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Introduction

For most animals with suspected neurologic disease, conventional diagnostic radiography remains the preferred method of initial evaluation [1-9]. 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. Advanced imaging techniques such as myelography, ultrasonography, scintigraphy, computed tomography, and magnetic resonance imaging are much more sensitive for detecting neurologic disease. For this reason, they are the preferred initial examination techniques in humans [10]. As advanced imaging techniques become increasingly available and less expensive, they are rapidly becoming standard diagnostic tools in veterinary neurology as well [2,7-9,11-20]. 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 [3,8,21-23]. 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 [24]. Diagnostic sensitivity of radiographs is maximized by the use of
good radiography equipment, film/screen combinations, technique charts, film processing techniques, and patient
positioning [25]. Chemical restraint (heavy sedation or general anesthesia) is highly recommended to ensure accurate
positioning [6,26,27]. 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 [4,28]. The areas of clinical concern should be centered in the x-ray beam in order
to minimize geometric distortion and maximize spatial resolution.

The standard radiographic views for the calvarium include lateral and dorsoventral projections [22,27,29]. 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 mesatocephalic 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 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 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. Opposite bulla views are recommended
for comparison purposes. 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.

![Figure 1. Positioning technique for rostrocaudal radiography of the tympanic bullae. (Courtesy Dr.
Don Barber, Virginia Tech). - To view this image in full size go to the IVIS website at
www.ivis.org. -](image-url)
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 [3,23]. It may also be used to guide placement of spinal contrast agents and to guide collection of tissue samples for cytology and culture/sensitivity.

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 [32,33]. The calvarium is smoothly marginated, with swirling convolutions on the dorsal and lateral surfaces. The cribriform 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 normal 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).

![Figure 2. Lateral radiograph of the normal canine atlanto-axial junction. Notice the relationship between the C1 and C2 laminae. - To view this image in full size go to the IVIS website at www.ivis.org. -](image)

![Figure 3. Lateral radiograph of the normal canine cervical spine. Notice the large C6 transverse processes. - To view this image in full size go to the IVIS website at www.ivis.org. -](image)

Slight enlargements of the C5 - T2 and L2 - 5 spinal canal occur where the brachial and pelvic plexuses 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 [34]. 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 [35]. 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 [36] (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 [37-39] (Fig. 5).
Some authors consider the malformation to be an incidental finding, especially in the Pekingese. Other authors theorize this malformation may cause an increased risk for intermittent tentorial herniation. Signs 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 [40]. Multilobular tumors of bone appear as lobulated, mixed soft tissue and bone opacity masses, which may or may not be locally invasive [41]. Synonyms include osteochondroma, osteochondrosarcoma, or chondroma rodens. In some cats, intracranial meningioma may be visible as a focal calcification or thickening of the calvarium [42] (Fig. 6).

Middle ear disease may cause neurologic dysfunction if it 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 [43] (Fig. 7).

In severe cases, the affected bulla may be expanded. With neoplastic disease of the middle ear, there may also be lysis of the petrous temporal bone and invasion of the cranial vault. In one study, 25 percent of dogs with surgically confirmed middle ear disease had negative radiographs [44]. 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 [45]. 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** - Radiographic signs of type I disk herniation include 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 [46,47] (Fig. 8a and Fig. 8b). Radiographic signs of type II disk herniation include narrowing of the disk space, sclerosis of the vertebral endplates, and spondylosis deformans (Fig. 9). Early
spondylosis may appear as faint bone spurs on the margins of the endplates [48].

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. Degenerative articular process joint disease appears as enlarged or irregular articular processes. 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 [49] (Fig. 10). Block vertebra are evident as absence of visualization of the articular process joint or intervertebral disk spaces [50].

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 [51]. Transitional lumbosacral vertebrae may appear as a caudal L7 vertebra with sacral characteristics (sacralization) or as sacral vertebrae with lumbar characteristics (lumbarization). Transitional lumbosacral vertebrae, in combination with degenerative disk disease, are predisposing factors for cauda equina syndrome in German Shepherd dogs [52]. One theory is that abnormal sacroiliac articulations may cause premature disk degeneration [53].

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 [54,55]. Feline mucopolysaccharidosis may cause partial fusion of cervical or lumbar vertebrae, irregularly shorted or misshapen vertebrae, widened intervertebral disk spaces, or an apparently widened spine [56]. Hyperparathyroidism is often characterized by a generalized decrease in bone density, with compression fractures of the vertebral bodies [57]. Vertebral neoplasms may be osteolytic, osteoblastic or both [58]. When there is extensive focal osteolysis, a compression fracture may be evident (Fig. 12a and Fig. 12b).

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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. Another differential diagnosis for focal vertebral osteolysis/osteoproliferation is vertebral osteomyelitis [59,60]. 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 diskospondylitis, bone changes are most often seen in adjacent endplates (Fig. 13). In physitis, the caudal vertebral physis appears widened and irregular. The caudal vertebral endplate may become sequestered and surrounded by an involucrum.

Radiographic signs of vertebral trauma include changes in shape, opacity, margination, angulation or alignment [61]. 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).
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 [6]. Dynamic vertebral subluxation may be demonstrated by comparing views obtained during flexion versus those obtained during extension [31].

**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 [22,62,63]. Non-ionic, isotonic contrast agents are preferred, due to their lower incidence of adverse reactions [64]. Commonly used myelographic contrast agents include iohexol and iopamidol. The contrast agent is injected into the cisterna magna or the lower lumbar subarachnoid space at a dose of 0.3 - 0.45 ml/kg. 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 cerebrospinal fluid (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.

**Figure 15.** Photograph of image-intensified fluoroscopy machine. - To view this image in full size go to the IVIS website at www.ivis.org.

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. 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 [65]. The epidural space may also be inadvertently opacified when there is leakage of contrast outside the subarachnoid space (Fig. 16a and Fig. 16b). This is especially a problem when there have been multiple needle punctures. Epidural contrast leakage impairs visualization of the myelographic columns and may create a streaming effect at the intervertebral foramina.

Normal Findings -
The spinal cord ends caudal to L6 in cats and small breed dogs [32]. 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. 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 [66]. 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 cervical and lumbosacral regions. The ventral subarachnoid space is normally narrower than the dorsal subarachnoid space at C1 - 2. 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 [67,68]. 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 [69]. Lumbosacral stenosis may also be present with a normal myelogram [70].

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) [62,69,71].

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/extradural. 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 [72,73]. 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 [47,74]. When the disk protrusion is lateral to the midline, the ventral contrast column may appear forked or split [75]. 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.

Normal cervical spinal diameters have been described for dogs [66]. 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 [50]. 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 [7]. 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 [76].

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) [77]. 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
Basic Principles and Techniques

Ultrasonography

Ultrasonography is an imaging technique that uses high frequency sound waves to visualize internal structures [21,80]. 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 gray 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, gray 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 [80].

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 cranietomy defects, open fontanelles or some of the larger neural foramina [80-82]. Some animals have sufficiently thin bone in the temporal region to allow transcranial imaging without a cranietomy 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 rostocaudal 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 cranietomy 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 [80,81]. 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 [83]. 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 [84]. 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 nuclei, thalamus, hippocampus, cerebellum, and osseous tentorium [81]. The gyri and sulci in neonatal brains are less well developed than those of mature brains. The hippocampi are 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 hypoechoic 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 [85]. 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 hypoechoic 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 homogenously hypoechoic [83]. 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 gray 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 [80,81]. Lateral ventricular enlargement is considered to be present when the mean height exceeds 0.35 cm [85] (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 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. (Courtesey Dr. Martha Moon Larson, Virginia Tech). - To view this image in full size go to the IVIS website at www.ivis.org . -

Spine - Common applications for ultrasonography of the spine include suspected retention of disk fragments, myelomalacia, intraparenchymal neoplasia, recurrent dural or spinal cyst [81]. 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. The adjacent spinal cord may appear compressed. Spinal or arachnoid cysts appear as discrete anechoic lesions. 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.

**Scintigraphy**

**Basic Principles and Techniques** - Scintigraphy is a noninvasive imaging technique that is based on the selective accumulation of radioactive chemicals (radionuclides) within tissues [87,88]. Synonyms include nuclear imaging, planar scintigraphy, or nuclear scintigraphy. To perform the procedure, a small volume of the radionuclide is injected into the patient. The radionuclide can be used alone or attached to a chemical that will be selectively accumulated by the tissue of interest. The radionuclide emits gamma radiation as it decays to an inert form. A gamma camera records the gamma radiation emitted and converts it to an electrical signal (Fig. 21). A computer converts the electrical signal to digital information that is in turn used to create the image.

![Figure 21. Photograph of gamma camera used for scintigraphy. (Courtesy Dr. Don Barber, Virginia Tech). - To view this image in full size go to the IVIS website at www.ivis.org . -](image)

Tissues with a high concentration of radionuclides appear dark (hotspots). Areas with a low concentration of radionuclides appear white (colds spots). New software programs also allow color enhancement of the images. Hotspots can appear bright red or bright yellow if desired. Following the imaging procedure, the patient is kept in an isolated holding area until the radiation emissions are reduced to background levels (usually 1 - 3 days). The most common radionuclide used in veterinary medicine is technetium 99m (99mTc). It is preferred because the radioactive decay is very fast (half life about 6 hours), and the energy of the gamma rays emitted is relatively low. The main limitation of planar scintigraphy is the relatively low sensitivity for early intracranial or spinal cord disease that is obscured by superimposition of overlying structures. Newer, tomographic, scintigraphy techniques show promise for increasing the sensitivity of scintigraphy procedures. Single photon emission computed tomography (SPECT) and positron emission tomography (PET) offer the advantage of functional imaging on a slice by slice basis [89]. Early alterations in cerebral/spinal blood flow and metabolism may be more quickly diagnosed in small animals if these techniques become less cost prohibitive in the future. Brain scintigraphy is most commonly performed using 99mTc-glucoheptonate, with dosages ranging from 5 - 35 mCi [9,87,88,90]. Images are acquired 1 - 4 hours after administration of radiopharmaceutical. The delay allows renal excretion of radiopharmaceutical from the blood pool, which in turn increased the lesion:background ratio of uptake. This improves the sensitivity of the procedure. General anesthesia is needed to insure precise positioning and control patient motion. Standard views include the right lateral, left lateral, dorsal, and caudal. Dorsal oblique views are obtained as needed to clarify a suspected lesion.

Spinal scintigraphy is most commonly performed using diphosphonate compounds such as 99mTc methylene diphosphonate (99mTc-MDP) [87,88,91]. When 99mTc-MDP is injected intravenously, it is first distributed in the blood pool then accumulates within the bone wherever there is active metabolism. Focal increases in uptake indicate locations where there is either increased blood flow or increased bone turnover. In small animals, doses typically range from 5 - 20 mCi. Three-phase bone imaging is a technique that is often used for distinguishing between soft tissue and bone lesions. Vascular phase images are initially obtained immediately after the injection. Soft tissue phase images are then obtained 10 - 20 minutes after injection. Images of bone accumulation (bone phase) are obtained 2 - 4 hours after injection.

**Normal Findings**

**Brain** - Normally there is a lack of radiopharmaceutical uptake in the brain parenchyma (Fig. 22). Radiopharmaceuticals are excluded from brain parenchyma by an intact blood brain barrier. Accumulation of radiopharmaceutical media within the surrounding skin, mucosal tissue, and muscle provide an outline for brain boundaries.

![Figure 22. Brain scintigraphy image of a normal dog. There is no evidence of increased uptake within the cranial vault. (Courtesy Dr. Greg Daniel, University of Tennessee). - To view this image in full size go to the IVIS website at www.ivis.org . -](image)
Spine - The spinal cord is not visible in scintigraphic images, but diseases of the vertebrae and paraspinal tissues can be assessed. Normal vertebrae should exhibit uniformly low radiopharmaceutical uptake in bone phase images. Paraspinal soft tissues should exhibit low uptake in soft tissue window phases. In growing animals, focal increased uptake may be seen in metaphyseal regions (e.g., vertebral endplates). In older animals, focal increased uptake may be associated with vertebral degenerative changes (e.g., spondylosis deformans, degenerative articular process joint disease). These are of variable clinical significance.

Clinical Applications -

Brain - Scintigraphy of the brain is indicated when there is suspected intracranial disease, and when CT or MRI is either unavailable or cost-prohibitive. A positive brain scan is interpreted when there are regions of focal accumulation (hotspots) within the brain parenchyma (Fig. 23).

Figure 23. Brain scintigraphy image of a dog with cerebral ependymoma. There is a focal region of increased uptake within the cranial vault. (Courtesy Dr. Greg Daniel, University of Tennessee). - To view this image in full size go to the IVIS website at www.ivis.org . -

Focal accumulation of radiopharmaceutical media within the extracellular space is caused by disruption of the blood brain barrier. The lesions should be visible in multiple views to rule out superimposition from overlying structures. Differentials for a positive brain scan include neoplasia, necrosis, active hemorrhage, abscess, granuloma, or focal inflammation. In a retrospective study of 116 dogs and cats with proven intracranial disease, scintigraphy had a 75% sensitivity and a 90% specificity for focal brain disease [92]. Correlation of scintigraphic and radiographic findings may be helpful for confirming suspected intracranial masses. Scintigraphy is less sensitive for detecting degenerative or diffuse brain disease [88].

Spine - The most common applications for scintigraphy of the skull or spine are suspected osteomyelitis or neoplastic bone disease [88,91,93,94]. These diseases are visible in scintigraphic images much earlier than they can be seen with radiographs. When active soft-tissue disease is present, there is increased activity on vascular and soft tissue phases, but relatively normal activity on bone phase images. When active osteolytic or osteoproliferative disease is present, vascular and soft tissue phases may demonstrate some increased activity, but bone activity will be much more focal and intense (Fig. 24a and Fig. 24b). Differential diagnoses for focal regions of intense uptake include degenerative joint disease, trauma, infection or neoplasia. Definitive diagnosis of scintigraphic bone lesions usually requires further investigation with radiographs, CT, MRI, or biopsy.

Figure 24a and 24b. Bone phase forelimb and thorax images of a dog with metastatic neoplasia. There are multiple focal regions of increased uptake in the humerus, scapula, spine and ribs (Courtesy Dr. Don Barber, Virginia Tech). - To view this image in full size go to the IVIS website at www.ivis.org . -

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 [21,95,96]. The x-ray tube is housed within
a ring-shaped structure called the gantry (Fig. 25).

![Figure 25. 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. -](image)

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 gray-scale picture elements (pixels) on the viewing monitor. White is assigned to pixels with higher CT numbers (e.g., bone). Varying shades of gray 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 detector design. Third generation scanners are configured such that the x-ray tube and arc of detectors rotate together around the patient for each slice. Fourth 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. 26). Beam hardening artifacts are caused when dense bone differentially absorbs the lower energy portion of x-ray beam (e.g., cerebellum/brainstem).
Figure 26. Transverse CT image of the caudal fossa in a normal dog. Beam hardening causes a black streak that obscures visualization of the brainstem. - To view this image in full size go to the IVIS website at www.ivis.org.

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 a false area of increased or decreased opacity in the image. They are caused by a voxel/pixel translation problem. The displayed gray-scale 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 gray-scale 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 [97]. 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 is 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 (I) at a dose of 800 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. 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 [12,14,98-100]. In general, all normal paired structures should be symmetrical. Bony structures should be smoothly marginated and well-defined. Cortical bone appears bright white and medullary bone exhibits varying shades of gray. The tentorium cerebelli may be calcified in some normal dogs [101]. Soft tissue structures are usually homogenous, with some variation in shades of gray caused by slight differences in tissue density (Fig. 27). To a limited extent, white matter can be distinguished from gray matter by a slightly lower density.

Figure 27. 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 gray 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 gray than brain parenchyma (hypodense), because the cerebrospinal fluid is approximately 2% less dense than brain tissue [98]. 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 intercrural 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. Venous structures of the normal brain (intracranial venous sinuses, parenchymal veins, choroid plexus, falx cerebri) may enhance after administration of contrast material (Fig. 28).

Figure 28. 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 gray matter in CT images [12,102,103]. Structures contained within the thecal sac are also indistinguishable in plain CT images, but become visible when CT is performed post-myelography [11]. 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. 29a, Fig. 29b and Fig. 29c). Epidural fat is less dense than soft tissue, so it will usually appear darker gray than adjacent nervous structures.

Figure 29a.

Figure 29b.

Figure 29c.

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 [104]. 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. 30).

Figure 30. Transverse CT image of the L6 - 7 disc space in a normal dog. Bone margins are smooth and symmetrical. Articular process joints are visible as paired curvilinear lucencies. - To view this image in full size go to the IVIS website at www.ivis.org.
Clinical Applications -

Brain - The most common veterinary applications for head CT include suspected intracranial neoplasia, nonneoplastic brain disease, or vestibular 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 [9,13,15,16,18,20,97,105,106]. 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 [107-110]. New software features also allow CT dose planning for radiation therapy of intracranial masses [15,111] (Fig. 31a and Fig. 31b).

Figure 31a and 31b. Transverse and sagittal CT images of a dog following craniotomy for partial removal of a meningioma. The green rectangles represent the boundaries of radiation fields and other colored lines demonstrate the radiation dose distribution calculated by the treatment planning sofware. (Courtesy Dr. Don Thrall, North Carolina State). - To view this image in full size go to the IVIS website at www.ivis.org . -

Figure 31a.

Figure 31b.

Common characteristics of intracranial neoplasms in dogs and cats have been documented, but some overlap exists [15,16,18]. 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. 32). 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. 33).

Figure 32. Post-contrast transverse CT image of a dog with cerebral meningioma. There is a broad-based, markedly-enhancing, sharply marginated mass in the dorsolateral aspect of the left temporal lobe. - To view this image in full size go to the IVIS website at www.ivis.org . -

Figure 33. Bone window transverse CT image of the same dog illustrated in Figure 32. There is focal sclerosis and hyperostosis of the left dorsolateral calvarium. - To view this image in full size go to the IVIS website at www.ivis.org . -

Figure 32.

Gliomas tend to be centrally located (intra-axial), peripherally enhancing (ring enhancement), and surrounded by a zone of edema (Fig. 34). 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. 35).
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. 36). New spiral CT techniques show promise for differentiating pituitary microadenomas based on changes in pituitary perfusion [112]. Metastatic neoplasia more commonly appears as multifocal regions of contrast enhancement, that may or may not be associated with ventricular displacement.

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. Patchy regions of edema and increased meningeal enhancement may also be seen with inflammatory brain disease. Abscesses and chronic hematomas may mimic gliomas, in that they are often centrally located and ring-enhancing [113]. Inflammatory brain disease may mimic neoplasia in appearance [20]. There may be solitary or multifocal regions of contrast enhancement (Fig. 37).

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 [114]. A previous study found that the diagnostic sensitivity for detecting middle ear disease was similar for radiographs and CT [115]. 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. 38). 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. 39a and Fig. 39b).
Figure 38. 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 39a and 39b. 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 39a and 39b.

Figures 39a and 39b. 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 40. 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.

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 [8,11]. 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. 40).

Type II disk herniation is characterized by circumferential bulging of the annulus, narrowing of the intervertebral disk spaces, endplate sclerosis, and endplate bone spurs (spondylosis 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 paraspinous mass, contrast-enhancing soft tissue in the vertebral canal, bone destruction or active proliferation, or pathologic fractures [58] (Fig. 41). Intramedullary neoplasms may sometimes be demonstrated with intravenous enhanced CT, however MRI is far more sensitive.

Figure 41. 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 [76] (Fig. 42).

Figure 42. 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 . -

Figure 43. 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 44. 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 . -

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 [116]. 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 [104]. Characteristics of degenerative stenosis include bulging of the disk margin, spondylosis, endplate sclerosis, hypertrophied ligamentum flavum, hypertrophied joint capsules, congestion of the venous structures, or subluxation (Fig. 43). Fragmentation of the vertebral endplate may occur with severe degenerative disc disease or preexisting sacral osteochondrosis [117] (Fig. 44). Dynamic subluxation is demonstrated by comparing mid-sagittal views obtained with the spine in flexion versus those obtained with the spine in extension (Fig. 45a and Fig. 45b).

Figures 45a. 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 . -
Figures 45b. 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 [21]. 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 gray in the image. Tissues with higher signal intensity are assigned whiter colors. Those with lower signal intensities are assigned darker gray 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. The possibilities are nearly endless. 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 (eg., 20 - 35 ms and 1500 - 2500 ms respectively). Fluid appears dark, fat appears white, and the gray 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.

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. 46). 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. 47). The void may obscure all adjacent structures or distort their shape.

Figure 46. 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 47. 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.

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,
3. The ability to acquire images in any plane desired, and
4. Absence of ionizing radiation (Fig. 48a and Fig. 48b). For example, MRI is much more sensitive than CT for early infarcts and edema.

Figures 48a and 48b. 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.

The main disadvantages of MRI vs. CT include:

1. Higher cost,
2. Shifting or heating up of metallic implants,
3. Severe distortion artifacts caused by metallic objects in the scan field,
4. More sensitive to motion artifacts and
5. Less sensitive for soft tissue calcification or bone proliferation.

High field magnets cannot be used for patients or personnel in early pregnancy or with cardiac pacemakers. The intravenous contrast agent most commonly used is gadolinium. This is a paramagnetic substance that causes adjacent hydrogen nuclei to relax more quickly. Tissues accumulating gadolinium have shorter T1 times and therefore appear bright in T1-weighted images. Causes of focal enhancement are similar to those previously described for CT. Future
developments of contrast material for MR imaging include non-gadolinium compounds, intrathecal contrast media, cerebral blood flow and volume evaluation, and, possibly, antibody-labeled contrast agents [118]. Recent advances in MR scanner technology also allow evaluation of intracranial vessels without the use of intravenous contrast material. The procedure is termed magnetic resonance angiography (MRA), because it resembles a conventional angiogram in appearance [119]. Image formation takes advantage of the fact that a signal void phenomenon occurs in regions with fast-moving blood. Pulse sequences are designed to selectively display regions where a signal void is present, without displaying the overlying structures. Three-dimensional reconstructions of blood vessels may also be created, so that the anatomic relationships can be more readily appreciated.

In the spine, some of the advantages of MRI versus CT include:

1. Earlier detection of Intervertebral disk degeneration,
2. Ability to differentiate the spinal cords and nerve roots from CSF ("myelogram effect"),
3. Higher sensitivity for intramedullary neoplasia, and
4. Ability to evaluate an entire region of the spine in a single examination (e.g., cervical, thoracic, lumbar).

One of the main disadvantages is the difficulty in getting good resolution in small-sized animals (less than 25 lbs). Often, image quality can be limited due to a low signal-to-noise ratio and partial volume averaging. Also, limited sensitivity for bony changes may make MRI less desirable for evaluating bone spurs, articular process joint disease, or calcified soft tissue masses.

Normal Findings -

Brain - For a detailed identification of anatomic structures, the reader is referred to one of several published anatomic atlases [12,120]. As with CT, all normal paired structures should be symmetrical. There should be no focal contrast enhancement (with the exception of the pituitary gland, veins, and sometimes the choroid plexus). T1-weighted images yield the best spatial resolution and morphologic detail for soft tissues overall [120]. However, there is poor to moderate contrast between the gray and white matter of the brain. Cerebrospinal fluid within the ventricles and subarachnoid spaces exhibits very low signal intensity and appears dark gray or black. Ventricles are normally well-visualized in dogs, but may be more difficult to appreciate in cats [121]. Ventricular asymmetry may be present as a normal anatomic variant, especially in beagles and labrador retrievers [122,123]. 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 gray matter and white matter. White matter has slightly lower signal intensity than gray 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 gray 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.

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 [11,124-126]. 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. 49). 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 49. 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. 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 vestibular disease [16,19,20,114]. 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 extra-axial 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. 50). Choroid plexus adenomas are most commonly found in intraventricular or cerebellopontine locations.

Figure 50. 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. Gliomas typically have an intra-axial location. Ependymomas and oligodendrogliomas are often periventricular. Medulloblastomas are often in the cerebellum. Gliomas tend to be hypointense in pre-contrast T1 weighted images, and hyperintense in T2 weighted images. They exhibit variable enhancement (Fig. 51a and Fig. 51b). Low grade gliomas may not enhance at all. High grade gliomas may have cavity areas and marked peritumoral edema. Pituitary adenomas are in the suprasellar region and are usually fairly sharply marginated. They appear isointense in pre-contrast T1 weighted images and are often uniformly enhancing.

Figures 51a and 51b. 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 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. 52). Syringohydromyelia of the cervical spine may also be present [127].

Intrarenchymal hemorrhage varies in signal intensity, based on the stage of hemoglobin breakdown [19,128]. 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. 53).

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. [129] Post-gadolinium T1-weighted images demonstrated increased leptomeningeal enhancement earlier than enhancement was seen with CT. Early intraparenchymal edema from encephalitis may be seen as ill-defined regions of increased T2 signal intensity, primarily within the white matter. Encephalitis may also be associated with ventricular asymmetry. Ring-enhancing abscesses may mimic gliomas. Multifocal, contrast-enhancing granulomas may mimic 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 [119] (Fig. 54a and Fig. 54b).

MRI is much more sensitive than CT for identifying central vestibular disease, primarily due to the absence of beam
hardening artifacts in the brainstem [114,130]. Peripheral vestibular disease is evident as an increased T1 and T2 signal intensity within the lumen of the affected tympanic bulla [130-132]. Post-gadolinium T1-weighted images may help differentiate free fluid from proliferative soft tissue. Sclerosis of the bulla wall cannot be identified when there is air in the lumen, due to a lack of signal from both air and cortical bone. Neoplastic middle ear disease may demonstrate T2-hyperintense tissue both inside and outside the tympanic bulla (Fig. 55).

Figure 55. Transverse, T2-weighted image of a cat with middle ear squamous cell carcinoma. There is mixed signal intensity tissue within the right tympanic bulla, external ear canal and para-aural region. - To view this image in full size go to the IVIS website at www.ivis.org.

Spine - Common applications for spinal MRI in animals include suspected degenerative spinal disease, early diskitis, neoplasia, or syringohydromyelia [7,11]. Degenerative disk disease is characterized by a decreased T2 signal intensity within the nucleus pulposus [124-126] (Fig. 56). Degenerative lumbosacral 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.

Figure 56. Sagittal, T2-weighted image of a dog with degenerative lumbosacral disk disease. There is decreased signal intensity within the L7 - S1 disc. - To view this image in full size go to the IVIS website at www.ivis.org.

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 canine experimental study MRI had a sensitivity of 93%, specificity of 97%, and accuracy of 95% for diagnosing disk infection [93]. 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. Epidural abscesses may exhibit ring enhancement in post-gadolinium T1-weighted images. In humans, MRI is considered to be the modality of choice for suspected spinal neoplasia [10]. It has been found to be more sensitive than scintigraphy for vertebral metastases [133]. Neoplasms most commonly appear hyperintense in T2-weighted images and exhibit contrast enhancement in post-gadolinium T1-weighted images. They are of variable T1-signal intensity. Arachnoid cysts are nonneoplastic masses that may cause spinal cord compression in humans and animals [10,78,134,135]. 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-extradural space. Syringohydromyelia is a focal accumulation of fluid within the spinal cord central canal or parenchyma [136]. 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.

References