency for the cervical spine. Positioning sponges are used to elevate the neck and sternum so that the caudal cervical vertebrae are in line with the cranial cervical vertebrae. For the thoracic, lumbar, and lumbosacral regions we prefer dorsal recumbency in order to minimize breathing motion artifacts. CT examinations with single slice scanners are usually limited to 3 - 4 disk spaces to avoid excessive scan times and tube heating. Scanning of larger spinal regions is more feasible with spiral CT scanners. Cost is more of a limiting factor in this situation, as scans are usually charged based on the total number of slices. Contrast enhancement can be performed either with intrathecal (post-myelogram) or intravenous administration of iodinated contrast medium. We prefer post-myelogram CT for suspected compressive lesions in the cervical, thoracic, and cranial lumbar spine. For suspected lumbosacral compression (L5 - S3), we prefer intravenous contrast-enhanced CT.
Normal Findings

Brain - For a detailed identification of individual anatomic structures, the reader is referred to one of several published anatomic atlases [118-123]. In general, all normal paired structures should be symmetrical. Bony structures should be smoothly margined and well-defined. Cortical bone appears bright white and medullary bone exhibits varying shades of grey. The tentorium cerebelli may be calcified in some normal dogs [124]. Soft tissue structures are usually homogenous, with some variation in shades of grey caused by slight differences in tissue density (Fig. 23). To a limited extent, white matter can be distinguished from grey matter by a slightly lower density.

Figure 23. Transverse, post-contrast CT image of the middle fossa in a normal dog. Cerebral hemispheres are homogenous and symmetrical in shape. The white matter is slightly less opaque than the grey matter. The lateral ventricles appear as paired, linear lucencies. - To view this image in full size go to the IVIS website at www.ivis.org.

The ventricles of the brain appear slightly darker grey than brain parenchyma (hypodense), because the cerebrospinal fluid is approximately 2% less dense than brain tissue [120]. The fourth ventricle and its communication with the cerebellomedullary cistern help distinguish the cerebellum from the medulla. The position of the thalamus and interthalamic adhesion can be inferred from the relationship between the lateral and third ventricles. The intercerebral cistern helps delineate the region of the pituitary gland. Bony landmarks such as the dorsum sellae, hypophyseal fossa, and rostral clinoid process help in identifying the anatomic structures not distinguishable by their tissue density alone. After administration of intravenous contrast medium, there should be no focal enhancement within the normal brain parenchyma. The exception to this rule is the pituitary gland. This structure may enhance in normal animals, because there is no blood-brain barrier. A study of CT contrast enhancement dynamics in the normal canine pituitary gland demonstrated that peak enhancement occurs between 10-30 seconds after contrast injection [125]. Initially, the gland enhances intensely and uniformly. After 50 seconds, a rim enhancement effect may be seen. Enhancement may persist as long as 400 seconds. Venous structures of the normal brain (intracranial venous sinuses, parenchymal veins, choroid plexus, falx cerebri) may enhance after administration of contrast material (Fig. 24). The normal structures of the middle and inner ear are well-visualized with 1 mm CT slice thickness, wide window settings, and bone algorithm reconstruction [123].

Figure 24. Transverse, post-contrast CT image of the rostral fossa in a normal dog. The falx cerebri exhibits contrast enhancement due to the presence of multiple small veins. - To view this image in full size go to the IVIS website at www.ivis.org.

Spine - Spinal cord white matter is normally indistinguishable from grey matter in CT images [118,126,127]. Structures contained within the thecal sac are also indistinguishable in plain CT images, but become visible when CT is performed post-myelography [8]. The outer margins of the thecal sac and nerve roots are visible in plain CT images, because they are surrounded by a layer of epidural fat (Fig. 25a, Fig. 25b, Fig. 25c). Epidural fat is less dense than soft tissue, so it will usually appear darker grey than adjacent nervous structures.

Figure 25a. Transverse and sagittal CT images of the lumbosacral spine in a normal dog. Radiolucent epidural fat in the vertebral canal and intervertebral foramen allow discrimination of nerve tissues. - To view this image in full size go to the IVIS website at www.ivis.org.

Figure 25b. Transverse and sagittal CT images of the lumbosacral spine in a normal dog. Radiolucent epidural fat in the vertebral canal and intervertebral foramen allow discrimination of nerve tissues. - To view this image in full size go to the IVIS website at www.ivis.org.

Figure 25c. Transverse and sagittal CT images of the lumbosacral spine in a normal dog. Radiolucent epidural fat in the vertebral canal and intervertebral foramen allow discrimination of nerve tissues. - To view this image in full size go to the IVIS website at www.ivis.org.

The normal intervertebral disk is of uniform soft tissue opacity, with no visible distinction between the nucleus pulposus and annulus fibrosus. The shape of the normal disk conforms to the shape of the adjacent vertebral endplates. The disk cannot be distinguished from the adjacent ventral and dorsal longitudinal ligaments. The dorsal margin of the combined disk and dorsal longitudinal ligament should be relatively flat. Venous structures of the normal spinal canal (vertebral venous plexus, intervertebral veins) may enhance after administration of intravenous contrast material [128]. Cortical bone is well-visualized in CT images. It is normally of a uniformly high opacity, with smooth margins. Cancellous bone has a lacy or honeycomb appearance. Focal lucencies within the marrow of the vertebral body can be associated with fatty
degeneration in some older dogs. The articular process joint spaces are visible as thin, curvilinear lucencies between adjacent articular processes (Fig. 26).

Clinical Applications -

Brain - The most common veterinary applications for head CT include suspected intracranial neoplasia, nonneoplastic brain disease, or middle/inner disease. The general CT characteristics of brain disease include a visible mass; change in ventricular size, shape or position; deviation of the falx cerebri (falx shift), and focal change in brain opacity [15,18,20,22,24,117,129-131]. CT is more sensitive than MRI for acute hemorrhage, soft tissue calcification, and intracranial gas. CT is less sensitive than MRI for edema, infarcts, low grade masses, and caudal fossa masses. Administration of iodinated contrast medium intravenously helps improve visibility of many brain lesions. Contrast is administered using a rapid bolus injection of 800 mgI/kg. Focal accumulation of contrast medium in the brain parenchyma is a sensitive but not specific indicator of brain disease. Enhancement occurs in locations where there are venous sinuses, disruption of the blood brain barrier, damaged blood vessels, or malformed vessels (neovascularization). Because CT characteristics of brain lesions are not specific, cerebrospinal fluid analysis and brain biopsy are needed for a definitive diagnosis. New devices for minimally invasive, stereotactic, CT-guided biopsy of canine brain lesions have recently been developed [132-135]. New software features also allow CT dose planning for radiation therapy of intracranial masses [22,136] (Fig. 27a, Fig. 27b).

Common characteristics of intracranial neoplasms in dogs and cats have been documented, but some overlap exists [15,20,22]. Meningiomas are usually peripherally located (extra-axial), broad-based at the edge of the brain or on the midline, markedly enhancing, and are large at the onset of clinical signs (Fig. 28). A "dural tail" may also be present. This is a region of linear enhancement that is associated with thickening of the dura mater adjacent to the mass. Meningiomas may also contain focal calcifications or be associated with bone remodelling (Fig. 29). After complete surgical excision of meningiomas, mild contrast enhancement may be visible in the immediate post-operative period [137]. This is believed to be caused by granulation tissue and resolving hematomas. Progressive enhancement of the postoperative site over time warrants a high suspicion of tumor recurrence.

Gliomas tend to be centrally located (intra-axial), peripherally enhancing (ring enhancement), and surrounded by a zone of edema (Fig. 30). Choroid plexus papillomas are often located either within or adjacent to a ventricle, appear hyperdense relative to surrounding brain tissue, exhibit marked enhancement, and are associated with hydrocephalus (Fig. 31).
Figure 30. Post-contrast transverse CT image of a dog with cerebral glioma. There is an irregular, ring-enhancing mass in the left frontal lobe. The falx cerebri is displaced to the right. - To view this image in full size go to the IVIS website at www.ivis.org.

Figure 31. Post-contrast, transverse CT image of a dog with choroid plexus papilloma. There is a markedly enhancing, sharply-marginated mass in the floor of the left lateral ventricle. Moderate generalized ventricular dilatation is also evident. - To view this image in full size go to the IVIS website at www.ivis.org.

Pituitary macroadenomas and adenocarcinomas are most commonly located in the mid-ventral fossa of the cranial vault, displace the 3rd ventricle dorsally, enhance uniformly, and may exhibit a "mushroom cloud" shape (Fig. 32). New spiral CT techniques show promise for differentiating pituitary microadenomas based on changes in pituitary perfusion [125]. Metastatic neoplasia more commonly appears as multifocal regions of contrast enhancement, that may or may not be associated with ventricular displacement.

Figure 32. Post-contrast, transverse CT image of a dog with pituitary macroadenoma. There is a markedly-enhancing, sharply-marginated mass that is centered over the pituitary fossa. - To view this image in full size go to the IVIS website at www.ivis.org.

Hydrocephalus is evident as generalized or localized ventricular enlargement. Localized enlargement is more likely to be obstructive. Generalized enlargement is more likely to be nonobstructive. Asymmetry of the lateral ventricles may be indicative of obstructive hydrocephalus, but this finding has also been reported as a normal anatomic variant in some breeds. Edema may be visible as patchy areas of decreased opacity that are non-enhancing. Hemorrhage varies in opacity, depending on the duration [19]. Acute hemorrhage (24 - 72 hrs) appears as a region of increased opacity. Chronic (>72 hrs) hemorrhage usually exhibits a decreased opacity. Inflammatory brain disease may mimic neoplasia or hematomas in appearance [131]. There may be solitary or multifocal regions of contrast enhancement (Fig. 33).

Figure 33. Post-contrast, dorsal planar CT image of a dog with fungal encephalitis. Multiple, ill-defined regions of contrast enhancement are present in both frontal lobes. The falx cerebri is displaced to the right. - To view this image in full size go to the IVIS website at www.ivis.org.

Central vestibular disease may be underdiagnosed in CT images, due to beam hardening artifacts in the caudal fossa. However, CT is very sensitive for identifying middle ear disease in small animals [16]. A previous study found that the diagnostic sensitivity for detecting middle ear disease was similar for radiographs and CT [141]. However, this has not been the author’s experience. It is possible that CT resolution has recently improved with advances in scanner technology. Otitis media is visible as an increased soft tissue opacity in the bulla lumen. With chronicity, there may also be thickening and sclerosis of the bulla walls, or expansion of the bulla (Fig. 34). Focal mineral opacities or otoliths may also be visible [142]. Otitis media may be associated with nasopharyngeal polyps, especially in cats. Middle ear neoplasia is more commonly characterized by lysis of the bulla or extension into the cranial vault (Fig. 35a, Fig. 35b).

Figure 34. Transverse CT image of a dog with otitis media. There is thickening and sclerosis of the left tympanic bulla wall. Increased soft tissue opacity is also present in the ventral portion of the bulla and in the horizontal portion of the external ear canal. - To view this image in full size go to the IVIS website at www.ivis.org.

Figure 35a. Transverse post-contrast and three-dimensional CT images of a cat with squamous cell carcinoma. An ill-defined, heterogenously-enhancing soft tissue mass involves the right external ear canal and tympanic bulla. There is lysis of the floor of the cranial vault, with enhancement of the meninges adjacent to the bone defect. The three-dimensional image demonstrates the size of the bone defect. - To view this image in full size go to the IVIS website at www.ivis.org.
Figure 35b. Transverse post-contrast and three-dimensional CT images of a cat with squamous cell carcinoma. An ill-defined, heterogeneously-enhancing soft tissue mass involves the right external ear canal and tympanic bulla. There is lysis of the floor of the cranial vault, with enhancement of the meninges adjacent to the bone defect. The three-dimensional image demonstrates the size of the bone defect. - To view this image in full size go to the IVIS website at www.ivis.org.

Spine - The most common applications for spine CT include suspected intervertebral disk disease, spinal stenosis, or spinal masses. CT is often less sensitive than MRI for discriminating soft tissues within the spinal canal [8,9]. However, CT is more sensitive than MRI for soft tissue calcifications, cortical bone spurs, and degenerative changes in the articular process joints. Type I intervertebral disk herniation is visible as either single or multiple bone opacity masses in the intervertebral canal, intervertebral foramina, or extraforaminal region (Fig. 36).

Figure 36. Transverse, post-myelogram CT image of a dog with cervical type I disk herniation. The myelographic contrast column appears normal. An irregular, sharply marginated bone opacity is present in the left intervertebral foramen. - To view this image in full size go to the IVIS website at www.ivis.org.

Type II disk herniation is characterized by circumferential bulging of the annulus, narrowing of the intervertebral disk spaces, endplate sclerosis, and endplate bone spurs (spondylisis deformans). Other signs of chronic degenerative disk disease may include endplate fragmentation, Schmorl’s nodes, and vacuum phenomena. Schmorl’s nodes are sharply marginated endplate lucencies that are caused by intravertebral disk herniation. They may mimic diskospondylitis, but usually exhibit more peripheral sclerosis. Vacuum phenomena are air opacities that are seen within the intervertebral disk or vertebral endplates. They are formed when nitrogen gas is forced out of the disk capillaries under pressure. Vertebral fractures are visible as linear lucencies, bone fragments, and may be associated with subluxation. Intraspinal hemorrhage may be apparent as amorphous, soft tissue opacity material within the vertebral canal. There may be concurrent traumatic herniation of disk material and spinal cord compression.

Vertebral neoplasia is suspected when there is a paraspinal mass, contrast-enhancing soft tissue in the vertebral canal, bone destruction or active proliferation, or pathologic fractures [23] (Fig. 37). Intramedullary neoplasms may sometimes be demonstrated with intravenous enhanced CT, however MRI is far more sensitive.

Figure 37. Sagittal, bone window CT image of a dog with thoracic spinal osteosarcoma. A large osteolytic lesion is present within the center of the T6 vertebral body. There is an associated compression fracture, with displacement of the dorsal fracture fragment into the vertebral canal. - To view this image in full size go to the IVIS website at www.ivis.org.

Intradural/extramedullary neoplasms are best demonstrated with CT myelography. Focal widening of the subarachnoid space, spinal cord compression, subarachnoid filling defects are all characteristic of intradural/extramedullary neoplasms. Expansion of the vertebral canal or intervertebral foramina may be seen, especially with slower growing neoplasms. Diskospondylitis is characterized by ill-defined, osteolytic lesions within adjacent endplates [98] (Fig. 38).

Figure 38. Sagittal, bone window CT image of a dog with thoracolumbar discospondylitis. There is focal osteolysis of the T13 - L1 vertebral endplates with active bone proliferation on the ventral aspects of the vertebral bodies. - To view this image in full size go to the IVIS website at www.ivis.org.

The disk margin may bulge outward and exhibit contrast enhancement. There may be an associated loss of epidural fat due to canal encroachment by protruding disk material or infiltration by inflammatory tissue (eg. meningomyelitis). Spondylitis may sometimes mimic neoplasia in appearance. There are often mixed osteoproliferative/osteolytic lesions involving one or more vertebral bodies. There may be contrast-enhancing soft tissue within the vertebral canal. However, paraspinal masses are less commonly seen with spondylitis than with neoplasia in this author's experience.

Congenital or idiopathic spinal stenosis is visible as thickened lamina and pedicles, bulbous articular processes, and an abnormal shape to the bony canal [143]. There is also a loss of epidural fat within the vertebral canal and/or intervertebral foramina. Soft tissues causing encroachment on the nerve roots or thecal sac often exhibit enhancement after administration of intravenous contrast medium [128]. Characteristics of degenerative stenosis include bulging of the disk margin, spondylisis, endplate sclerosis, hypertrophied ligamentum
flavum, hypertrophied joint capsules, congestion of the venous structures, or subluxation (Fig. 39). Fragmentation of the vertebral endplate may occur with severe degenerative disc disease or preexisting sacral osteochondrosis [144] (Fig. 40). Dynamic subluxation is demonstrated by comparing mid-sagittal views obtained with the spine in flexion versus those obtained with the spine in extension (Fig. 41a, Fig. 41b).

Figure 39. Sagittal, soft tissue window CT image of a dog with degenerative lumbosacral stenosis. There is bulging of the L6 - 7 and L7 - S1 disc margins, with loss of epidural fat ventrally and dorsally. - To view this image in full size go to the IVIS website at www.ivis.org . -

Figure 40. Parasagittal, bone window CT image of a dog with degenerative L7 - S1 disk disease and sacral endplate fragmentation. There is blunting of the craniodorsal sacral margin with a bone opacity fragment adjacent to the defect. - To view this image in full size go to the IVIS website at www.ivis.org . -

Figure 41a. Sagittal, flexion and extension CT images of a dog with lumbosacral stenosis and dynamic subluxation. There is cranioventral displacement of the sacrum relative to L7 and increased narrowing of the L7 - S1 vertebral canal with extension of the spine. - To view this image in full size go to the IVIS website at www.ivis.org . -

Figure 41b. Sagittal, flexion and extension CT images of a dog with lumbosacral stenosis and dynamic subluxation. There is cranioventral displacement of the sacrum relative to L7 and increased narrowing of the L7 - S1 vertebral canal with extension of the spine. - To view this image in full size go to the IVIS website at www.ivis.org . -

Magnetic Resonance Imaging

Basic Principles and Techniques - Magnetic resonance imaging (MRI) is an imaging technique that uses a strong magnetic field and pulses of radiofrequency energy to cause tissues to emit characteristic energy signals [106]. A motorized table centers the patient in a tube-shaped or open gantry in which there is a constant strong magnetic field. While inside the gantry, hydrogen atoms within the patient's tissues align themselves with the magnetic field. Tissues are intermittently exposed to brief pulses of radiofrequency energy to temporarily knock the hydrogen atoms out of alignment. A weak energy signal (resonance) is released from the tissues as the hydrogen atoms realign themselves with the magnetic field. A receiver coil is placed near the anatomic region of interest to record the signal coming from the tissues. The strength of the returning signal varies based on multiple factors: inherent tissue factors, concentration of hydrogen atoms, interactions of the atoms with each other, strength of the magnetic field, technique settings assigned by the computer operator, duration of each radio-pulse, frequency of radio pulses (repetition time or TR), and how long the signal is recorded by the receiver coil after the pulse occurs (echo time or TE). The MRI computer converts the signal intensity to varying shades of grey in the image. Tissues with higher signal intensity are assigned whiter colors. Those with lower signal intensities are assigned darker grey colors. Tissues having no signal appear black.

MRI system components include a magnet, receiver coil, computer station, and gradient coils. The magnet maintains a strong external magnetic field around the patient. The magnetic strength is measured in Tesla units (1 Tesla = 10,000 X earth's magnetic field). Three ranges of magnetic field strength are available for medical MRI scanners:

1. low field = < 0.5 Tesla,
2. mid field = 0.5 - 1.0 Tesla, and
3. high field = > 1.0 Tesla.

The two most common types of magnet construction are superconducting or permanent. Superconducting magnets are made using coils of electrical wires that are cooled with liquid helium or nitrogen. Permanent magnets consist of magnetic discs, usually made of iron. The receiver coil detects the electromagnetic signals being emitted by the tissues. Receiver coils are available in different sizes and shapes, so they can be as close to the area of interest as possible. This helps maximize the signal to noise ratio and improve image quality. The computer station controls the technical parameters and radiofrequency pulse sequences. The plane of scanning can be altered without moving the patient.
by the use of gradient coils. These gradient coils cause slight changes in the main magnetic field, that are used as localization tools by the MRI computer.

Numerous radiofrequency pulse sequences have been designed in order to improve visualization of specific tissues of interest. However, the most commonly used pulse sequence is the spin-echo technique. This involves the use of a 90 degree radiofrequency pulse followed by a 180 degree radiofrequency pulse. T1-weighted images are created when short TE and short TR intervals are used in a spin echo pulse sequence (eg. 20 - 35 ms, 300 - 500 ms respectively). Tissues that appear bright white in T1-weighted images include fat, gadolinium contrast medium, and proteinaceous fluid. Tissues that appear dark on T1-weighted images include all other fluids, edema, air, bone, and fast-flowing blood. Proton-density weighted images are created using short TE and long TR intervals e.g., 20 - 35 ms and 1500 - 2500 ms respectively). Fluid appears dark, fat appears white, and the grey matter appears brighter than the white matter. T2-weighted images are created using long TE and long TR intervals (e.g., 75 - 150 ms, 1500 - 2500 ms respectively). Tissues appearing bright white in T2-weighted images include fluid and edema. Tissues that appear dark on T2-weighted images include soft tissue, air, bone, and fast-flowing blood. Other pulse sequences used for small animal MRI may include fluid-attenuated inversion recovery (FLAIR), diffusion-weighted, magnetization transfer, and fat-saturation techniques. The FLAIR pulse sequence is increasingly being included in standard brain MRI studies. This sequence is especially helpful for visualizing periventricular pathology, because it dampens the signal coming from cerebrospinal fluid while demonstrating intraparenchymal edema as high signal intensity [146].

Common MRI artifacts include motion, ferromagnetic, signal void, and signal drop-off. Motion appears as blurred streaks that run perpendicular to the direction of motion (Fig. 42). They are present in all images obtained during a given pulse sequence. Ferromagnetic artifacts are caused by such objects as gunshot fragments or pellets, vascular clamps, skin staples, intravenous catheter needles, or orthopedic fixation devices. These artifacts appear as a large black void that surrounds the metallic object (Fig. 43). The void may obscure all adjacent structures or distort their shape.

High field strength magnets may also cause metallic objects to move or heat up during scanning. A signal void artifact is caused by fast-moving blood within a vessel. The protons that are knocked out of alignment by the radiofrequency pulse move out of the scan field before they can release their resonating signal. Signal drop-off artifact occurs at the edges of the receiver coil. As the signal-to-noise ratio drops, the image becomes increasingly dark and grainy in appearance.

The main advantages of MRI versus CT include:

1. No beam hardening artifacts,
2. Higher sensitivity for subtle changes in soft tissue chemical properties. For example, MRI is much more sensitive than CT for early infarcts and edema.
3. The ability to acquire images in any plane desired, and
4. Absence of ionizing radiation (Fig. 44a, Fig. 44b).

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**Figure 42.** Sagittal, T2-weighted image of a dog with degenerative lumbar spinal stenosis. Motion artifacts appear as wavy, parallel, longitudinal streaks across the entire image. - To view this image in full size go to the IVIS website at www.ivis.org .

**Figure 43.** Transverse, T1-weighted, post-contrast image of a dog with cerebral glioma. A metallic artifact obscures visualization of the right retropharyngeal region. The artifact was caused by a metallic needle within the dog’s cephalic catheter. - To view this image in full size go to the IVIS website at www.ivis.org .

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**Figure 44a.** Transverse post-contrast CT versus post-contrast MRI in a dog with cerebellar glioma. The mass is partially obscured by beam-hardening artifacts in the CT image. With MRI, the extent of the mass is more clearly distinguishable. - To view this image in full size go to the IVIS website at www.ivis.org .

**Figure 44b.** Transverse post-contrast CT versus post-contrast MRI in a dog with cerebellar glioma. The mass is partially obscured by beam-hardening artifacts in the CT image. With MRI, the extent of the mass is more clearly distinguishable. - To view this image in full size go to the IVIS website at www.ivis.org .
Normal Findings

Brain - For a detailed identification of anatomic structures, the reader is referred to one of several published anatomic atlases [118,149]. As with CT, all normal paired structures should be symmetrical. There should be no focal contrast enhancement (with the exception of the pituitary and pineal glands, veins, and sometimes the choroid plexus). T1-weighted images yield the best spatial resolution and morphologic detail for soft tissues overall [149]. However, there is poor to moderate contrast between the grey and white matter of the brain. Cerebrospinal fluid within the ventricles and subarachnoid spaces exhibits very low signal intensity and appears dark grey or black. Ventricles are normally well-visualized in dogs, but may be more difficult to appreciate in cats [150]. Ventricular asymmetry may be present as a normal anatomic variant, especially in beagles and labrador retrievers [151,152]. Ventricles in Yorkshire Terriers are larger than those in German Shepherds [153]. Fat in the bone marrow of the skull, subcutaneous tissue, and fascial planes has high signal intensity and appears bright white. Proton-density weighted images yield an image very similar to T1-weighted images, with improved contrast resolution between grey matter and white matter. White matter has slightly lower signal intensity than grey matter. T2-weighted images are of overall lower signal intensity compared to other pulse sequences and yield darker images. The spatial resolution is also decreased, with a more grainy appearance. This technique provides the best contrast resolution between grey and white matter of the brain. Also, cerebrospinal fluid within the ventricles and subarachnoid spaces appears bright white. In all pulse sequences, arteries and veins with fast-moving blood exhibit low signal intensity because of signal void artifacts. Cortical bone also appears dark black in all pulse sequences because the protons are so rigidly bound they cannot move out of alignment when pulsed. Air within the tympanic bullae, nasal cavities, frontal sinuses, and nasopharynx also appears black in all pulse sequences, due to the low concentration of hydrogen protons. The pituitary gland normally exhibits uniform enhancement post-contrast administration. In the dog, contrast enhancement occurs in the pituitary stalk at 52 - 65 seconds and becomes most uniform at 104 - 143 seconds post-injection [154]. Normal pituitary gland dimensions in cats have been described using MRI. Results from 17 cats were: mean length 0.54 cm, mean width 0.50 cm, mean height 0.34 cm and mean volume 0.05 cm3 [155].

Spine - In general, the spatial resolution of CT for evaluation of the spine is higher than with MRI. However, the superior contrast resolution of soft tissues offers a significant advantage [8,156-158]. On T1-weighted images, the intervertebral disk is of uniformly medium signal intensity, slightly greater than that of the spinal cord, nerve roots, and bone marrow. Epidural fat has very high signal intensity and appears bright white (Fig. 45). The cerebrospinal fluid around the spinal cord has lower signal intensity and helps distinguish the margins of the nervous tissue structures from adjacent fat.

Figure 45. Transverse, T1-weighted image of the L6 - 7 vertebral canal in a normal dog. High signal intensity fat facilitates visualization of lower signal intensity nerve roots. - To view this image in full size go to the IVIS website at www.ivis.org . -
In T2-weighted images, normal intervertebral disks consist of a high signal nucleus pulposus surrounded by a medium signal annulus fibrosus. The variation in signal intensity is related to varying concentrations of ground substance. Ground substance contains hyaluronic acid and glycosaminoglycans, which in turn attract and hold water. The nucleus pulposus normally possesses the highest concentration of ground substance, and therefore has the highest T2 signal intensity. The cerebrospinal fluid also has high signal intensity. The subarachnoid space can be seen as a zone of increased signal intensity that surrounds the spinal cord and nerve roots (myelogram effect). The central canal is visible as a thin, linear region of increased signal intensity within the center of the spinal cord. Epidural fat exhibits intermediate signal intensity, higher than spinal cord or nerve roots on fast spin echo T2-weighted images. Vertebral marrow is of lower signal intensity than either fat or the spinal cord. In all pulse sequences, cortical bone has low signal intensity. Spinal ligaments and joint capsules are also of low signal intensity, making them mostly indistinguishable from cortical bone. Short segments of the dorsal and ventral longitudinal ligaments can be distinguished where they span the intervertebral disk space. The ligamentum flavum is partially visible at some interlaminar spaces.

Clinical Applications -

**Brain** - Common veterinary applications for head MRI are similar to those for head CT: suspected intracranial neoplasia, non-neoplastic brain lesions, or middle/inner ear disease [15,16,19,131,159]. Also similar to CT, typical MRI characteristics of common brain neoplasms have been established and there are some exceptions to the rules. A definitive diagnosis still requires a biopsy. Meningiomas usually have an extraxial location, are broad-based and appear sharply marginated. They are isointense in pre-contrast T1 weighted images, hyperintense in T2-weighted images, and uniformly enhancing (Fig. 46). A linear enhancement of thickened dura mater, or "dural tail" may be visible on the periphery of the mass in post-contrast images. In one study of 18 dogs and 3 cats, a dural tail was observed in 60% of animals with confirmed meningiomas [160]. Other differentials to consider for localized enhancement of the meninges include meningitis associated with meningoencephalomyelitis, intracranial extension of otitis interna, and feline infectious peritonitis, as well as metastatic neoplasia [161]. Choroid plexus adenomas are most commonly found in intraventricular or cerebellopontine locations.

**Figure 46.** Transverse, post-contrast, T1-weighted image of a dog with brainstem meningioma. The mass is broad-based, markedly-enhancing, and sharply marginated. - To view this image in full size go to the IVIS website at www.ivis.org. -

They are solitary, and often associated with hydrocephalus. They appear isointense in pre-contrast T1 weighted images, hyperdense in T2-weighted images and are uniformly enhancing. In one dog, choroid plexus carcinoma and meningoic carcinomatosis appeared in MR images as multiple, cyst-like structures found in the parenchyma of the cerebrum, cerebellum and brainstem [162]. Gliomas typically have an intraxial location. Ependymomas and oligodendrogliomas are often periventricular. Medulloblastomas, though uncommon, may be seen in the cerebellum of young animals. Gliomas tend to be hypointense in pre-contrast T1 weighted images, and hyperintense in T2 weighted images. They exhibit variable enhancement (Fig. 47a, Fig. 47b). Low grade gliomas may not enhance at all. High grade gliomas may have cavitary areas and marked peritumoral edema. Pituitary macroadenomas are found in the suprasellar region and are usually fairly sharply marginated [163]. They appear isointense in pre-contrast T1 weighted images, are often uniformly enhancing and can displace adjacent structures. In a case report of one dog, intravascular lymphoma appeared as multifocal regions of increased T1, T2, and FLAIR signal intensity, with mild contrast enhancement [146].

**Figure 47a.** Dorsal planar, T1 post-contrast and T2 weighted images of a dog with cerebellar glioma. The mass is T1-hypointense, non-enhancing and T2-hyperintense. - To view this image in full size go to the IVIS website at www.ivis.org. -

**Figure 47b.** Dorsal planar, T1 post-contrast and T2 weighted images of a dog with cerebellar glioma. The mass is T1-hypointense, non-enhancing and T2-hyperintense. - To view this image in full size go to the IVIS website at www.ivis.org. -
Characteristics of nonobstructive and obstructive hydrocephalus are similar to those described for CT. With MRI, periventricular edema may be easier to see as an indicator of possible acute hydrocephalus or inflammation. Periventricular edema appears as a zone of increased T2 and FLAIR signal intensity that surrounds the ventricles. Obstructive hydrocephalus secondary to a Chiari malformation may also be more readily identified with MRI. The most common form is the Chiari I malformation, which is characterized by caudal displacement of a portion of the cerebellum through the foramen magnum (Fig. 48). Syringohydromyelia of the cervical spine may also be present [41]. Focal lesions in the pyriform and temporal lobes have been reported as reversible phenomena caused by seizures in dogs [165]. These lesions may exhibit variable signal characteristics and are caused by localized edema, neovascularization, reactive astrocytosis, and acute neuronal necrosis.

Figure 48. Sagittal, T1-weighted image of a dog with Chiari I malformation. The caudal margin of the cerebellum is flattened, with protrusion of the caudoventral margin through the foramen magnum. - To view this image in full size go to the IVIS website at www.ivis.org . -

Intraparenchymal hemorrhage varies in signal intensity, based on the stage of hemoglobin breakdown [19,166]. Within the first few hours, a hematoma will usually be T1-hypointense and T2-hyperintense. In the first few days, the T1 signal may vary from hypointense to hyperintense while the T2 intensity remains hypointense. As hemolysis occurs over the next few weeks, the T1 intensity ranges from hyperintense to hypointense, while the T2 signal becomes more consistently hyperintense. Non-hemorrhagic infarcts are usually visible with MRI earlier than with CT. Initially, the infarct may appear hyperintense in T2 and proton-weighted images (Fig. 49).

Figure 49. Dorsal planar, T2-weighted image of a dog with cerebral infarction. A T2-hyperintense, periventricular lesion is present in the right frontal lobe. There is no displacement of adjacent structures. - To view this image in full size go to the IVIS website at www.ivis.org . -

Parenchymal enhancement is uncommon within the first few days. After several weeks, the infarct decreases in size. There is often focal atrophy of the adjacent brain tissues, with dilation of nearby sulci and ventricles. In experimental canine studies, MRI was found to be more sensitive than CT for identification of early meningitis. [167] Post-gadolinium T1-weighted images demonstrated increased leptomeningeal enhancement earlier than enhancement was seen with CT. MRI characteristics of meningoencephalitis include: ill-defined regions of increased T2 or FLAIR signal intensity consistent with edema, ventricular asymmetry, multifocal areas of enhancement, and ring-enhancing masses [168-170] (Fig 50a, Fig 50b, Fig 50c, Fig 50d). Similar characteristics have been described for metastatic neoplasia. Vascular disorders may also mimic a solitary brain neoplasm. Magnetic resonance angiography can be used to noninvasively depict aneurysms, malformations, occlusive disease, and fistulas [148] (Fig. 51a, Fig. 51b). Encephalomalacia may appear as multiple ovoid to punctate, T1 hypointense and T2-hyperintense lesions. Lesions typically do not enhance with contrast and do not exhibit a mass effect. [171,172]

Figure 50a. Dorsal planar image of the brain in a dog with encephalitis: T1-hyperintense lesions in the left cerebral cortex with ventricular asymmetry. (Image courtesy Dr. John Rossmeisl) - To view this image in full size go to the IVIS website at www.ivis.org . -

Figure 50b. Dorsal planar image of the brain in a dog with encephalitis: focal areas of contrast enhancement involving the left cerebral cortex and meninges. (Image courtesy Dr. John Rossmeisl) - To view this image in full size go to the IVIS website at www.ivis.org . -

Figure 50c. Dorsal planar image of the brain in a dog with encephalitis: T2-hyperintense lesions in the left cerebral white matter and cortex. (Image courtesy Dr. John Rossmeisl) - To view this image in full size go to the IVIS website at www.ivis.org . -
and exhibit contrast enhancement in post-gadolinium T1-weighted images [188]. They are of variable T1-signal intensity. Arachnoid cysts are more sensitive than scintigraphy for vertebral metastases [187]. Neoplasms most commonly appear hyperintense in T2-weighted images [186]. In humans, MRI is considered to be the modality of choice for suspected spinal neoplasia [14]. It has been found that MRI had a sensitivity of 93%, specificity of 97%, and accuracy of 95% for diagnosing disk infection [185]. Epidural or paraspinal abscesses usually exhibit ring enhancement in post-gadolinium images [184]. In one canine experimental study MRI had a sensitivity of 93%, specificity of 97%, and accuracy of 95% for diagnosing disk infection [185]. Epidural or paraspinal abscesses usually exhibit ring enhancement in post-gadolinium images [184].

In one study of 12 military working dogs with degenerative lumbarosacral stenosis, no association between postoperative outcome and MRI characteristics could be found [182]. In another study of 27 dogs with degenerative lumbarosacral stenosis, no association between severity of compression and severity of clinical signs could be found [183]. Extruded calcified disc material appears as a focal signal void, usually in the ventral epidural space [184]. The adjacent spinal cord tissue may exhibit increased T2 signal due to edema or contusion. Early diskitis is evident as increased signal intensity or contrast enhancement of the intervertebral disk. With diskospondylitis, there is also increased T2 signal intensity or contrast enhancement that extends into the adjacent vertebral endplates or vertebral bodies. Vertebral endplate margins may appear irregular or fragmented. In one canine experimental study MRI had a sensitivity of 93%, specificity of 97%, and accuracy of 95% for diagnosing disk infection [185]. Epidural or paraspinal abscesses usually exhibit ring enhancement in post-gadolinium T1-weighted images [186]. In humans, MRI is considered to be the modality of choice for suspected spinal neoplasia [14]. It has been found to be more sensitive than scintigraphy for vertebral metastases [187]. Neoplasms most commonly appear hyperintense in T2-weighted images and exhibit contrast enhancement in post-gadolinium T1-weighted images [188]. They are of variable T1-signal intensity. Arachnoid cysts are

**Spine** - Common applications for spinal MRI in animals include suspected degenerative spinal disease, early diskitis, neoplasia, synovial cysts, or syringohydromyelia [8,97,179]. Degenerative disk disease is characterized by a decreased T2 signal intensity within the nucleus pulposus [156-158,180] (Fig. 53). Degenerative lumbarosacral stenosis is evident as a focal loss of epidural fat within the vertebral canal or intervertebral foramina. This finding is often associated with intervertebral disk protrusion, displacement of nerve tissue, and low signal tissue encroaching on ventral and dorsal vertebral canal [179]. Similar MRI characteristics have been reported for cervical stenotic myelopathy in dogs [181].

Intervertebral disk protrusion is characterized by dorsal displacement of the disk margin, fragmentation, or loss of the normal ovoid shape of the disk. In one study of 12 military working dogs with degenerative lumbarosacral stenosis, no association between postoperative outcome and MRI characteristics could be found [182]. In another study of 27 dogs with degenerative lumbarosacral stenosis, no association between severity of compression and severity of clinical signs could be found [183]. Extruded calcified disc material appears as a focal signal void, usually in the ventral epidural space [184]. The adjacent spinal cord tissue may exhibit increased T2 signal due to edema or contusion. Early diskitis is evident as increased signal intensity or contrast enhancement of the intervertebral disk. With diskospondylitis, there is also increased T2 signal intensity or contrast enhancement that extends into the adjacent vertebral endplates or vertebral bodies. Vertebral endplate margins may appear irregular or fragmented. In one canine experimental study MRI had a sensitivity of 93%, specificity of 97%, and accuracy of 95% for diagnosing disk infection [185]. Epidural or paraspinal abscesses usually exhibit ring enhancement in post-gadolinium T1-weighted images [186]. In humans, MRI is considered to be the modality of choice for suspected spinal neoplasia [14]. It has been found to be more sensitive than scintigraphy for vertebral metastases [187]. Neoplasms most commonly appear hyperintense in T2-weighted images and exhibit contrast enhancement in post-gadolinium T1-weighted images [188]. They are of variable T1-signal intensity. Arachnoid cysts are
nonneoplastic masses that may cause spinal cord compression in humans and animals [14,101,114,145,189]. These lesions are similar to neoplasms in that they appear hyperintense in T2-weighted images, but they do not enhance with contrast. They are most commonly found in the intradural-extramedullary space. Synovial or ganglion cysts appear as well encapsulated masses arising from the articular process joints [179,190]. These cysts are hyperintense to CSF in T1 weighted images and isointense to CSF in T2-weighted images. Syringohydromyelia is a focal accumulation of fluid within the spinal cord central canal or parenchyma [179,191-193]. It may be developmental or acquired. Developmental syringohydromyelia may remain subclinical until it is exacerbated by concurrent spinal cord compression due to other causes. In T2-weighted sagittal images, syringohydromyelia is readily apparent as a tubular region of high signal intensity within the center of the spinal cord.

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