Magnetic Resonance Imaging in Small Animal Medicine: Clinical Applications

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ABSTRACT:
Magnetic resonance imaging (MRI) produces high-contrast, anatomically detailed tomographic images without the use of x-rays. Although MRI has traditionally been used for diagnosing various diseases affecting the central nervous system, in recent years the range of clinical applications for MRI has broadened considerably. MRI is now being used for diagnosis in areas such as nasal neoplasia, eye and orbital diseases, and musculoskeletal diseases, including shoulder osteochondrosis, canine elbow dysplasia, and cranial cruciate ligament injuries. Magnetic resonance angiography (MRA) allows noninvasive depiction of vascular malformations, such as fistulas, aneurysms, and thrombi, and identification of precise anatomic locations of portosystemic shunts. As experience with MRI and MRA increases, there will surely be additional diagnostic roles for these techniques.

HOW MRI WORKS
Magnetic resonance imaging (MRI) is being used with increased frequency in veterinary medicine because of its ability to produce high-contrast, anatomically detailed tomographic images. Unlike radiography and computed tomography (CT), which use attenuation of an x-ray beam to create an image, techniques that use magnetic resonance (MR) do not reflect changes in tissue density. Instead, MR uses the electromagnetic signal emitted from protons in different tissues.
The electromagnetic field of the body is zero. During MRI, the body, or the part of the body being imaged, is placed in a large magnet, which causes all the free protons to align with the external magnetic field (Figure 2). Simultaneously, the external magnetic field causes the protons to wobble like a spinning top—a phenomenon called precession (Figure 3). This creates a magnetic field produced by the protons of the body, which can be represented by a vector (Figure 4).

To create an image, a radiofrequency pulse is transmitted through the body under the influence of the external magnetic field. This pulse causes the vector of the electromagnetic fields of the protons to shift with respect to their original orientation and precess in synchrony, also known as in phase. This creates an overall shift in the vector of the body’s magnetic field. Immediately after the radiofrequency pulse is discontinued, the protons relax, which means that they (1) realign their electromagnetic fields in relation to the external magnetic field (T1 relaxation) and (2) precess out of synchrony so that they become out of phase (T2 relaxation). The overall magnetic field of the body thereby returns to baseline (Figure 5). Because protons in different environments (i.e., tissues) relax at different rates, the intensity of the signal coming from an electromagnetic field differs with respect to the local environment. Thus different tissues emit signals of different intensity (in relation to their respective magnetic fields) during the relaxation period. The emitted signals can be collected in tomographic slices. On the basis of relaxation properties, the computer assigns a shade of gray to each pixel according to the intensity of the signal and can

\textbf{One of the most frequent indications for MRI is central nervous system disease.}
Figure 2. Protons are normally aligned in a random fashion and cancel out each other’s magnetic field. However, when they are exposed to an external magnetic field, they align themselves in one of only two possible ways: either in the same direction as the external field (parallel, as shown) or in the opposite direction (antiparallel). Many more protons align themselves parallel to the external field because it is a lower energy state. (From MRI Made Easy … Well Almost. © Berlex Laboratories; used with permission.)

Figure 3. Protons in a strong external magnetic field wobble like a spinning top, which is called precession. (From MRI Made Easy … Well Almost. © Berlex Laboratories; used with permission.)

display different tissues on a given image.

Several different MRI protocols (pulse sequences) are used to optimize anatomic and physiologic information. With conventional spin echo pulse sequences, an image can be T1, T2, or proton-density weighted if most of the contrast between tissues is due to a difference in T1 relaxation, T2 relaxation, or proton concentration, respectively. A contrast agent, most often gadolinium diethylenetriamine pentaacetic acid (Gd-DTPA, Magnevist, Berlex Laboratories), can modify the relaxation properties of tissues and can make two tissues that would otherwise have similar relaxation characteristics appear more distinct. A paramagnetic contrast medium with a T1 effect thus shortens the T1 relaxation time.

ADVANTAGES

Patients with a variety of clinical signs arising from a number of different organ systems can benefit from MRI. The technique is mostly helpful for reaching a diagnosis but can also be instrumental for planning therapy such as surgical excision or irradiation of a neoplasm. MRI is certainly not appropriate for every patient, and a diagnosis can often be derived with more traditional imaging modalities such as radiography or ultrasonography. However, some organ systems such as the central nervous system (CNS) are quite difficult to image with these traditional modalities. When the differential diagnosis includes diseases that are difficult or impossible to image with traditional methods, advanced imaging techniques such as CT, MRI, or magnetic resonance angiography (MRA) can help in formulating a shorter list of diagnostic differentials or in arriving at the final diagnosis. As with any other diagnostic test, MRI will never replace a thorough anamnesis and physical examination. In fact, the decision to conduct MRI, as with any other diagnostic test, should be dictated by the results of such initial evaluations.

Whether CT or MR techniques are better can be debated. A dying adage stipulated that CT is better for imaging bones, whereas MR techniques are better for imaging soft tissues. With technologic advances in both of these imaging modalities, this notion is becoming obsolete. Very few comparative studies exist in veterinary medicine, and their results are at best short-lived as
advances in both technologies continue to improve imaging capabilities. Comparing CT with MRI may be similar to comparing a PC with an Apple computer: The results of the comparison are true only for as long as the technology for each computer does not change.

**DISADVANTAGES**

Disadvantages of MRI examinations are related to cost, the necessity to use heavy sedation or general anesthesia, limited availability, and logistics of coordinating everything when MRI is not available on-site (i.e., scheduling the MRI examination, having staff available to help, transporting the patient, bringing the necessary material, inducing anesthesia outside the veterinary hospital, and being prepared for a possible anesthetic emergency). MRI is becoming more accessible, and a few veterinary colleges and private practices have the technology available on-site. Alternatively, some veterinarians have been able to make arrangements with human medicine imaging centers in their own areas. The typical cost of examining small animals via MRI ranges from $750 to $1,500, depending on the type of examination and the number of sequences required.

**INDICATIONS FOR USE**

One of the most frequent indications for using MRI is a possible CNS disorder. Clinical signs such as seizures, ataxia, cranial nerve abnormalities, paresis, and paralysis are indications for use. The nerve tissues within the cranium (i.e., the cerebrum, cerebellum, and brain stem) are virtually impossible to image with conventional radiography and ultrasonography. The MR anatomy of both canine and feline brains has been described. Cerebrospinal fluid appears black (hypointense) on a T1-weighted image and white (hyperintense) on a T2-weighted image. Gray matter, because of its greater water content, is darker than white matter on T1-weighted images and whiter than white matter on T2-weighted images. Gd-DTPA enhancement during intracranial imaging reveals damage to the blood–brain barrier. Intracranial structures that normally lack a blood–brain barrier, which include the choroid plexus, pituitary, infundibulum, dura, cavernous sinuses, cortical veins, and sinus mucosa, are also enhanced.

**Neoplasms**

MRI is quite helpful for diagnosing neoplasms of the CNS (Figure 6). Intracranial tumors that have been diagnosed in this way include meningioma, astrocytoma, oligodendroglioma, ependymoma, mixed glioma, dermoid cyst, choroid plexus papilloma, carcinoma, and meningeal carcinomatosis. Abnormal cell infiltrates usually change the signal intensity and are visible as an altered signal from the surrounding brain. A small percentage of benign tumor types are isointense relative to normal brain tissue; therefore, administering contrast medium for T1-weighted imaging is always recommended for optimal detection of lesions. Neoplasms usually appear hypointense relative to normal brain parenchyma on a T1-weighted image and hyperintense on T2- and proton density–weighted images.

In one study, the origin, site, shape, growth pattern, signal intensity, and contrast enhancement were characteristics that were diagnostic for tumor type. Meningiomas tend to be lenticular, broad-based, or plaque-like masses; ependymomas and choroid plexus tumors tend...
to be circumscribed, smooth, or lobulated tumors associated with the ventricular system; and astrocytomas, oligodendrogliomas, and lymphomas are typically more amorphous and infiltrative with poorly defined margins or can manifest as a diffuse infiltrative process in the parenchyma or leptomeninges. In a different study, all tumors exhibited contrast enhancement with gadolinium. Gd-DTPA–enhanced T1-weighted images helped delineate a tumor from surrounding edema.

Dogs with pituitary-dependent hyperadrenocorticism have been evaluated with MRI for the presence of a visible mass of the hypophysis. In this study, 52% of dogs diagnosed with the disorder had a mass visible via MRI. Dogs with a visible pituitary mass may or may not exhibit neurologic signs. A cat with acromegaly had a large pituitary mass revealed by MRI.

**Inflammatory and Other Nonneoplastic Conditions**

MRI can also depict inflammatory and other nonneoplastic conditions of the CNS. MRI was used to help diagnose granulomatous meningoencephalitis in dogs and necrotizing encephalitis in a Yorkshire terrier, and it aided in making a presumptive diagnosis of neurocysticercosis in a dog. MRI can demonstrate lesions in animals with encephalitides caused by viruses (e.g., distemper), bacteria, or fungi (e.g., cryptococcosis). Cats with neurologic manifestations of feline infectious peritonitis may show ventricular dilation and hyperintensity of the ventricular lining, choroid plexus, and meninges on T2-weighted images and abnormal enhancement with Gd-DTPA. Generally, foci of inflammation appear hypointense on T1-weighted images obtained without contrast agents and hyperintense on T2- and T1-weighted images after administering Gd-DTPA. MRI was also used to image an intracranial epidermal cyst in a dog. In cats, MRI has been used to help diagnose cerebellar hypoplasia, cerebellar degeneration, and an arachnoid cyst in the cerebellar pontine area. Although the presence of certain MRI changes or features can be highly suggestive of a particular CNS disease, MRI changes are not pathognomonic, and histopathology is often required for a final diagnosis.
Seizures

Because of the sensitivity of MRI in depicting intracranial lesions, it should be considered in the diagnostic workup of animals that present with seizures. A diagnosis of idiopathic epilepsy requires that a dog have no metabolic diseases and normal MRI studies. However, MRI studies revealed lesions that were thought to be the result rather than the cause of seizures in three dogs. In one dog, the lesion completely resolved during follow-up MRI studies. In humans, histopathology of these lesions revealed normal brain tissue, gliosis, or reactive astrocytosis.

Spinal Cord and Vertebal Column Disorders

MRI is commonly performed in the pursuit of a diagnosis for diseases affecting the spinal cord. Clinical signs such as paresis or paralysis, spinal pain, and ataxia localized to the spinal cord are indications for MRI of the spine. At Washington State University, MRI is routinely conducted in cases of paralysis and has been invaluable in diagnosing intervertebral disk disease. Enhancing the subarachnoid space with contrast material such as that used in myelography is not necessary, and using MRI eliminates the risk of iatrogenic trauma to the cord or of local or systemic adverse reactions to contrast media.
MRI has been used to diagnose syringomyelia,15 hydro- 
myelia,16 and occipital dysplasia in dogs22 as well as spinal 
arachnoid cysts in dogs and a cat.18 Radiography has been 
unreliable in diagnosing lumbosacral disease in dogs, even 
with the use of contrast studies.19,20 Abnormalities can be 
present on radiographs of normal dogs, and radiographic 
findings can be normal in affected dogs.20 MRI, however, 
is reliable in evaluating lumbosacral disorders without the 
use of a contrast agent19 (Figure 7). MRI gave more exact 
information than radiography,19 and MRI findings were 
consistent with surgical findings.20 MRI demonstrated 
nerve root displacement, loss of epidural fat, interverte-
bral disk degeneration and protrusion into the vertebral 
canal and intervertebral foramina, osteophytes, and 
fractures of the articular processes.20 MRI was used to 
make a presumptive diagnosis of lumbosacral dis-
kospondylitis in a dog before the appearance of definitive 
radiographic abnormalities.21

The cervical vertebral column and spinal cord have 
been evaluated by means of MRI. In one study, MRI 
results were consistent with surgical findings in dogs 
with cervical myelopathy.22 Neoplasia of the spine was 
also diagnosed using MRI (Figure 8). Anatomic loca-
tions of tumors were accurately determined with MRI 
in all dogs in one study.23 T2-weighted images helped 
identify the anatomic location, and transverse T1-
weighted images obtained before and after adminis-
tering Gd-DTPA assisted in revealing additional localization 
and definition of tumor extension. In the same 
study, bone infiltration was correctly assessed in most 
dogs, but localizing the tumor in the intradural-extra-
medullary compartment was not always possible.23 MRI 
was useful in diagnosing cervical extradural synovial 
cysts in a dog,24 peripheral nerve sheath tumors,25 and an 
intradural-extramedullary meningioma in a cat.26

Nasal Tumors

Epistaxis and chronic nasal discharge are indications 
for nasal MRI, and patients with suspected nasal tumors 
are candidates for this study (Figure 9). The results of 
MRI can help in procuring a biopsy sample, especially 
when the sample is obtained without using endoscopy. 
Radiographs often underestimate the extent of the dis-
ease. Documenting the extent of the tumor is important 
in treatment planning when radiation therapy or surgery 
is contemplated. MRI may be superior to CT because of 
its ability to provide more detailed anatomic features of 
the mass as well as secondary changes.27

Eye and Orbital Disease

Although exophthalmos and strabismus can be indi-
cations for MRI, the technique has also been used to 
describe the normal anatomy of the feline and canine 
eye and orbit.28 B-mode ultrasonography has proved
its inherent sensitivity to flow phenomena, MRI is a particularly useful and noninvasive means of identifying intracranial vascular lesions such as cavernous sinus syndrome in dogs.

Musculoskeletal System Conditions
Clinicians are finding more MRI applications within the musculoskeletal system in small animals, mostly for patients in which radiographs fail to identify the cause of lameness. MRI may make it possible to reach a diagnosis, which would lead to recommendations for a proper therapeutic plan. MRI aided evaluation of the extent and severity of inflammatory changes within the subchondral bone in dogs with shoulder osteochondrosis and was shown to be superior to CT in identifying nonmineralized cartilaginous fragments. It has also been valuable in detecting changes in cartilage thickness, osteophytosis, and intraarticular loose bodies in experimental osteoarthritis of the stifle in dogs. In addition, MRI has provided images of the canine elbow delineating the coronoid and anconeal processes. Another application of MRI is diagnosis of cranial cruciate ligament injury in dogs with no or minimal cranial drawer signs (Figure 10). The normal anatomy of the canine stifle and carpal ligaments has also been described via MRI. It may

Veterinary Schools That Offer MRI for Small Animals

**United States**
- Auburn University
- Colorado State University
- Kansas State University
- Louisiana State University
- Mississippi State University
- Ohio State University
- Oklahoma State University
- Purdue University
- Tufts University
- University of California, Davis
- University of Florida
- University of Georgia
- University of Illinois
- University of Maryland
- University of Missouri
- University of Pennsylvania
- University of Wisconsin, Madison
- Virginia Polytechnic Institute and State University
- Washington State University

**Canada**
- Ontario Veterinary College, University of Guelph
- University of Saskatchewan

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**Figure 10.** Parasagittal T1-weighted image of the stifle of a 6-year-old, 88-lb (40-kg) mixed-breed dog presented for left hindlimb lameness. Irregularity and lack of continuity in the cranial cruciate ligament (black arrow) can be seen. The continuity of the caudal cruciate ligament is visible (white arrowheads) as it spans the femoral condyle (F) and tibial plateau (T). On subsequent MR images in this series, the continuity of the cranial cruciate ligament could not be observed. The dog suffered a complete tear of the cranial cruciate ligament.
eventually be possible to diagnose sprains, strains, and other conditions of the ligaments, tendons, and muscles more accurately in cases in which the diagnosis would otherwise be made by exclusion. In experimental studies, MRI has been used to evaluate the growing physis in goats after trauma.38

**Vascular Abnormalities**

Various abnormalities affecting the vascular system can be diagnosed via MRI or MRA. The MRA image closely resembles a conventional angiogram, and MRA is a noninvasive means of depicting vascular malformations, fistulas, and aneurysms. Thrombus of the external iliac artery in a dog was imaged using MRI and MRA. Collateral circulation via the lumbar arteries was also shown in this case.39 In another study, MRA was beneficial in diagnosing and determining the anatomic location of portosystemic shunts in dogs.40 This capability may be beneficial for breeds of dogs with suspected intrahepatic shunts when clinicians require more accurate information about the feasibility of surgically correcting the shunt before performing surgery (e.g., right-sided versus left-sided intrahepatic shunts). The vascular origin of the lesions in two dogs diagnosed with cavernous sinus syndrome was confirmed by using MRA techniques.41

**Bulla-Related Disorders**

MRI can help identify dogs that suffer from diseases of the bullae and, therefore, can aid in decisions about which patients should have surgery for bulla osteotomy.42 It has also been used to image a recurrent draining tract in a dog and allowed identification of the nidus, which led to successful surgical treatment of the tract.43

**CONCLUSION**

MRI is becoming the imaging modality of choice for many common small animal disorders. The superior image contrast available with MRI has long been recognized in CNS disorders. Numerous other applications are emerging, and more should follow with additional experience. MRI can be quite useful in reaching a diagnosis when other imaging methods fail and can be instrumental in planning a therapeutic strategy because of its ability to produce high-contrast, anatomically detailed tomographic images.

**REFERENCES**


1. The MR image is created by
   a. attenuation of an x-ray beam.
   b. an electromagnetic signal emitted from protons.
   c. radioactivity emitted from an isotope.
   d. a sound wave emitted through the tissues.

2. Which statement about protons in tissues is true?
   a. Protons and hydrogen nuclei are not the same.
   b. The electromagnetic fields of protons normally can cancel each other.
   c. When placed in the magnet of the MR unit, protons stop precessing.
   d. none of the above

3. Gd-DTPA enhancement
   a. is caused by shortening the T1 time.
   b. may occur in the CNS because it can cross the blood–brain barrier.
   c. does not normally occur in any intracranial structures.
   d. cannot help delineate a tumor from surrounding edema in the CNS.

4. Which statement about MRI and CNS hemorrhage is true?
   a. The MRI appearance of hemorrhage does not change over time.
   b. MRI cannot usually help diagnose intracranial hemorrhage.
   c. The physical state of the iron in hemoglobin affects the MRI appearance of tissues containing extravasated blood.
   d. none of the above

5. Which statement about MRI and animals with seizures is true?
   a. MRI provides poor images of the CNS and, therefore, does not help.
   b. Any lesion of the CNS found by using MRI is the cause of the seizures.
   c. MRI findings for the CNS are usually normal in patients with idiopathic epilepsy.
   d. none of the above

6. For dogs or cats with myelopathy,
   a. contrast-enhanced radiographic studies consistently provide excellent results.
   b. MRI cannot provide accurate information without the use of a contrast agent.
   c. MRI cannot provide accurate information on bone infiltration of spinal tumors.
   d. MRI provides accurate information about the anatomic location of spinal tumors.

7. MRI can be used to detect
   a. suspected nasal neoplasia.
   b. orbital and preorbital diseases.
c. suspected peripheral nerve sheath tumors.
d. all of the above

8. For the musculoskeletal system, MRI
   a. can help diagnose a ruptured cranial cruciate ligament.
   b. has not been helpful in detecting intraarticular loose bodies in experimental osteoarthritis.
   c. is inferior to CT in identifying nonmineralized cartilaginous fragments.
   d. none of the above

9. Which statement about MRA is true?
   a. MRA images are quite different compared with those obtained by conventional angiography.
   b. MRA is not helpful in determining the anatomic location of portosystemic shunts.
   c. MRA can help depict vascular fistulas and aneurysms.
   d. none of the above

10. Known indications for performing MRI include
    a. chronic draining tracts.
    b. disorders of the tympanic bullae.
    c. epistaxis.
    d. all of the above