

Magnetic Resonance Imaging in Dogs with Neurologic Impairment Due to Acute Thoracic and Lumbar Intervertebral Disk Herniation

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Background: Magnetic resonance imaging (MRI) is a correlate to physical examination in various myelopathies and a predictor of functional outcome.

Objectives: To describe associations among MRI features, neurological dysfunction before MRI, and functional outcome in dogs with disk herniation.

Animals: One hundred and fifty-nine dogs with acute thoracolumbar disk herniation.

Methods: Retrospective case series. Signalment, initial neurological function as assessed by a modified Frankel score (MFS), and ambulatory outcome at hospital discharge and >3 months (long-term) follow-up were recorded from medical records and telephone interview of owners. Associations were estimated between these parameters and MRI signal and morphometric data.

Results: Dogs with intramedullary T2W hyperintensity had more severe pre-MRI MFS (median 2, range 0–4) and lower ambulatory proportion at long-term follow-up (0.76) than those dogs lacking hyperintensity (median MFS 3, range 0–5; ambulatory proportion, 0.93) ($P=.001$ and $.013$, respectively). Each unit of T2W length ratio was associated with a 1.9 times lower odds of long-term ambulation when adjusted for pre-MRI MFS (95% confidence interval 1.0–3.52, $P=.05$). Dogs with a compressive length ratio >1.31 (which was the median ratio within this population) had more severe pre-MRI MFS (median 3, range 0–5) compared with those with ratios ≤ 1.31 (median MFS 3, range 0–4; $P=.006$).

Conclusions and Clinical Importance: MRI features were associated with initial injury severity in dogs with thoracolumbar disk herniation. Based on results of this study, the T2W length ratio and presence of T2W intramedullary hyperintensity appear to be predictive of long-term ambulatory status.

Key words: Neuroimaging; Neurology; Spinal cord disease.

Thoracolumbar intervertebral disk herniation is a common cause of spinal cord injury (SCI) in dogs, resulting in clinical signs that can range in severity from paraspinal hyperesthesia to paraplegia with loss of pelvic limb nociception. Assessment of pelvic limb deep nociception is the most commonly used physical examination-based prognostic indicator to determine the likelihood of postsurgical voluntary ambulation. In nonambulatory dogs affected with thoracolumbar disk herniation, surgical decompression results in return of voluntary ambulation in 86–96% of dogs that have deep nociception intact upon initial examination.^{1–4} Voluntary ambulation after surgical decompression occurs in 43–62% of dogs with lack of deep nociception before surgery.^{5–8} In addition to physical examination-based assessments, historical factors,^{1,8–10} biomarkers,^{11,12} and magnetic resonance imaging (MRI)

Abbreviations:

MFS	modified Frankel score
MRI	magnetic resonance imaging
SCI	spinal cord injury
T2W	T2-weighted
T1W	T1-weighted

data⁶ can be associated with injury severity and surgical outcome.

MRI signal patterns and morphometry have received increasing attention in dogs and humans with spinal cord disease.^{13–20} Intraparenchymal T1-weighted (T1W) hyperintensity, T2-weighted (T2W) hyperintensity, and T2*-weighted (T2*) hypointensity have been associated with poor long-term functional outcome in humans with traumatic SCI.^{15,16,21} Morphometric measures, such as maximal sagittal spinal cord compression, are associated with initial severity of neurologic signs and neurologic outcome in humans with vertebral column trauma.¹⁵ In dogs with surgical thoracolumbar disk herniation, all dogs (44/44) lacking T2W signal changes within the spinal cord recovered voluntary ambulation, but only 20% of dogs (3/15) with T2W hyperintensity greater than three times the length of the second lumbar (L2) vertebral body returned to ambulatory status.⁶

While MRI findings have been associated with outcome and injury severity in several vertebral column diseases, the value of certain signal characteristics and morphometric measures might be limited or etiology dependent.²⁰ For example, in humans with surgical spondylotic myelopathy, intramedullary T2W signal

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change in the absence of spasticity is not consistently associated with negative outcomes.^{22,23} Furthermore, MRI-derived maximal transverse spinal cord compression is not associated with degree of functional impairment in dogs with thoracolumbar disk extrusion.¹⁴

The limited data available concerning MRI-based indicators of SCI in dogs with thoracolumbar disk herniation prompted the authors to undertake the retrospective multicenter study reported here. The goal of this report was to determine if MRI signal characteristics and morphometric measures were associated with the degree of neurological dysfunction before MRI and functional outcome.

Materials and Methods

Case Selection

Medical records of dogs admitted between January 2006 and September 2008 to Texas A&M University Veterinary Medical Teaching Hospital (TAMU), University of Georgia Veterinary Medical Teaching Hospital (UGA), and Washington State University Veterinary Medical Teaching Hospital (WSU) were searched for thoracolumbar MRI. To be included in the study all dogs had to meet the following criteria: disk herniation confirmed via MRI and surgery or necropsy, extradural disk-associated spinal cord compression located between the T3–L7 vertebral articulations, ≤ 7 day duration of neurological dysfunction before MRI, MRI available for review in Digital Imaging and Communications in Medicine format, and the availability of sufficient clinical data from initial evaluation at the study site to derive a modified Frankel score (MFS). Short-term functional outcome was determined by an MFS on the day of discharge after hospitalization associated with MRI and surgery. Long-term functional outcome was determined through telephone follow-up performed at least 3 months after discharge from the primary hospital visit. All clinical examination data were obtained by a board-certified surgeon or neurologist or by a house officer under the direct supervision of a board-certified surgeon or neurologist.

Procedures

Age, sex, breed classification, weight, admitting university, duration of hospitalization, status at discharge (alive, dead, or euthanized), and administration of glucocorticoids before or at admission were recorded for each case. Dogs were classified as chondrodystrophoid (Dachshund [miniature and standard], Pekingese, West Highland White Terrier, Corgi, Japanese Chin, Basset Hound, Shih Tzu, Cocker Spaniel, Lhasa Apso, Bichon Frise, and Beagle) or nonchondrodystrophoid.^{24–27}

Data concerning the duration of neurologic dysfunction before MRI and the MFS immediately before MRI and at discharge from the hospital (short-term functional outcome) were recorded. The duration of neurological dysfunction was calculated as the time in days between client-observed paraparesis, paraplegia, or pelvic limb ataxia and MRI. The MFS was selected to describe neurological dysfunction because it has high interrater agreement ($\kappa = 0.93$), is predictive of functional outcome in dogs with disk herniation, and is easy to determine retrospectively.^{11,28,29} The MFS was defined as paraplegia with no deep nociception (grade 0), paraplegia with no superficial nociception (grade 1), paraplegia with nociception (grade 2), nonambulatory paraparesis (grade 3), ambulatory paraparesis and ataxia (grade 4), spinal hyperesthesia only (grade 5), or no dysfunction.^{11,28} Dogs were considered ambulatory only if they could consistently rise and walk without support. Dogs admitted at Washington State University did not have superficial nociception assessed

and therefore all paraplegic dogs with deep nociception intact admitted at this site were assigned a MFS of 2. Dogs that were euthanized at any time were considered nonambulatory when determining functional outcome, but if euthanasia was performed before release from the hospital they were not included in the calculation of discharge MFS.

Telephone Follow-Up

The owners of all dogs alive at discharge were contacted by telephone during March 2009 to determine long-term outcome. A >3 month interval between discharge from the primary hospital visit and telephone contact was required. A standardized telephone script and database were used to aid in acquiring information. Owners assessed whether their dog regained voluntary ambulation after surgery.

Imaging Data

A 1.0 T magnet^a was utilized for all cases at Texas A&M University. Spin echo T1W transverse (TR = 760, TE = 15, slice thickness = 3 mm), T1W sagittal (TR = 430, TE = 15, slice thickness = 2 mm), T2W transverse (TR = 4,500, TE = 99, slice thickness = 3 mm), and T2W sagittal (TR = 3,500, TE = 90, slice thickness = 2 mm) images were acquired. A 1.0 T magnet^b or 3.0 T magnet^c was utilized at University of Georgia. The 1.0 T UGA magnet was used to obtain spin echo T1W transverse (TR = 400, TE = 14, slice thickness = 3 mm), T1W sagittal (TR = 400, TE = 16, slice thickness = 3 mm), T2W transverse (TR = 3,250, TE = 103, slice thickness = 3.0 mm), and T2W sagittal (TR = 2,000, TE = 95, slice thickness = 3 mm) images. The 3.0 T UGA magnet was used to acquire spin echo T2W transverse (TR = 3,500, TE = 123, slice thickness = 3 mm) and T2W sagittal (TR = 3,866, TE = 115, slice thickness = 3 mm) images. A 1.0 T magnet^d was utilized for all dogs at Washington State University and spin echo T2W transverse (TR = 2,674, TE = 100, slice thickness = 3 mm) and T2W sagittal (TR = 3,370, TE = 120, slice thickness = 3 mm) images were obtained. Head, knee, and spine array receiver coils were used by all institutions; coil selection was dependent on animal conformation.

MRIs were evaluated by a board certified neurologist (JML) using a computer workstation with a 19 in. flat panel display^e and commercially available software^f; the neurologist was blinded to clinical information during image review. Data recorded included site of disk herniation, hyperintensity within the spinal cord on sagittal T1W and T2W images, and hypointensity within the spinal cord on sagittal T1W images. If T2W hyperintensity was present on sagittal MRI, the length of the hyperintensity was measured and divided by the length of the L2 vertebra to create a standardized ratio as described previously (T2W length ratio).⁶ Additionally, in dogs in which T2W hyperintensity was detected, a 0.1 cm² round region of interest was placed over the site of the spinal cord that subjectively had the highest signal and also over immediately adjacent spinal cord with normal intensity to obtain pixel intensity measures; a ratio of the hyperintense:normal spinal cord pixel intensity was created.

The morphometry of the extradural, disk associated compressive lesions was also assessed based on criteria established in human neuroradiology.^{15,30} All morphometric measures were performed on T2W images. A ratio (spinal cord compression ratio) of the sagittal height of spinal cord at maximal compression to the sagittal height of the spinal cord one vertebral articulation cranial to any observed compression was recorded. A ratio (vertebral canal compression ratio) of the sagittal height of vertebral canal at site of maximal compression to the sagittal height of vertebral canal one vertebral articulation cranial to any observed compression was recorded; for the purposes of this measure the dorsal extent of disk-associated compression or normal disk was considered to represent the ventral

extent of the canal. Finally, the length of extradural compression was measured on sagittal images and divided by the length of the L2 vertebra to create a ratio (compressive length ratio).

Statistical Analysis

MFS, proportion of dogs ambulatory at discharge, and proportion of dogs ambulatory at phone follow-up were summarized based on institution, sex, age, weight, breed, glucocorticoid administration, T2W hyperintensity, and morphometry of the compressive lesions. Continuous variables were dichotomized based on the median value for descriptive purposes and statistical testing. Kruskal-Wallis or Mann-Whitney *U*-tests were used to compare MFS medians and chi-square (or Fisher's exact) tests were used to compare ambulatory proportions across categories. The proportion of dogs ambulatory at follow-up was stratified by initial MFS and compared by chi-square or Fisher's exact tests. The association between magnet strength and detection of T2W hyperintensity was evaluated through calculation of a Mantel-Haenszel odds ratio stratified by MFS at presentation. Within dogs with detectable T2W hyperintensity, logistic regression was performed to estimate the association between length of spinal cord hyperintensity (less than or equal to the median, 1.24 or >1.24) and ambulatory proportion while adjusting for MFS at presentation. Linear regression was used to assess the associations of signalment with MFS at presentation and length of hospitalization was compared across institutions by Kruskal-Wallis tests. One statistical package was used for categorical analyses^g and other statistics were performed by commercially available software.^h Results were considered significant at $P \leq .05$.

Results

One hundred and fifty-nine dogs met inclusion criteria, with 44 originating from TAMU, 59 from UGA, and 56

from WSU. All dogs had surgical confirmation of disk herniation. Three of 5 animals that were euthanized before discharge had necropsy performed, and in each case gross and histopathologic data supported disk-associated SCI. Long-term follow-up data were available for 81% of dogs (129/159) with a median duration between MRI and long-term follow-up of 15.9 months (range, 5.9–70.8 months). Duration of clinical signs before MRI was 2.7 ± 1.9 days (mean \pm SD; range, 0.5–7 days). Duration of hospitalization was 7.0 ± 3.7 days and did not differ significantly among institutions ($P = .07$). Dogs were 6.1 ± 2.8 years of age (range, 1–17 years). There were 12 sexually intact females, 70 spayed females, 12 sexually intact males, 68 castrated males, and one male dog of unknown neuter status. Weight was 10.3 ± 8.0 kg (range, 3.1–45 kg). Breeds included Dachshund (miniature and standard grouped together; $n = 95$), mixed breed (23), Corgi (Pembroke Welsh and Cardigan Welsh grouped together, 7), Poodle (miniature and standard grouped together, 4), Cocker Spaniel (4), and 20 other breeds with <4 dogs each (30). The majority of dogs were chondrodystrophoid (124/163).

There were significant associations between the pre-MRI MFS and admitting hospital, age, weight, breed, and long-term ambulatory outcome (Table 1). Dogs admitted to WSU had a lower pre-MRI MFS (median 2) compared with those from TAMU (MFS median 3) or UGA (MFS median 3) ($P < .001$). Dogs that were ≤ 6 years of age, that weighed ≤ 7.1 kg, or were Dachshunds had a significantly lower pre-MRI MFS than comparison groups (Table 1). Multiple linear regression suggested that breed and weight were not independent and when

Table 1. Descriptive statistics and comparison of modified Frankel score (MFS) at presentation and recovery for 159 dogs surgically confirmed with disk herniation from three veterinary hospitals (2006–2008).

Variable	Level	N	Initial MFS		Ambulatory at Discharge		Ambulatory at Follow-up ^a	
			Median (range)	<i>P</i> value [†]	Proportion (n)	<i>P</i> value [‡]	Proportion (n)	<i>P</i> value [‡]
Hospital	TAMU	44	3 (0–4)	<.001	0.52 (44)	<.001	0.78 (37)	.073
	UGA	59	3 (1–5)		0.60 (58)		0.94 (48)	
	WSU	56	2 (0–4)		0.25 (56)		0.91 (44)	
Sex	Female	81	3 (0–5)	.51	0.41 (80)	.27	0.86 (66)	.47
	Male	78	3 (0–4)		0.50 (78)		0.90 (63)	
Neuter status	Neutered	136	3 (0–5)	.65	0.46 (136)	.86	0.88 (113)	.69
	Intact	22	3 (0–4)		0.48 (21)		0.94 (16)	
Age	≤ 6 years	100	3 (0–4)	.012	0.44 (99)	.71	0.88 (81)	.74
	>6 years	59	3 (0–5)		0.47 (59)		0.90 (48)	
Weight	≤ 7.1 kg	80	3 (0–4)	.021	0.44 (80)	.64	0.84 (68)	.09
	>7.1 kg	79	3 (0–5)		0.47 (78)		0.93 (61)	
Chondrodystrophoid	Yes	121	3 (0–5)	.08	0.44 (121)	.42	0.89 (98)	.76
	No	38	3 (1–4)		0.51 (37)		0.87 (31)	
Dachshund	Yes	92	3 (0–4)	.026	0.45 (92)	.77	0.88 (78)	.34
	No	67	3 (0–5)		0.47 (66)		0.92 (49)	
Glucocorticoids administration	Yes	89	3 (0–4)	.051	0.43 (89)	.32	0.90 (72)	.36
	No	66	3 (0–5)		0.51 (65)		0.85 (53)	

^aOwners contacted by phone at least 3 months postsurgery.

[†]*P* value based on Kruskal-Wallis for hospital and Mann-Whitney *U*-tests for other variables.

[‡]*P* value based on uncorrected chi-square or Fisher's exact tests.

TAMU, Texas A&M University Veterinary Medical Teaching Hospital; UGA, University of Georgia Veterinary Medical Teaching Hospital; WSU, Washington State University Veterinary Medical Teaching Hospital.

Table 2. Descriptive statistics and comparison of modified Frankel score (MFS) at presentation and improvement for magnetic resonance imaging (MRI) findings in 159 dogs surgically confirmed with disk herniation from 3 veterinary hospitals (2006–2008).

Variable	Feature	n	Initial MFS		Ambulatory at Discharge		Ambulatory at Follow-up ^a	
			Median (range)	<i>P</i> value [†]	Proportion (n)	<i>P</i> value [‡]	Proportion (n)	<i>P</i> value [‡]
T2-weighted hyperintensity (T2H)	Present	44	2 (0–4)	.001	0.39 (44)	.28	0.76 (38)	.013
	Absent	115	3 (0–5)		0.48 (114)		0.93 (91)	
T2H in dogs presenting ≤ 24 hours	Present	23	2 (0–4)	.006	0.35 (23)	.71	0.67 (21)	.070
	Absent	39	3 (0–4)		0.39 (38)		0.90 (30)	
T2H in dogs presenting > 24 hours	Present	21	2 (0–4)	.08	0.43 (21)	.43	0.88 (17)	.3
	Absent	76	3 (0–5)		0.53 (76)		0.95 (61)	
T2H length greater than median (1.24)	Present	22	2 (0–4)	.003	0.36 (22)	.76	0.62 (21)	.026
	Absent	22	3 (0–4)		0.41 (22)		0.94 (17)	
T2H pixel greater than median (1.31)	Present	21	2 (0–4)	.096	0.43 (21)	.75	0.79 (19)	.71
	Absent	21	3 (0–4)		0.38 (21)		0.71 (17)	
Spinal cord compression ratio	<0.67	45	3 (0–4)	.44	0.33 (45)	.051	0.94 (35)	.35
	0.67	114	3 (0–5)		0.50 (113)		0.86 (94)	
Vertebral canal compression ratio	<0.5	58	3 (0–5)	.74	0.36 (58)	.07	0.96 (46)	.055
	0.5	101	3 (0–4)		0.51 (100)		0.84 (83)	
Compressive length ratio	≤1.31	78	3 (0–5)	.004	0.44 (77)	.80	0.93 (67)	.18
	>1.31	78	3 (0–4)		0.46 (78)		0.85 (60)	

^aOwners contacted by phone at least 3 months postsurgery.

[†]*P* value based on Kruskal-Wallis for hospital and Mann-Whitney *U*-tests for other variables.

[‡]*P* value based on uncorrected chi-square or Fisher's exact test.

included in a single model neither was significantly associated with pre-MRI MFS. Age, weight, and breed status were not associated with ambulatory status at discharge or long-term follow-up. Admitting hospital was associated with ambulatory status at discharge, with dogs from WSU being less likely to ambulate ($P < .001$). When dogs were stratified by pre-MRI MFS into three severity groups (0–2, 3, 4–5) there was a significant difference in the proportion ambulatory at long-term follow-up between the MFS 0–2 (44/55 dogs), 3 (40/44), and 4–5 (34/35) categories ($P = .043$).

Disk herniation was identified at 10 articulations, with T12–T13 ($n = 47$), T13–L1 (37), T11–T12 (20), L1–L2 (13), and L3–L4 (12) being most common. Dogs had the following imaging sequences available for review: sagittal T1W (57/159) and sagittal T2W (159/159). No hyperintensity or hypointensity was detected within the spinal cord on any sagittal T1W image. Hyperintensity was identified in the spinal cord of 44/159 dogs on sagittal T2W images.

The compressive length ratio, the presence of T2W hyperintensity within the spinal cord, and the T2W length ratio were significantly associated with pre-MRI MFS (Table 2). The odds of T2W spinal cord hyperintensity were not significantly different among dogs imaged with 3 T MRI (45/163) compared with those imaged with 1 T MRI when adjusting for pre-MRI MFS OR = 1.58 (95% confidence interval [CI] 0.97–2.57; $P = .14$). Dogs with compressive length ratios > 1.31 had a significantly lower pre-MRI MFS than those with ratios ≤ 1.31 ($P = .004$). Hyperintensity of the spinal cord on T2W sagittal images also was associated with a lower pre-MRI MFS (median 2) compared with normal spinal cord signal intensity (median 3; $P = .001$). Those dogs

with T2W length ratios greater than the median (1.24) had lower pre-MRI MFS (median 2) compared with those with T2W length ratios ≤ 1.24 (median 3; $P = .003$). In dogs with injury duration less than or equal to the median (24 hours), T2W hyperintensity within the spinal cord was associated with a lower pre-MRI MFS compared with dogs without T2W signal change ($P = .006$); dogs with an injury duration > 24 hours with T2W spinal cord hyperintensity did have lower pre-MRI MFS compared with those with normal T2W spinal cord signal, but the relationship was nonsignificant ($P = .083$). No morphometric measure was associated with ambulatory status at discharge or long-term follow-up, although a higher proportion of dogs with compressive length ratios and vertebral canal compression ratios below the median were ambulatory at long-term follow-up compared with dogs with ratios greater than or equal to the median (Table 2).

The presence of T2W spinal cord hyperintensity and the T2W length ratio were associated with long-term ambulatory outcome (Table 2). The proportion of dogs with T2W spinal cord hyperintensity that walked at long-term follow-up (0.76) was lower than the proportion of dogs without signal change that were ambulatory (0.93; $P = .013$). A lower proportion of dogs with T2W length ratios > 1.24 ambulated at long-term follow-up (0.62) compared with those with T2W length ratios ≤ 1.24 (0.93). The odds of being nonambulatory at long-term follow-up were 1.9 times greater with each unit increase in T2W length ratio (95% CI 1.0–3.5, $P = .05$) when adjusted for initial MFS. Among dogs with T2W spinal cord hyperintensity, the T2W pixel intensity ratio was not associated with ambulatory status at discharge or long-term follow-up. The proportion of dogs walking at

long-term follow-up were 0.83 (95% CI, 0.70–0.92), 0.89 (95% CI, 0.80–0.95), and 0.95 (95% CI, 0.79–1.00) when follow-up duration was stratified as <1 year, 1–2 years, and >2 years, respectively; these proportions did not differ significantly ($P = .356$).

Discussion

The present study shows that in dogs with acute thoracolumbar disk herniation, those with T2W intramedullary hyperintensity had significantly more severe pre-MRI MFS (median 2) compared with those dogs without hyperintensity (median 3). This relationship appeared strongest in dogs with a pre-MRI injury duration of ≤ 24 hours. Additionally, dogs with T2W spinal cord hyperintensity that had T2W length ratios > 1.24 had significantly lower pre-MRI MFS (median 2) than those with ratios ≤ 1.24 (median 3). Although the presence of T1W signal changes within the spinal cord has been associated with neurologic grade in humans with traumatic SCI and spondylitic myelopathy, in the study reported here all dogs with T1W images available for review had normal spinal cord signal characteristics.^{23,31,32}

The compressive length ratio, a measure of the number of L2 vertebral lengths of extradural spinal cord compression on sagittal T2W images, also was associated with pre-MRI MFS. Dogs with compressive length ratios greater than the median (1.31) had a significantly more severe MFS than those with ratios less than or equal to the median. There is a similar association in humans with traumatic cervical myelopathy.¹⁵ Transverse maximal spinal cord compression does not correlate with initial physical examination-based neurological scores in dogs with acute thoracolumbar disk herniation.¹⁴ Similarly, in our study other measures of spinal cord compression, such as the spinal cord compression ratio, were not predictive of pre-MRI MFS. While the data from this report cannot address the mechanisms underlying differences in injury association between various MRI measures of compression, interface pressure is well known to influence injury severity and varies based on extradural lesion extent.^{33,34} Changes in spinal cord interface pressure caused by compressive masses can alter regional spinal cord blood flow and intraparenchymal tissue pressure.^{33,34} Perhaps effects over a greater length of spinal cord exert more influence over functional impairment compared with more localized compression, which was evaluated in this report through various ratios and has been assessed previously.

Intraparenchymal T2W hyperintensity was predictive of long-term functional outcome in dogs in the present study. The proportion of dogs ambulating at long-term follow-up (> 3 months after discharge from the primary hospitalization) was higher in those lacking intraparenchymal T2W hyperintensity (0.93) compared with those with hyperintensity (0.76). These results are generally supportive of published data in dogs with thoracolumbar disk herniation, although the outcome effect of intraparenchymal T2W hyperintensity appeared less dramatic in the study reported here.⁶ In a previously

described single center population, paraplegic dogs with thoracolumbar disk herniation that lacked intraparenchymal T2W hyperintensity all achieved long-term ambulation (44/44), whereas only 55% of dogs (18/33) with intraparenchymal T2W hyperintensity were ambulatory at follow-up.⁶ Data in the study reported here were generated in a population of dogs with subjectively less neurological dysfunction (ambulatory and nonambulatory paraparetic dogs were included), which could have affected the magnitude of associations. Dogs in this study had a < 7 -day history of neurological dysfunction before MRI whereas a previous report included dogs with clinical signs of 1–14 days duration, which may also explain differences.⁶ Additionally, higher field magnets were used in the study reported here (1.0 and 3.0 T field strength) compared with earlier work (0.3 T field strength), which may have enhanced the detection of T2W hyperintensity in our overall population; the positive effect of field strength on T2W lesion recognition has been demonstrated across several diseases in humans.^{35–37} Finally, multicenter studies should be more representative than single institution studies relating to patient population, assessment, and follow-up.

The T2W length ratio was associated with long-term functional outcome, independent of pre-MRI MFS. Per unit of T2W length ratio, the odds of long-term ambulation were reduced by a factor of 1.9. The length of T2W hyperintensity has been associated with poor functional outcome in humans with traumatic myelopathies in a limited number of reports.^{38,39} Outcome effects, however, are not consistent across all measures (eg, lower extremity motor index) and signal changes suggestive of intraparenchymal hemorrhage appear to be of greater prognostic value.³⁸ It has been suggested that T2W length ratios are associated with long-term functional outcome in dogs with thoracolumbar disk herniation, through the presentation of descriptive data which indicated that only 3/15 dogs with ratios > 3 units returned to voluntary ambulation.⁶ Data from dogs with acute, noncompressive cervical and thoracolumbar disk extrusion indicate that T2W length ratios > 1.28 have a sensitivity and specificity of 57 and 82% to determine unsuccessful outcome, respectively; quasi-complete data prevented the assessment of confounding by severity of neurologic dysfunction through logistic regression.⁴⁰ Our findings support the contention that T2W length ratios are of prognostic value and also clearly show that this value is independent of MFS. Again, differences in magnet field strength, study population, and study design may explain the divergence in the magnitude of associations between reports.

Various morphometric ratios were not associated with functional outcome. This might reflect the fact that primary compressive SCI is only one factor associated with lesion evolution and recovery in canine disk herniation. For example, contusion velocity plays a role in functional impairment independent of compressive volume in experimental SCI.⁴¹ Secondary injury also can evolve in the absence of biologically significant compression, as has been demonstrated in experimentally induced spinal

cord contusion.⁴²⁻⁴⁴ Finally, all dogs in this report received surgical decompression immediately after MRI. Rapid spinal cord decompression reduces spinal cord interface pressure and improves functional recovery, which may negate the influence of compression on lesion development.³³

Various factors beyond MRI signal patterns and morphometry were associated with pre-MRI MFS. These included admitting hospital, age, weight, and breed. Differences in the referral populations of each hospital likely explain the observed relationships with pre-MRI MFS. The fact that younger, lighter, and Dachshund-breed dogs were more likely to have more severe pre-MRI MFS may indicate a propensity for Dachshunds (which are lighter than many breeds and are often affected relatively young) to have severe SCI associated with disk herniation. Previous reports indicate that Dachshunds may be the most common breed to have loss of deep nociception and myelomalacia associated with disk herniation, although this association may simply represent the high proportion of dogs with disk herniation that are Dachshunds.^{7,8}

The study reported here does have several limitations, including the retrospective study design, interinstitution differences in MRI, lack of reliability data for MRI measurements, and the moderate number of dogs included. A prospective study would allow for prestudy standardization of data recording and MRI protocols and would likely enhance the number of dogs with long-term follow-up. A multi-institutional retrospective approach was chosen to overcome difficulties concerning dog recruitment. Even with participation of 3 universities that predominantly use MRI to assess the vertebral column, cases admitted over a 3-year span had to be searched to obtain 159 dogs that met inclusion criteria. A second limitation in design concerns variability in MRI protocol and field strength between universities, which likely produced differences in scan quality. For example, variable scan protocol between universities may have influenced image weighting and thus the relative ability to detect T2W hyperintensity. While several multi-institutional studies in humans with neurological disease have standardized MRI by manufacturer, field strength, and protocols, this is by no means standard for MRI study design in human clinical medicine and was not practical in the study reported here considering the small number of veterinary institutions that possess MRI and sufficient case load. Another limitation of this report is that MRI measures used have not been tested for reliability in veterinary medicine. Despite this, limited data from experimental rodent and clinical human studies suggest that measures identical to or similar to those used in this report are valid and internally consistent.^{17,30,45} Finally, despite the inclusion of 159 dogs, the power of this study to detect small but clinically important differences in pre-MRI MFS or functional outcome associated with MRI measures was limited. For example, a total of 376 dogs with equal group sizes would be required to achieve a power of 80% to discern differences in long-term ambulation between dogs with compressive length ratios ≤ 1.31 and > 1.31 .

Footnotes

- ^a Magnetom Expert, Siemens Medical USA, Malvern, PA
^b Signa, General Electric Healthcare, Milwaukee, WI
^c Signa HDx, General Electric Healthcare
^d Gyroscan, Philips Medical Systems, Best, the Netherlands
^e Dell 1905 FP, Dell Corporation, Round Rock, TX
^f eFilm 2.1 Veterinary, MERGE Healthcare, Cleveland, OH
^g Epi Info, version 6.04, CDC, Atlanta, GA
^h SPSS version 15.0, SPSS Inc, Chicago, IL
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