Establishing Standard MR Imaging Protocols for Brain and Spine Evaluation in Small Animals

Fred Wininger, VMD, MS, DACVIM (Neurology)

The Animal Neurology Center, St. Louis, MO, USA

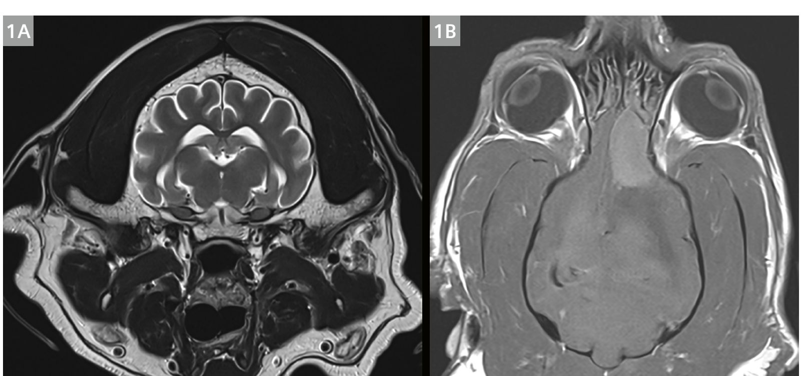
Introduction

The development of standardized magnetic resonance imaging (MRI) protocols in veterinary medicine is driven by a unique constellation of clinical, logistical, and anatomical challenges that distinguish it from human radiology practice. While MRI is widely accepted as the gold standard for central nervous system (CNS) imaging in both species, the workflow, personnel, and patient variables in veterinary settings necessitate a fundamentally different approach to protocol design [1].

One of the most notable differences lies in who is operating the scanner. In human medicine, MRI studies are conducted by board-certified radiology technologists with formal training in MRI physics, pulse sequence optimization, and image interpretation. These professionals frequently adjust scan parameters on the fly, tailoring the acquisition to subtle patient-specific anatomical or pathological features. In contrast, most veterinary imaging centers rely on licensed veterinary technicians to operate MRI scanners. While these technicians possess deep knowledge of animal anatomy and are well-equipped to set up basic scan planes, they often lack advanced MRI-specific training, especially in adjusting sequence parameters such as bandwidth, echo spacing, or matrix resolution. Although remote supervision or image review by a neurologist or radiologist can help bridge this gap, the protocols themselves must be inherently robust, intuitive, and reproducible, capable of producing diagnostic-quality studies without relying on real-time expert intervention [2]. In practical terms, this means that sequences must be pre-optimized, require minimal adjustments, and follow a structured workflow that is intuitive for technicians to execute without ongoing intervention. Sequences should be set up to yield high diagnostic utility without needing constant optimization or parameter tweaking.

Another significant difference between human and veterinary MRI lies in the initial interactive decision to perform the procedure between the client and clinician. In many ways, veterinary medicine mirrors human pediatrics, where the client and patient are two separate entities with the prior advocating for the latter under the guidance of the clinician. Three significant considerations distinguish human from animal MRI and play significant role when electing to proceed with the procedure:

1. Anesthesia: The typical pet will not lie still for an MRI study. Further, the sound and experience would be frightful for them, perhaps even considered inhumane [3]. In addition to concerns for patient comfort, the potential for damage to their more sensitive hearing is well documented [4, 5]. However, the awake patient will not tolerate sitting still with hearing protection a challenging task for research animals that undergo months of extensive training with an experience behaviorist — unfeasible in the clinical setting [6]. For this reason, patients must undergo general anesthesia. General anesthesia is in many cases safe, but some patients (elderly or with other comorbidities) can



1 The planes of section in the dog have different designation in domestic animals from humans. The supratentorial structures in the human are perpendicular to the axis of the spinal cord, whereas in the dog they line in parallel. For this reason, the designation of coronal in a human is the transverse plane in a dog, whereas the axial of a human would be analogous to a "dorsal" plane in a dog.

have a significantly elevated anesthesia “ASA physical classification” [7]. It is perhaps the most common reason for owners to elect to pursue MR imaging. Potential cost-benefit ratios for diagnostics, well beyond financial tolls, are a large part of the veterinary neurologic consultation.

2. Financial considerations: MRI purchase and maintenance is expensive by any measure, and those costs translate to increase expenses for the client. Above the imaging, pet owners are also paying for general anesthesia, and at a minimum, three care of staff members (the clinician, the MR operator and the anesthetist). While the intrinsic financial value of advanced care for animals is in the eye of the beholder, the plain fact is that regardless of desire, the means to pursue care is often out of reach for those in need [8]. Insurance is available for veterinary patients, but in the United States has a low attrition rate, with estimates by the North American Pet Health Insurance Association partial coverage for 4% (6.4 million) of the American Veterinary Medical Association’s estimated 162.9 million US pets [9].
3. Therapeutic value: Because of these constraints, the likelihood a diagnostic with alter the therapeutic course becomes the greatest impactor on the decision to pursue the diagnostic at all. If an owner is disinclined to consider measures of treating a brain tumor, regardless of how debilitating the lesion’s effects might be or minimally morbid the therapy is, imaging is often not pursued. Though there is certain merit in diagnostics for the sake of owner understanding and emotional resolution, that is often trumped by patient concerns.

The paradox of veterinary MRI: Needing more with less

There exists a persistent misconception among clients, vendors, and even some clinicians that veterinary medicine requires less than its human counterpart in terms of imaging sophistication. Naturally, human brains are more complex in their forebrain anatomy, and because of our eloquent cortex, small lesions in anatomically “important” areas can have larger consequences than in domestic animals given their lack of prefrontal cortex and dominant brainstem function [10]. However, the reality is that veterinary MRI demands more from both the equipment and the operators. While veterinary hospitals often operate under tighter financial constraints and with fewer staff than human institutions, they are tasked with imaging a much more variable patient population, including a range of species, morphologies, and sizes. Drawing sufficient signal from small bodies demands higher field strengths, stronger gradients, and advanced algorithms [1].

Consider the diversity of patients encountered in veterinary neurology: Human imaging protocols benefit from relative anatomical consistency within the population, with limited variance in height, weight, and proportional limb length. In veterinary medicine, by contrast, a single imaging facility may be tasked with scanning patients ranging from a sub-2 kg, 8-week-old kitten to a 60-kg Great Pyrenees. Protocols must therefore be adaptable to a wide range of body sizes and anatomical variations, often necessitating multiple size-specific protocol groupings — small, medium, and large patients — with tailored field of view, coil selection, and sequence parameters [11]. Specifically, a traditional head-and-neck coil may be ideal for a dog with a similar sized head to a human, but a conforming contour coil is preferrable in smaller patients where element density closest to the region of interest is essential. Positioning these patients in the magnet isocenter is paramount — but certainly not easy in the anesthetized patient. Spine coils are adequate for human patients but are almost unusable in smaller ones [12].

The challenge is further compounded by the fact that veterinary patients are smaller, which reduces the inherent signal-to-noise ratio (SNR) and places even greater demands on the magnet and coils to generate diagnostically useful images. Many of our species (cats) have proportionally lower body-water content, increasing signal challenges. Thus, veterinary imaging requires more signal, not less. This places premium demands on the hardware *and* software, highlighting the benefits of AI/Deep Resolve technology. It also requires more versatility, as operators must be prepared to evaluate anatomical variants, breed-specific morphologies, and diseases not commonly encountered in humans. And perhaps most importantly, veterinary imaging requires more comprehensiveness in every study, as the opportunity to repeat imaging is often limited by cost, anesthesia risk, and logistical feasibility. Yes, we often will image multiple body regions, evaluating for multiple unrelated differential lists, with contrast, in a single session — because there is literally a single opportunity to perform the studies optimally.

This need for higher SNR cannot be remedied by longer scan times because of the anesthetic duration. Small patients cannot shiver. In the traditional MRI room, they quickly become hypothermic, increasing the need for expedient imaging. This requirement imposes strict time constraints, with optimal acquisitions being sub-4 minutes and total scan times ideally under 45 minutes. Certain sequences, such as echo planar imaging, are acoustically louder and may require higher levels of anesthetic, inversely proportional to safety. Anesthesia also precludes certain voluntary-effect sequences, such as breath-hold studies or functional imaging. Protocols must be efficient and time-conscious, minimizing scan duration to reduce anesthetic risk while still maximizing diagnostic value. It is also noteworthy that MRI often immediately precedes surgery and, in the common case of emergent intervertebral disc herniation, is performed under the same anesthetic event, furthering the need for time sensitive studies. There is one value add of an 100% anesthetized patient population: Claustrophobia is not a concern and smaller bore (60 cm) units are considered commonplace.

Whenever possible, the presence of an imaging specialist at the console — whether a radiologist or neurologist — greatly enhances the diagnostic yield. Real-time feedback on sequence quality and lesion identification allows for dynamic adjustment of the protocol, additional targeted imaging, or even early cessation of the scan once diagnostic goals have been met. However, in reality, this level of involvement is not always achievable, especially in busy or resource-limited practices. The protocols must therefore be designed to succeed in the absence of immediate specialist input, with built-in redundancy and robustness.

Standard brain imaging protocols

To meet these challenges, brain imaging protocols in veterinary medicine are highly standardized and stratified by patient size. Technicians are typically responsible for selecting the appropriate protocol based on body weight, which governs key parameters such as field of view, slice thickness, and matrix resolution. Once selected, the protocol provides a consistent set of sequences, and the technician's primary task is to correctly identify and prescribe the planes of section relative to the patient's anatomy.

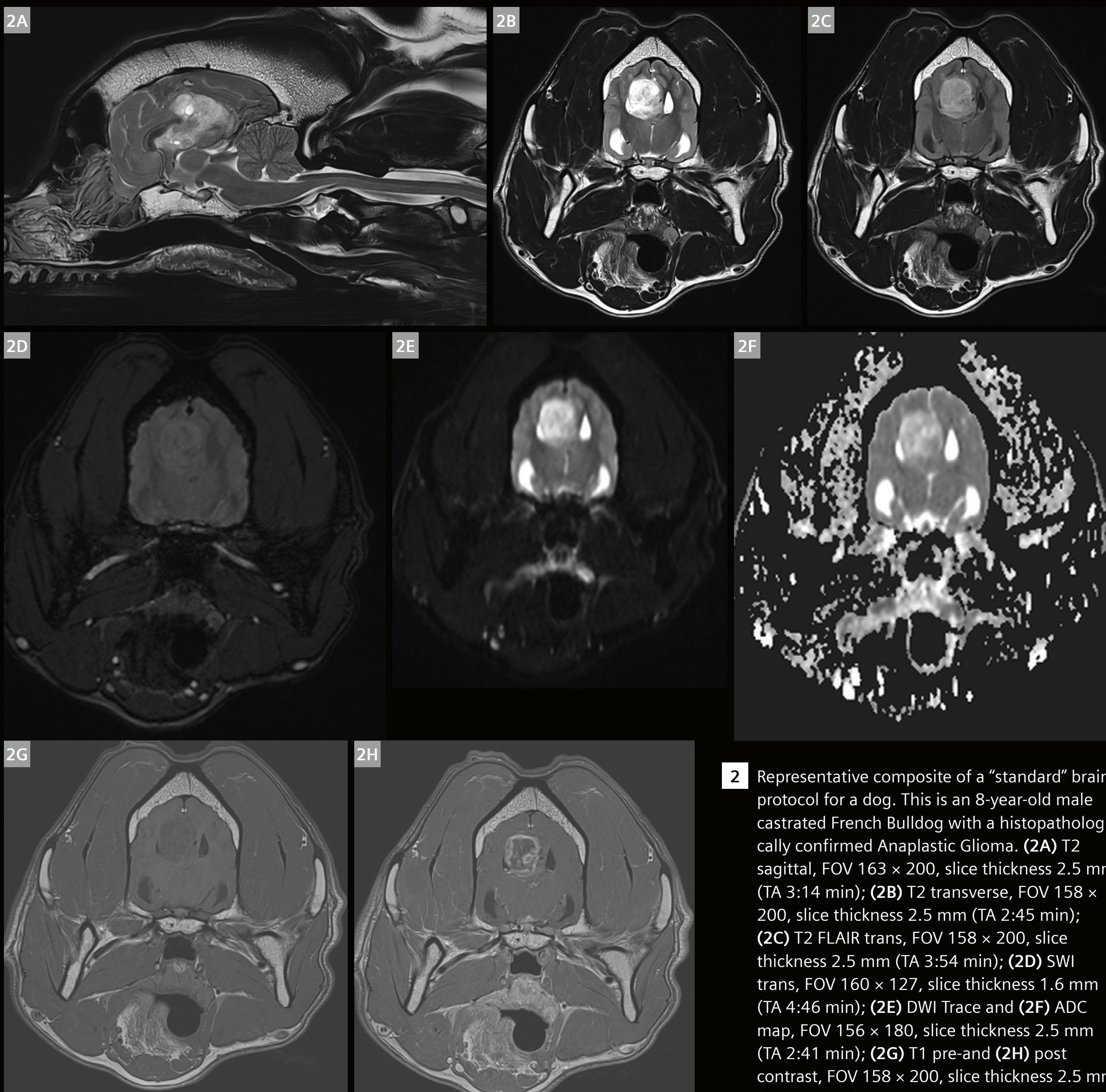
The orientation of imaging planes in veterinary neurology differs significantly from human conventions. Because the long axis of the canine brain is parallel to the brainstem (unlike the perpendicular relationship in humans), what is referred to as a coronal plane in humans is more analogous to a transverse or axial plane in animals, and vice versa. Veterinary brain MRI protocols typically align transverse sections perpendicular to the hard palate to ensure optimal visualization of forebrain and brainstem structures. Phase encoding is preferably in the lateral plane to avoid aliasing of the pulsating carotid arteries over the brain parenchyma.

Core sequences include:

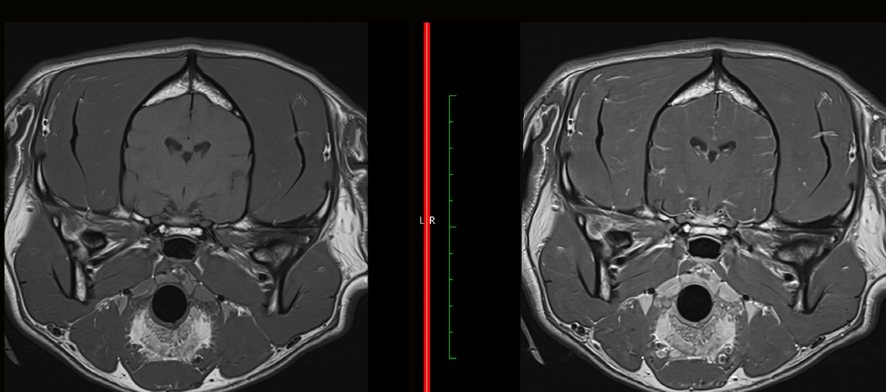
- **T2-weighted sagittal:** Evaluation of midline, ventricles, and global architecture.
- **T2-weighted transverse:** The workhorse for pathology; most CNS disease is T2-hyperintense.
- **FLAIR transverse:** Critical for detecting periventricular lesions and making inflammatory conditions more conspicuous. One of the most common pathologies in veterinary medicine is sterile meningitis (meningoencephalitis of unknown origin, MUO). This immune-mediated pathology is most frequently seen in female, middle-aged toy-breed dogs. Often focal regions of T2 signal are the only abnormality, and FLAIR imaging makes the lesions significantly more conspicuous [11, 13].
- **Susceptibility-weighted imaging:** SWI has supplanted T2* GRE imaging as the gold standard in detecting brain hemorrhages. Hemorrhagic strokes are being recognized with increasing frequency in dogs. Microhemorrhages are a frequent finding in senior patients [14, 15].
- **Diffusion-weighted imaging with ADC map:** Ischemic cerebrovascular accidents (CVA) are five times more common than hemorrhagic CVA in dogs. DWI/ADC is a common technique with relatively high specificity to confirm vascular infarction and differentiate it from intra-axial neoplasms, with the former showing higher levels of restricted diffusion [16, 17]. DWI is also valuable for identifying cytotoxic edema and polioencephalomalacia [18].
- **T1-weighted transverse (pre-contrast):** Predominantly used as a structural reference for post-contrast studies. The pre-contrast T1 can also be used to identify inherent paramagnetic tissues, such as melanin in neoplasms and hemorrhage degenerative staging [2].
- **T1-weighted post-contrast:** This is typically acquired as both a 2D TSE and using **3D isotropic sequences** (e.g., T1 SPACE or MPRAGE) to replace traditional three-plane imaging and facilitate multiplanar reformatting (MPR) in any orientation. The primary need for paramagnetic contrast studies is to identify and characterize neoplasms. The two most common brain tumors in dogs are meningiomas and gliomas. Extra-axial meningiomas generally have homogenous, strong contrast enhancement because of their high vascularity. Gliomas have variable contrast uptake, most commonly a peripheral ring-enhancement pattern because of their disruption of the blood-brain barrier and adjacent necrotic/poorly vascular center [19]. In addition to resolved post-contrast imaging, we often utilize 3D gradient-based imaging for volume assessment of certain brain structures, such as in cases of canine cognitive dysfunction, the dog equivalent of Alzheimer's disease [20]. These studies are also essential for neuronavigation registration for brain biopsy and other surgical approaches [21].

Optional sequences

- **Diffusion tensor imaging (DTI):** At present, DTI is considered an academic pursuit. Though scant, evidence-based reports have attempted to use mean diffusivity and fractional anisotropic measurements to assess neurodegenerative conditions. This has largely remained in the research sphere [22].
- **MR spectroscopy:** MRS, too, has been considered largely academic given poor specificity in differentiating neoplastic lesions. Both DTI and MRS are more difficult in the smaller brains of domestic animals, and voxels large



2 Representative composite of a "standard" brain protocol for a dog. This is an 8-year-old male castrated French Bulldog with a histopathologically confirmed Anaplastic Glioma. **(2A)** T2 sagittal, FOV 163 × 200, slice thickness 2.5 mm (TA 3:14 min); **(2B)** T2 transverse, FOV 158 × 200, slice thickness 2.5 mm (TA 2:45 min); **(2C)** T2 FLAIR trans, FOV 158 × 200, slice thickness 2.5 mm (TA 3:54 min); **(2D)** SWI trans, FOV 160 × 127, slice thickness 1.6 mm (TA 4:46 min); **(2E)** DWI Trace and **(2F)** ADC map, FOV 156 × 180, slice thickness 2.5 mm (TA 2:41 min); **(2G)** T1 pre-and **(2H)** post contrast, FOV 158 × 200, slice thickness 2.5 mm (TA 3:47 min).



3 Sterile Meningoencephalitis is a common presentation in the veterinary field, much more so than infectious etiologies. Pachy- and Leptomeningeal enhancement is the hallmark finding for diagnosis and can be made more conspicuous with subtraction post-processing. (T1 trans pre- and post-contrast, FOV 142 × 180, slice thickness 2.8 mm, TA 2:58 min.)

enough for adequate signal often suffer from severe volume averaging and incorporation of fluid signal from the ventricular system and subarachnoid space [23].
- **Radial acquisitions:** BLADE sequences can be used in patients that have high anesthetic risk or are so mentally debilitated (stuporous/comatose) that anesthesia is not required. Historically, these sequences have been faster and more motion-robust. Since the advent of Deep Resolve, the inherent value of these sequences has diminished.
- **Phase-contrast:** Chiari-like malformation (caudal occipital malformation syndrome) and subsequent syringohydromyelia is very common in certain breeds, with an anatomical prevalence nearing 90% in King Charles Cavalier Spaniels and Brussels Griffons. While not essential for the individual patient, cerebrospinal-fluid (CSF) flow studies are essential in our understanding of the pathology in these patients [24].

Spinal imaging protocols

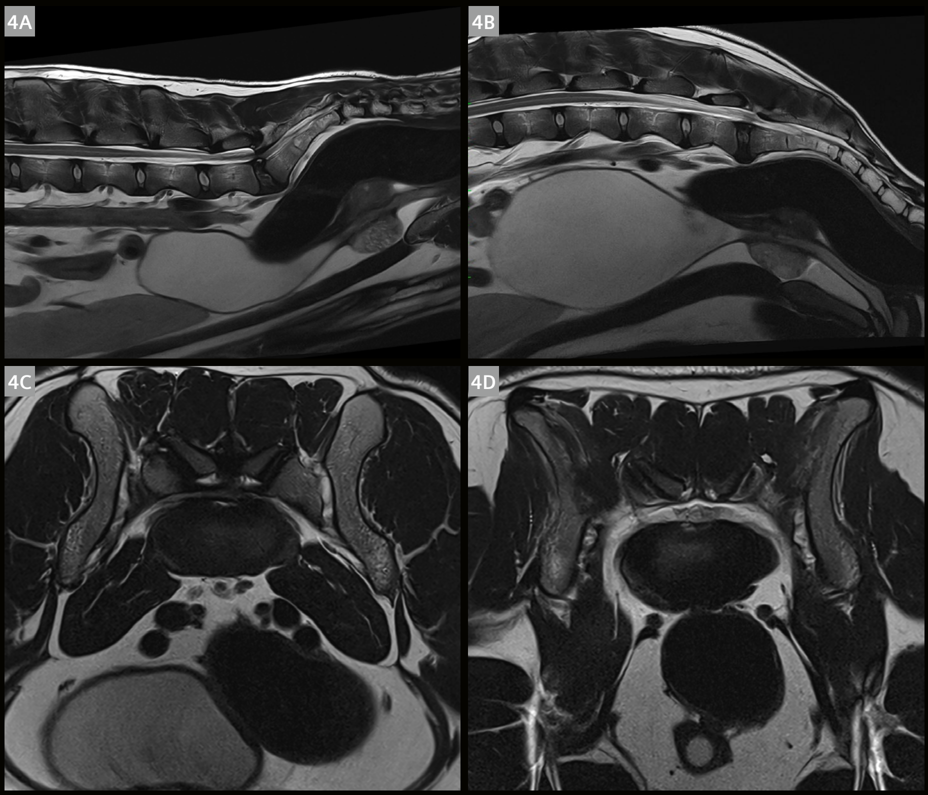
Spinal MRI is inherently more interpretive and problem-solving in nature. Because pathology is often highly localized, spinal protocols must be tailored to the suspected region of interest (ROI), which is typically determined by clinical neurolocalization. This approach makes spinal MRI less standardized and more iterative. Though technologists are trained to identify lesions, the diagnostician is present to confirm completion of the study, since important ROIs may be overlooked.

Standard spinal MRI sequences include:
- **T2-weighted sagittal (C1–T2 or T2–S1):** The overwhelming majority of spinal pathologies are due to intervertebral disc herniation. Veterinary medicine is overwhelmed by "chondrodystrophic breeds" such as dachshunds, French bulldogs, beagles, and other short-legged, long-backed breeds [25]. These dogs undergo chondroid dysplasia of their nucleus pulposus, and fibroid metaplasia of their annulus fibrosis at 3 years of age. This genetic predisposition to intervertebral disc degeneration, coupled with high-impact activities lead to the intervertebral disc herniations on a scale far greater than in the human field. Herniations with spinal cord compression that occlude 90% of the spinal canal are the norm. The T2 sagittal sequence is the workhorse for identifying nuclear degeneration and the site of disc herniation with subsequent venous hemorrhage and spinal cord compression.
- **Dorsal STIR:** This sequence is often acquired while the subsequent transverse sequence is planned through the ROI. The sequence serves many functions, most specifically identifying paravertebral lesions that are less conspicuous in the face of the T2 fat signal, such as myositis or the relatively common discospondylitis [26, 27]. Muscular changes may also be noted on STIR sequences in cases of intervertebral disc disease [28]. It is also efficacious in visualizing the vascular margins of the ribs. Since chondrodystrophic breeds have a high incidence of transitional vertebrae with inconsistent landmarks that can make surgical localization challenging, the sequence confirms the number of thoracic and lumbar vertebrae as well as the general rib anatomy [29].
- **Transverse T2-weighted through the ROI:** Particularly in cases of intervertebral disc disease, the transverse section identifies the sidedness and compression level of the herniation. This sequence is most able to identify intraparenchymal signal. Sagittal plan imaging in small animals has a high degree of volume averaging given patient size and is also susceptible to truncation artifacts. Common pathologies for these changes include the dog equivalent of transverse myelitis, myelomalacia, ischemic myelopathy (fibrocartilaginous embolus), contusion and neoplasia.

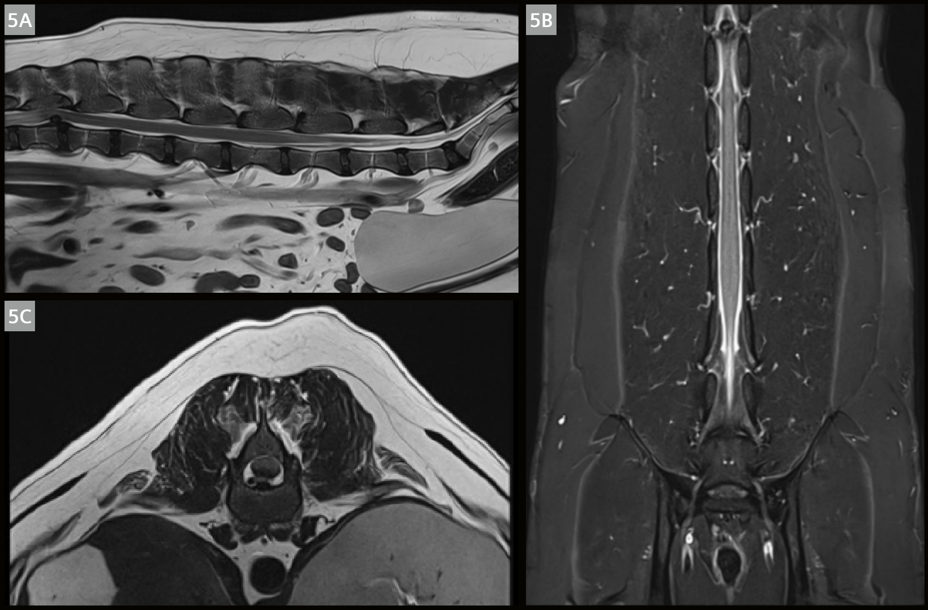
MRI remains the gold standard for spinal imaging, but CT is still used in some settings, due to its speed and availability. However, with advances like 3D T2-weighted sequences (e.g., SPACE), MRI total acquisition times are now often < 8 minutes, making speed a lesser issue. SPACE obviated the need for the interpreter to be present at the MRI console, because the post-processing power allows alternate planes of section through the ROI. The sequence also permits thinner sections, which minimizes volume averaging artifacts, a very real variable when one considers the average animal spinal cord diameter is 2.2 mm in the Dachshund, our most imaged dog. The extent and details of spinal cord compression can be interrogated with more accuracy, given the higher resolution and absence of slice gap.

SPACE is particularly beneficial for brachycephalic breeds that are prone to congenital malformations (e.g., hemivertebrae, spina bifida, severe curvature deformities). The French Bulldog is now the most common breed in the United States and 96.8% of the breed has severe congenital vertebral malformations [30, 31]! Multiplanar reformatting of 3D SPACE allows accurate orthogonal reconstructions even when conventional positioning is difficult.

The utility of T1 weighted post contrast imaging is less in the spine than the brain because of the nature of the pathology. Common spinal cord tumors include meningioma and malignant nerve sheath tumor. When neoplasia is suspected, fat-suppressed T1-weighted post-contrast imaging is commonly valued because of the large amount of fat adjacent to the vertebral canal and intervertebral



4 Dynamic imaging is often performed in patients with positional syndromes that are exacerbated in different postures. Here, flexed and neutral positions in a 5-year-old police service German Shepherd demonstrate resolution of caudal equina compression and foraminal stenosis at the lumbosacral space. These findings may alter the surgical course of treatment, favoring stabilization over decompression. Notably dogs and cats have seven lumbar vertebrae. (T2 sag neutral **(4A)**, flexion **(4B)**, FOV 190 × 300, slice thickness 2.5 mm, TA 2:10 min. **(4C, 4D)** T2 trans, FOV 137 × 180, slice thickness 2.5 mm, TA 1:57 min.)



5 Standard spinal protocol in dogs. The imaging volume encompassed either the C1–T2 or T2–S1 spinal segments. Sagittal T2-weighted and dorsal T2-weighted STIR sequences were acquired for planning the region of interest (ROI), followed by transverse T2-weighted images through the ROI.
(5A) T2 sag, TA 2:11 min, FOV 210 × 260, slice thickness 2.5 mm;
(5B) T2 STIR dorsal, TA 2:04 min, FOV 179 × 260, slice thickness 3 mm;
(5C) T2 tra, TA 2:13 min, FOV 137 × 180, slice thickness 2.5 mm.

foramina. Recent literature has suggested it to be superior to subtraction imaging, which is more challenging in the spine because of respiratory motion.

Myelographic-style (HASTE) MRI using heavily T2-weighted sequences remains valuable for identifying extradural and intradural-extramedullary lesions. One of the most quickly emerging pathologies presenting to neurologists are patient with dorsal funicular subarachnoid diverticula, particularly in breeds such as Pugs and French Bulldogs [32].

In the absence of a defined capsule or secondary mechanical gliosis, differentiating these dilations for spinal cord atrophy normal variation can prove difficult, these studies with the assistance of post-processing when combined with other 3D techniques improves diagnostic yield.

Conclusion

This is by no means a comprehensive list of utilized sequences or representative pathology we encounter. Instead, it is na introduction to demonstrate our different challenges and future opportunities.

Standardized MRI protocols in veterinary neurology are essential not only for image quality and diagnostic accuracy, but also for ensuring efficiency, safety, and reproducibility across a diverse and challenging patient population. Unlike human radiology, veterinary imaging must accommodate multiple species, a wide range of sizes, and varied pathologies — all while operating under the constraints of anesthesia, cost, and staffing.

By designing thoughtful, size-based, and anatomically grounded protocols that anticipate these demands, veterinary teams can maximize the utility of MRI as a diagnostic tool. As technology advances and training continues to evolve, these protocols will form the backbone of consistent, high-quality neurological care in small-animal practice.

References

1 Mai W (Ed.). Diagnostic MRI in Dogs and Cats. CRC Press; 2018.
2 Gavin PR, Bagley RS (Eds.). Practical Small Animal MRI. Wiley-Blackwell; 2009.
3 Schroers M, Zablotski Y, Meyer-Lindenberg A. Investigation of stress in dogs during an MRI examination in response to hearing protection. PloS One. 2024;19(10):e0312166. doi:10.1371/journal.pone.0312166
4 Lauer AM, El-Sharkawy AMM, Kraitchman DL, Edelstein WA. MRI acoustic noise can harm experimental and companion animals. J Magn Reson Imag. 2012;36(3):743–747. doi:10.1002/jmri.23653
5 Venn RE, McBrearty AR, McKeegan D, Penderis J. The effect of magnetic resonance imaging noise on cochlear function in dogs. Vet J Lond Engl 1997. 2014;202(1):141–145. doi:10.1016/j.tvjl.2014.07.006
6 Boch M, Karl S, Sladky R, Huber L, Lamm C, Wagner IC. Tailored haemodynamic response function increases detection power of fMRI in awake dogs (Canis familiaris). NeuroImage. 2021;224:117414. doi:10.1016/j.neuroimage.2020.117414
7 Redondo JI, Otero PE, Martínez-Taboada F, Doménech L, Hernández-Magaña EZ, Viscasillas J. Anaesthetic mortality in dogs: A worldwide analysis and risk assessment. Vet Rec. 2024;195(1):e3604. doi:10.1002/vetr.3604
8 Niemiec R, Champine V, Frey D, Lobdell A, Steele A, Vaiden C, et al. Veterinary and pet owner perspectives on addressing access to veterinary care and workforce challenges. Front Vet Sci. 2024;11:1419295. doi:10.3389/fvets.2024.1419295
9 2025 AVMA Pet Ownership & Demographics Sourcebook.
10 De Lahunta A, Glass E, Kent M. De Lahunta's Veterinary Neuroanatomy and Clinical Neurology. 5th edition. Elsevier; 2021.
11 Cherubini GB, Platt SR, Howson S, Baines E, Brodbelt DC, Dennis R. Comparison of magnetic resonance imaging sequences in dogs with multi-focal intracranial disease. J Small Anim Pract. 2008;49(12):634–640. doi:10.1111/j.1748-5827.2008.00628.x
12 Giles A. Image Acquisition of the Canine and Feline Spine. ↗ MAGNETOM Flash. 2024. https://marketing.webassets.siemens-healthineers.com/2b471b-640cd904bd/cfc0957af2f9/siemens-healthineers_Giles_Veterinary_Spine_MRI.pdf
13 Cornelis I, Van Ham L, Gielen I, De Decker S, Bhatti SFM. Clinical presentation, diagnostic findings, prognostic factors, treatment and outcome in dogs with meningoencephalomyelitis of unknown origin: A review. Vet J Lond Engl 1997. 2019;244:37–44. doi:10.1016/j.tvjl.2018.12.007
14 Hammond LJ, Hecht S. Susceptibility artifacts on T2*-weighted magnetic resonance imaging of the canine and feline spine. Vet Radiol Ultrasound Off J Am Coll Vet Radiol Int Vet Radiol Assoc. 2015;56(4):398–406. doi:10.1111/vru.12245
15 La Rosa C, Donato PD, Specchi S, Bernardini M. Susceptibility artifact morphology is more conspicuous on susceptibility-weighted imaging compared to T2* gradient echo sequences in the brains of dogs and cats with suspected intracranial disease. Vet Radiol Ultrasound Off J Am Coll Vet Radiol Int Vet Radiol Assoc. 2023;64(3):464–472. doi:10.1111/vru.13210
16 Garosi LS. Cerebrovascular disease in dogs and cats. Vet Clin North Am Small Anim Pract. 2010;40(1):65–79. doi:10.1016/j.cvsm.2009.09.001
17 Cervera V, Mai W, Vite CH, Johnson V, Dayrell-Hart B, Seiler GS. Comparative magnetic resonance imaging findings between gliomas and presumed cerebrovascular accidents in dogs. Vet Radiol Ultrasound Off J Am Coll Vet Radiol Int Vet Radiol Assoc. 2011;52(1):33–40.
18 Alisauskaite N, Wang-Leandro A, Dennler M, Kantyka M, Ringer SK, Steffen F, et al. Conventional and functional magnetic resonance imaging features of late subacute cortical laminar necrosis in a dog. J Vet Intern Med. 2019;33(4):1759–1765. doi: 10.1111/jvim.15526
19 Young BD, Fosgate GT, Holmes SP, Wolff CA, Chen-Allen AV, Kent M, et al. Evaluation of standard magnetic resonance characteristics used to differentiate neoplastic, inflammatory, and vascular brain lesions in dogs. Vet Radiol Ultrasound. 2014;55(4):399–406. doi: 10.1111/vru.12137
20 Lesta GD, Deserno TM, Abani S, Janisch J, Hänsch A, Laue M, et al. Automated brain extraction for canine magnetic resonance images. BMC Vet Res. 2025;21(1):537. doi: 10.1186/s12917-025-05003-4
21 Wininger F. Neuronavigation in small animals: development, techniques, and applications. Vet Clin North Am Small Anim Pract. 2014;44(6):1235–1248. doi:10.1016/j.cvsm.2014.07.015

22 Henry J, Ukai M, Antonakakis M, Zhou T, Moreno JA, Burzynska AZ, et al. Diffusion tensor imaging analysis of aged dogs with and without canine cognitive dysfunction. BMC Vet Res. 2025;21(1):550. doi: 10.1186/s12917-025-04973-9
23 May JL, Garcia-Mora J, Edwards M, Rossmeisl JH. An Illustrated Scoping Review of the Magnetic Resonance Imaging Characteristics of Canine and Feline Brain Tumors. Anim Open Access J MDPI. 2024;14(7):1044. doi:10.3390/ani14071044
24 Rusbridge C, MacSweeny JE, Davies JV, Chandler K, Fitzmaurice SN, Dennis R, et al. Syringohydromyelia in Cavalier King Charles spaniels. J Am Anim Hosp Assoc. 2000;36(1):34–41. doi:10.5326/15473317-36-1-34
25 Dewey CW, Costa RC da, Da Costa RC, eds. Practical Guide to Canine and Feline Neurology. Third edition. Wiley Blackwell; 2016.
26 Platt SR, McConnell JF, Garosi LS, Ladlow J, de Stefani A, Shelton GD. Magnetic resonance imaging in the diagnosis of canine inflammatory myopathies in three dogs. Vet Radiol Ultrasound Off J Am Coll Vet Radiol Int Vet Radiol Assoc. 2006;47(6):532-537. doi:10.1111/j.1740-8261.2006.00181.x
27 Okonji S, Di Paola A, Benini S, et al. Clinical Signs, Advanced Diagnostic Imaging Findings, Treatment, and Outcome of Mycotic Discospondylitis in 11 Dogs. J Vet Intern Med. 2025;39(3):e70097. doi:10.1111/jvim.70097
28 Morrison EJ, Baron-Chapman ML, Chalkley M. MRI T2/STIR epaxial muscle hyperintensity in some dogs with intervertebral disc extrusion corresponds to histologic patterns of muscle degeneration and inflammation. Vet Radiol Ultrasound Off J Am Coll Vet Radiol Int Vet Radiol Assoc. 2021;62(2):150-160. doi:10.1111/vru.12932
29 Mayhew PD, McLear RC, Ziemer LS, et al. Risk factors for recurrence of clinical signs associated with thoracolumbar intervertebral disk herniation in dogs: 229 cases (1994-2000). J Am Vet Med Assoc. 2004;225(8):1231-1236. doi:10.2460/javma.2004.225.1231
30 Albertini GM, Stabile F, Marsh O, Uriarte A. Clinical, magnetic resonance imaging, surgical features and comparison of surgically treated intervertebral disc extrusion in French bulldogs. Front Vet Sci. 2023;10:1230280. doi:10.3389/fvets.2023.1230280
31 Bridges J, Windsor R, Stewart SD, Fuerher-Senecal L, Khanna C. Prevalence and clinical features of thoracolumbar intervertebral disc-associated epidural hemorrhage in dogs. J Vet Intern Med. 2022;36(4):1365-1372. doi:10.1111/jvim.16442
32 Smith CJ, Guevar J. Spinal subarachnoid diverticula in dogs: A review. Can Vet J Rev Veterinaire Can. 2020;61(11):1162-1169.

Contact

Fred Wininger, VMD, MS,
DACVIM (Neurology)
The Animal Neurology Center
11652 Studt Ave
St. Louis, MO, 63141
USA
fwininger@animalneurology.com