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ORIGINAL ARTICLE - RESEARCH

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Outcomes and prognostic indicators in 59 paraplegic medium to large breed dogs with extensive epidural hemorrhage secondary to thoracolumbar disc extrusion

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Abstract

Objective: To evaluate outcomes and prognostic factors after decompressive hemilaminectomy in paraplegic medium to large breed dogs with extensive epidural hemorrhage (DEEH) and thoracolumbar intervertebral disc extrusion (TL-IVDE).

Study design: Retrospective, cohort, descriptive study.

Animals: Fifty-nine client-owned dogs.

Methods: Medical records and advanced imaging were reviewed for paraplegic dogs with DEEH. Ambulatory status 6 months after surgery and postoperative complications were recorded. Multiple logistic regression models were constructed to explore prognostic factors.

Results: Records of 22 dogs with and 37 dogs without pelvic limb pain perception at presentation were included. Median age of dogs was 5 years (interquartile range, 4-7), and mean weight was 26.9 kg (SD, ±9.71). Labradors and Labrador mixes were most common (17/59 [28.8%]). Recovery of ambulation occurred in 17 of 22 (77.3%) dogs with and in 14 of 37 (37.8%) dogs without pain perception prior to surgery. Progressive myelomalacia was recorded in three of 59 (5.1%) dogs, one with pain perception and two without pain perception at presentation. Postoperative complications (14/59 [23.7%]) were common. Factors independently associated with outcome included clinical severity (odds ratio [OR] 0.179, $P = .005$), number of vertebrae with signal interruption in half Fourier single-shot turbo spin-echo sequences (HASTEi; OR, 0.738; $P = .035$), and ratio of vertebral sites decompressed to HASTEi (OR, 53.79; $P = .03$).

Conclusion: Paraplegic medium to large breed dogs with DEEH have a less favorable outcome after surgical decompression than paraplegic dogs with TL-IVDE.

Clinical significance: Dogs with DEEH can have severe postoperative complications. Loss of pain perception and increased HASTEi are associated with a poor outcome, while more extensive decompression improves outcome.

1 | INTRODUCTION

Acute thoracolumbar intervertebral disc extrusion (TL-IVDE) is a common disorder in dogs because of the high prevalence of intervertebral disc degeneration in this species.[1] Dogs with spinal cord injury (SCI) due to TL-IVDE can have a range of clinical severity from spinal hyperpathia only to paraplegia with loss of pelvic limb pain perception.[2,3] Decompressive surgery is usually advised when a dog is nonambulatory or when medical management is considered unsuccessful.[4,5] The surgical outcome of dogs with intact pain perception is excellent (> 90%), while dogs without pain perception have more variable outcomes, with most studies reporting recovery rates of 50% to 60%, as summarized in a recent meta-analysis.[6]

The calcified disc material extruded secondary to acute TL-IVDE can lacerate the internal vertebral venous plexus, causing extensive epidural hemorrhage and hematoma formation, previously given the acronym of DEEH for *disc-associated extensive epidural hemorrhage*.[7] This sequela can lead to multilevel extradural compression of the spinal cord, requiring a multisite decompressive surgery. Advanced imaging characteristics, clinical features, and outcomes of dogs with DEEH have been described.[7-12] Researchers in two of these studies examined the outcome of dogs with DEEH and concluded that the results of surgical decompression were similar to those obtained in dogs with TL-IVDE without extensive epidural hemorrhage.[7,11] However, these studies included dogs of all sizes and injury severity. Nearly 9% of all nonambulatory dogs with IVDE that present to our institution have DEEH; they are a small but important part of our emergency caseload.[13] Our perception was that these dogs did not have the same outcomes as dogs with TL-IVDE without DEEH. Researchers in several studies have found that body size impacts recovery,[14-16] and there is evidence that dogs with multilevel SCI have a worse prognosis compared with dogs with focal injury.[17-19]

We hypothesized that medium to large breed dogs with DEEH causing paraplegia with or without pain perception would have a worse outcome than that reported for dogs with TL-IVDE without DEEH. We sought to determine the long-term outcome of this specific group of dogs, to describe complications in their care, to identify prognostic factors, and to investigate the relationship between extent of surgical decompression and outcome.

2 | MATERIALS AND METHODS

2.1 | Case selection criteria

Radiology reports and discharge summaries from North Carolina State Veterinary Hospital (NCSVH) were searched to identify dogs with DEEH between January 1, 2009 and August 31, 2019. Search terms included intervertebral disc extrusion/herniation, epidural/extradural hemorrhage/hematoma, and extensive epidural/extradural compression. Dogs were identified that met the following inclusion criteria: paraplegic with or without pain perception at presentation, weight > 10 kg, MRI or computed tomography (CT) results that provided evidence of acute IVDE with epidural hemorrhage causing compression over > 2 consecutive intervertebral disc spaces, surgical decompression, and outcome established 6 months after injury. A diagnosis of epidural hemorrhage was made according to MRI results when the compressive epidural material had T2-weighted (T2W) hyperintense or heterogeneous signal, variable T1-weighted intensity, and susceptibility artifact on T2*-weighted sequences, if available.[11] On CT images, epidural material with an intermediate attenuation (50-90 Hounsfield units) was identified as hemorrhage (Figure 1).[8,10]

Dogs were divided into two groups, paraplegic with pain perception and paraplegic without pain perception. Dogs with only a partial sensorimotor loss (eg, lack of pain perception in one hind limb only) were placed in the category of paraplegic with pain perception.

2.2 | Data collection

Data were collected from the medical records and review of advanced imaging. Clinical data obtained from the medical record included breed, age, weight, sex (female, male; spayed, castrated), and severity of SCI (presence of pain perception, yes or no) at presentation.

2.2.1 | Imaging morphometry

Images were generated with either a 1.5- or 3.0-T magnet (Siemens Medical Solutions, Erlangen, Germany) or with 64- or 16-slice CT (Siemens Medical Solutions, Erlangen, Germany or GE, Boston, Massachusetts; respectively). Images were viewed in eUnity software (Client Outlook Inc, Ontario, Ontario, Canada). Measurements were made by one of the authors (C.W.W.) as follows: (1) number of vertebrae with interruption (loss) of the subarachnoid signal on half Fourier single-shot turbo spin-echo (HASTE) sequences, called HASTEi (the length of HASTE signal loss was rounded to the nearest half vertebra; HASTEi was unable to be determined on dogs with CT imaging); and (2) maximum spinal cord compression ratio (MSCC), calculated by taking the ratio of remaining spinal cord area at maximum compression to the mean spinal cord area one intervertebral disc space cranial and caudal to the end of compression on transverse images.[20] For dogs in which the spinal cord area measurement caudal

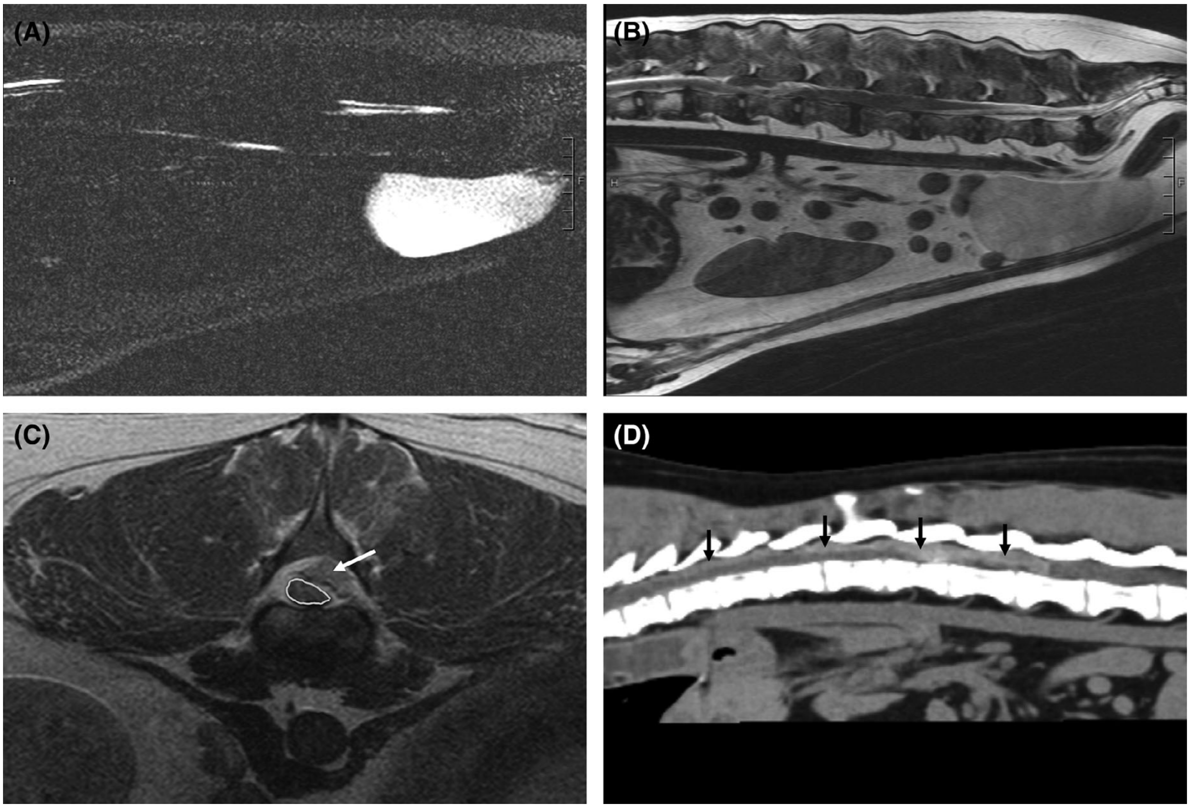

FIGURE 1 A-C, Magnetic resonance imaging of extensive epidural hemorrhage due to intervertebral disc extrusion in a dog. A, An example of interruption of subarachnoid signal on half Fourier single-shot turbo spin-echo imaging due to extensive epidural hemorrhage. B, Sagittal T2-weighted image from the same dog illustrating extensive epidural material. C, Transverse proton density-weighted image from the same dog illustrating epidural material dorsolateral to the spinal cord at L1. White arrow, epidural material; white line outlines the compressed spinal cord. D, Sagittal computed tomographic image without contrast in another dog. Black arrows, extensive epidural material with intermediate attenuation

to the compression would involve the conus medullaris or cauda equina, only the cranial spinal cord area measurement was used. The MSCC ratio was calculated on both MRI and CT images.

2.2.2 | Surgical information and postoperative management

Surgeries were performed by neurology or surgery residents and/or board-certified neurologists. Data obtained from the medical record included time from nonambulatory status (as identified by the owner and/or referring veterinarian) to surgery (categorized as $<$ 24 hours or $>$ 24 hours), number and location of vertebral sites decompressed, and the ratio of the number of vertebral sites decompressed to the number of vertebral sites with HASTE interruption (cut:HASTEi). The duration of hospitalization and postoperative complications were recorded. A diagnosis of progressive myelomalacia (PMM) was made either presumptively by consistent, progressive clinical signs in paraplegic pain perception negative dogs (advancement of caudal border of cutaneous trunci reflex, pelvic limb areflexia, loss of abdominal tone)[18] or was definitively identified by results of necropsy.

2.3 | Outcomes

Outcomes were assessed at 6 weeks and 6 months postoperatively. Methods of follow-up included recheck examinations at NCSVH or with referring veterinarians or telephone interviews with owners. A successful outcome was defined as recovery of independent ambulation (the ability to take $\geq$ 10 unassisted steps). Within the 6-month follow-up period, dogs that died or were humanely euthanized for reasons related to their neurologic status and/or complications of surgery were included in the study and interpreted as an unsuccessful outcome when they had not returned to ambulation at their time of death. Gross pathology and histology from necropsies were reviewed when they were available.

2.4 | Statistical analysis

Summary statistics were prepared for clinical presenting data, imaging morphometry, surgical data, and outcomes with dogs grouped according to the severity of signs (paraplegic with or without pain perception) at presentation. Continuous data are reported as mean and SD when they were normally distributed or as median and interquartile range (IQR) when there was a nonnormal distribution. The Shapiro–Wilk *W* test was used to test for normality. Categorical and ordinal data are reported as frequency of occurrence. These data were prepared in JMP Pro 14 (SAS Institute, Cary, North Carolina).

Multiple logistic regression models were fit predicting successful long-term recovery to identify factors associated with long-term outcome. Models were built to represent the different stages of animal management; thus, the first model evaluated factors associated with clinical presentation. These factors were age, weight, and severity of SCI (intact pain perception, yes or no). The second model incorporated clinical presentation and imaging data (morphometric measurements of HASTEi and MSCC ratio) to allow predictions to be made after imaging. Variables that could be rapidly and easily measured were chosen to ensure clinical utility. The third model incorporated these data as well as surgical decisions (time from nonambulatory status to surgery, number of vertebral sites of surgery, and cut:HASTEi). Models were fit by using the stated variables and reduced via Bayesian information criteria and then reported. Odds-ratios (OR) were then calculated by exponentiation of the slope with 95% CI reported on the OR scale. $P < .05$ was considered significant. These analyses were performed R version 3.6.2 (R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. http://www.R-project.org/).

3 | RESULTS

3.1 | Clinical presentation and outcome

Sixty-eight paraplegic dogs had evidence of DEEH according to advanced imaging studies (Figure 2). Nine dogs were excluded; six dogs were euthanized after advanced imaging and prior to surgery, and three dogs

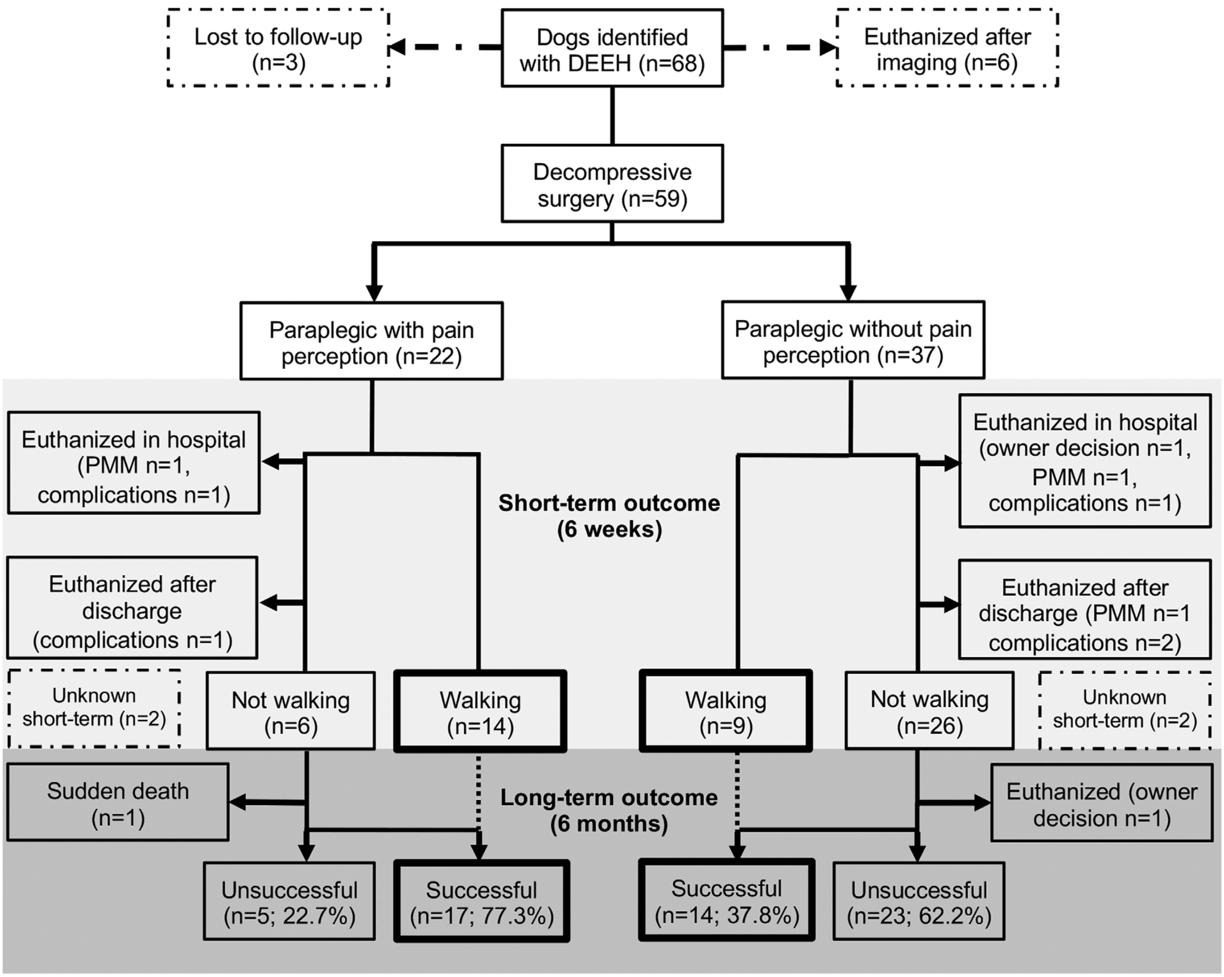

FIGURE 2 Flow diagram of the outcome of dogs with DEEH. Successful outcome was defined as a return to walking, and unsuccessful outcome was defined as an inability to ambulate or euthanasia/death. Euthanasia was performed because of postoperative complications or PMM, unless otherwise specified. DEEH, extensive epidural hemorrhage due to intervertebral disc extrusion; PMM, progressive myelomalacia

(two that were paraplegic with pain perception and one that was paraplegic without pain perception) did not have long-term follow-up information available.

Records of 22 paraplegic dogs with pain perception and 37 paraplegic dogs without pain perception were included (Table 1). Overall, the most common breed was Labrador retriever or Labrador mixes, accounting for 17 of 59 (28.8%) dogs. Median age for the entire DEEH cohort was 5 years (IQR, 4-7), and mean weight was 26.9 kg (SD, ±9.71). There were 28 female spayed and 30 male castrated dogs and one male intact dog. Magnetic resonance imaging was used for imaging in 51 dogs, and CT was used for imaging in eight dogs. The time from loss of walking to surgery was not available in the records of five dogs; among the 54 dogs with this information available, 38 (70.4%) had surgery within 24 hours of becoming nonambulatory. Both groups (dogs with and dogs without pain perception) had similar hospitalization times (dogs with pain perception, median 5 days [IQR 4-6]; dogs without pain perception, 6 days [IQR 5-8]).

Overall, 17 of 22 (77.3%) dogs with pain perception and 14 of 37 (37.8%) dogs without pain perception recovered ambulation by 6 months after surgery (Figure 2). Three (3/59 [5.1%]) dogs developed PMM, two of which lacked pain perception at presentation. One of these dogs developed PMM 22 days after surgery, which was confirmed by necropsy results. Postoperative complications occurred in 14 of 59 (23.7%) cases; one dog had two

TABLE 1 Descriptive data of dogs with extensive epidural hemorrhage due to DEEH

Stages of patient management	Variables	Paraplegic with pain perception, n = 22	Paraplegic without pain perception, n = 37
Clinical presentation	Breed, n (%)[a]		
	Labrador retrievers and mixes	9 (40.9)	8 (21.6)
	Other mixed breeds	6 (27.3)	7 (19.0)
	Pit bull terriers	1 (4.3)	5 (13.5)
	Hound breeds and mixes	0 (0)	4 (10.8)
	Rottweilers and mixes	0 (0)	3 (8.1)
	Spaniel breeds and mixes	0 (0)	3 (8.1)
	German shepherd dogs and Mixes	2 (9.1)	3 (8.1)
	Sex, n (%)		
	Female spayed	9 (40.9)	19 (51.4)
	Male castrated	13 (59.1)	17 (45.9)
	Male intact	0 (0)	1 (2.7)
	Age, y, median (IQR)	5 (5-7)	5 (4-7)
	Weight, mean ± SD, kg	27.6 ± 9.36	26.4 ± 10.01
Imaging morphometry	MSCC ratio, mean ± SD	0.65 ± 0.134	0.60 ± 0.151
	HASTEi, mean ± SD	6.15 ± 2.248	6.65 ± 2.527
	Vertebral sites of compression, n, median (IQR)	3.5 (2.5-4.3)	3 (2.4-4)
Surgical information	Time to surgery, n (%)[b]		
	< 24 h	13/22 (59.1)	25/37 (67.6)
	> 24 h	7/22 (31.8)	8/37 (21.6)
	Unknown	2/22 (9.1)	3/37 (10.8)
	Sites cut, n, median (IQR)[c]	3 (2-3.3)	3 (2-4)
	Cut:HASTEi, mean ± SD	0.55 ± 0.204	0.52 ± 0.194

Abbreviations: Cut:HASTEi, ratio of the number of vertebral sites decompressed to the number of vertebral sites with HASTE interruption; DEEH, extensive epidural hemorrhage due to intervertebral disc extrusion; HASTE, half Fourier single-shot turbo spin-echo; HASTEi, number of vertebrae (to nearest half vertebra) with interruption (loss) of subarachnoid signal on HASTE sequences; IQR, interquartile range; MSCC, maximum spinal cord compression.
[a]Breeds are omitted from table when there was only one dog of that breed represented in population.
[b]Defined as time from nonambulatory (as identified by the owner and/or referring veterinarian) to surgical time, separated into <24 h or > 24 h.
[c]Vertebral sites of surgical decompression.

complications (aspiration pneumonia in the hospital with subsequent recovery from pneumonia and then sudden death 60 days after surgery with no necropsy performed; Figure 3). In addition to the three dogs that were euthanized because of PMM, five of 14 (33.3%; two with pain perception, three without pain perception) dogs had complications that resulted in death or euthanasia, and three of five (60%) of these fatal complications occurred within the first 2 postoperative weeks.

3.2 | Factors associated with outcome

Multiple logistic regression models were built to evaluate variables that predict the outcome at three different points in case management: presenting signs and history, imaging morphometry, and surgical information (Table 2). The only factor at presentation that was associated with outcome was clinical severity, with paraplegic dogs without pain perception having a worse outcome than those with pain perception (OR, 0.179; $P = .005$). Weight and age were not associated with outcome. When imaging was added to the model, there was a negative association between HASTEi and successful outcome in addition to clinical severity (OR, 0.738; $P = .035$). Finally, when surgical data were incorporated, there was a positive association between a successful outcome and cut: HASTEi (OR, 53.79; $P = .03$), providing evidence that outcome is improved by a more extensive longitudinal decompression.

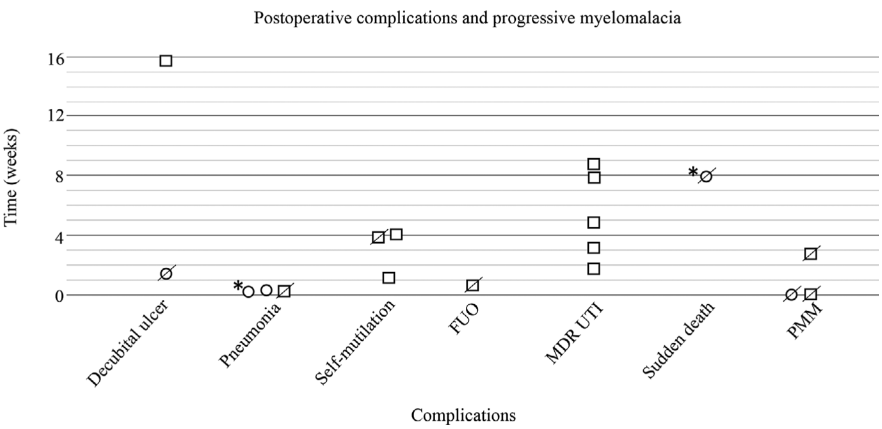

FIGURE 3 Postoperative complications and PMM in dogs with extensive epidural hemorrhage due to intervertebral disc extrusion. Asterisks, same dog that had two complications; circles, paraplegic with pain perception; squares, paraplegic without pain perception; virgule, dog died or was humanely euthanized as a result of the complication. FUO, fever of unknown origin; MDR UTI, multiple drug resistant urinary tract infection; PMM, progressive myelomalacia

TABLE 2 Prognostic factors in paraplegic medium to large breed dogs with DEEH

Stages of patient management	Variables	P-value	OR estimate	OR lower	OR upper
Clinical presentation	Grade	*0.005*	0.179	0.054	0.593
	Age	0.383	0.877	0.652	1.179
	Weight	0.248	1.036	0.976	1.1
Imaging morphometry	Grade	*0.008*	0.151	0.038	0.605
	HASTEi	*0.035*	0.738	0.556	0.979
	MSCC	0.171	29.036	0.232	3629.131
Surgical information	Grade	*0.007*	0.144	0.035	0.582
	Cut:HASTEi	*0.030*	53.790	1.476	1959.750
	Sites cut[a]	0.638	1.189	0.578	2.443
	Time to surgery[b]	0.737	1.292	0.290	5.760

Note: Multiple logistic regression for model selection, fit to represent the different stages of animal management. All reported confidence intervals are 95% intervals for the OR.

Abbreviations: Cut:HASTEi, ratio of the number of vertebral sites decompressed to the number of vertebral sites with HASTE interruption; DEEH, extensive epidural hemorrhage due to intervertebral disc extrusion; HASTE, half Fourier single-shot turbo spin-echo; HASTEi- number of vertebrae (to the nearest half vertebra) with interruption (loss) of subarachnoid signal on HASTE sequences; MSCC- maximum spinal cord compression; OR, odds ratio; Pr(>|z|).

[a]Number of vertebral sites decompressed.

[b]Time from nonambulatory status (as identified by the owner and/or referring veterinarian) to surgery.

4 | DISCUSSION

Medium to large breed dogs with DEEH causing severe SCI had a poorer outcome compared with dogs with TL-IVDE,[6] partially because of frequent complications. Factors associated with outcome included injury severity at presentation, HASTEi, and cut:HASTEi.

The ventral internal venous plexus is a bilateral thin-walled and valveless blood vessel which lies on the floor of the vertebral canal and extends from the basilar sinus of the calvarium to the caudal vertebrae.[21] The vertebral venous system has long been implicated as a route for spread of metastasis or migration of bacterial emboli[22] and, more recently, has been shown to have abnormalities that can cause radiculopathy and myelopathy in dogs.[23] As we confirmed in our study, laceration of this venous plexus due to IVDE can be associated with extensive spinal cord compression, paralysis, and loss of pain perception. Our search terms included both IVDE (typically indicating extrusion of calcified nuclear material) and intervertebral disc herniation, which is a broader umbrella term. However, it is notable that every case identified by using these search terms had extruded calcified disc material, providing evidence that acute IVDE is more likely to injure the venous plexus compared with other forms of disc herniation.

In this study, we focused on the outcome of surgically treated paraplegic dogs with DEEH. There are extensive data on the outcome of dogs with TL-IVDE not complicated by extensive epidural hemorrhage. When a meta-analysis of published data was performed, the mean percentages of paraplegic dogs with and without pain perception that recovered from hemilaminectomy were 93% and 61%, respectively.[6] In comparison, the population of dogs with DEEH in the study reported here had a worse prognosis for recovery of walking (77.3% and 37.8% with and without pain perception, respectively). There are several potential reasons why these dogs had a poorer outcome. Multilevel spinal cord disease has been associated with a worse outcome in dogs, both in the extent of intramedullary T2W hyperintensity[17,18,24,25] and in the extent of longitudinal epidural compression.[18,19,26] Extensive epidural compression may affect spinal cord perfusion and intraparenchymal pressure and, consequently, damage neuropil integrity more than focal compression. In addition, hemorrhage can initiate an inflammatory cascade that may further exacerbate injury in the adjacent spinal cord parenchyma. Erythrocyte breakdown products lead to production of inflammatory cytokines with resultant free radical formation, lipid peroxidation, and extravasation of macrophages and neutrophils.[27] This inflammation can lead to vasospasm, which can further worsen spinal cord perfusion and propagate SCI. Furthermore, the poorer outcome of our population of dogs may be reflected in the weight cutoff for this medium to large breed DEEH cohort. The mean weight of our population was 26.5 kg, and weight has been shown to have an influence on postoperative recovery speed and overall outcome in some studies.[14,15,28]

Postoperative complications, many of which resulted in euthanasia, were commonly associated with the challenges of nursing large, paralyzed dogs. This complication rate affected the overall outcomes reported. For example, were the dogs that were euthanized in the first 2 weeks because of complications removed from outcome analysis, the recovery rates would improve to 17 of 20 (85%) for paraplegic dogs with pain perception and 14 of 35 (40%) for paraplegic dogs without pain perception. The high complication rates provide evidence that nursing large, paralyzed dogs is more challenging than nursing smaller dogs, and this warrants thorough conversations with owners about potential postoperative pitfalls. However, it is important to note that postoperative complications in paraplegic dogs with TL-IVDE are not limited to medium to large breed dogs. In an effort to prevent complications in hospital, the clinician should pay particular attention to the instructions provided to the nursing staff to help avoid the development of decubital ulcers, aspiration pneumonia, and urinary tract infections, and diligent monitoring (eg, frequent respiratory rate and effort checks, monitoring rectal temperature trends) is important. It is essential to communicate clinical concerns to hospital nursing staff to increase awareness of and help reduce potential complications.

Short- and long-term outcomes were defined at 6 weeks and 6 months after surgery in our study. The return to unassisted ambulation after decompressive surgery in paraplegic dogs with pain perception is often rapid but can be protracted in dogs lacking pain perception.[14,29] In a meta-analysis, Langerhuus and Miles[6] found that the mean time to walking was 15 days in paraplegic dogs with pain perception and 38 days in paraplegic dogs without pain perception. In a prospective study, dogs that lacked pain perception continued to improve 3 months after injury.[30] The choice of 6 months as a realistic final outcome time point was based on these data. Among the dogs in our study, 14 of 20 (70%) paraplegic dogs with pain perception and nine of 35 (25.7%) paraplegic dogs without pain perception were walking 6 weeks after surgery. While most dogs that recovered were walking by 6 weeks, a small number went on to regain ambulation by 6 months, providing evidence that recovery can be quite protracted.

The owners of six dogs (three from each group of severity) pursued MRI but ultimately elected humane euthanasia prior to surgery. Reasons documented for euthanasia included owners reconsidering financial commitment, concerns about postoperative management and their pets' quality of life, and overall prognosis. Clinicians discussing multilevel spinal cord compression, extensive surgery, and challenges associated with nursing these large paralyzed dogs may have prompted the owners' decisions. Complications occurred in the hospital and at home, highlighting the requirement for clear discussion of the challenging nature of these cases with owners. In addition, the potential for emotional toll in taking care of these dogs is reflected in the findings in a previous study in which owner-assessed quality of life (QOL) was worse in nonambulatory dogs.[31] Indeed, some owners have reported a decrease in their own QOL while caring for a pet with severe SCI.[32] However, many of these QOL studies were conducted in predominantly small breed dogs.[32,33] Future studies could determine whether there is any discrepancy in owner and pet QOL in caring for medium to large breed paraplegic dogs compared with previously reported small breeds.

Labrador retrievers and Labrador retriever mixes were most commonly represented (28.8%) in our population. This may reflect the popularity of this breed in our hospital but justifies further investigation of breed prevalence. Magnetic resonance angiography or postmortem examination of the vasculature may be useful to evaluate potential differences of ventral internal venous plexus in this breed. In addition, additional examination of the relative dimensions of the vertebral canal and spinal cord in different breeds is warranted to potentially account for the spread of epidural hemorrhage. The FGF4 retrogene insertion on chromosome 12 has been identified as the mutation responsible for chondrodystrophy and subsequent IVDE in dogs.[34] However, by selecting dogs >10 kg, we excluded many of the short-legged breeds with a high prevalence of this retrogene (eg, dachshund, Pekingese). Therefore, additional investigation is warranted to determine why the Labrador retriever and other nonchondrodystrophic breeds can have prematurely calcified intervertebral discs, which lead to the potential for DEEH.

Multivariate analyses of clinical presenting factors were initially used to provide prognostic information that builds on clinical information gained during imaging and then at surgery. We then added imaging findings to this model, and, finally, taking significantly associated factors into account, we added surgical information. The severity of signs at presentation (ie, whether the dog had intact pain perception) unsurprisingly influenced outcome. When imaging was incorporated, increased HASTEi was associated with a poor outcome. The maximum compression of the spinal cord in the transverse plane was not associated with outcome. The HASTE sequence highlights the cerebrospinal fluid (CSF) within the subarachnoid space and is, therefore, useful for assessing the extent of extradural, intradural, and intraparenchymal lesions.[35] Disturbance in CSF flow will result in loss of the HASTE signal, making it sensitive to changes within the spinal cord beyond the site of compression. Therefore, the HASTEi likely captures extensive epidural hemorrhage and spinal cord swelling, both of which potentially lead to a poorer outcome. Quantitation of HASTEi is straightforward, unlike more involved measurements of the degree of spinal cord compression, and it has been used previously to predict development of PMM.[19,36] While the combination of clinical severity and HASTEi was associated with outcome, quantitative MRI can be an inconsistent prognosticator in dogs with SCI, and these data should be represented to the owner with care.[37]

Determining the extent of decompression presents a problem in dogs with extremely extensive lesions because of concerns about stability of the vertebral column[38] and the effect of prolonged anesthesia.[39,40] We evaluated the ratio of number of vertebral sites decompressed to number of vertebral sites with loss of subarachnoid signal (cut: HASTEi), and there was a better chance for a recovery with more extensive decompression even when the initial injury severity was taken into account. Another point of discussion for surgeons is the timing of surgery. We evaluated the time from when dogs became nonambulatory to when they received surgery and found that it had no effect on outcome, which is in line with recent studies.[41,42] However, all but four dogs underwent surgery within 36 hours of becoming nonambulatory. Among these four outliers, two dogs had surgery within 36 to 48 hours from loss of walking (both had pain perception and successful long-term outcomes), and two dogs had surgery >48 hours from loss of walking (both had absent pain perception and unsuccessful outcomes). It is therefore not possible for us to evaluate the effect of delaying surgery more than 36 hours after onset of paralysis.

Our study was limited by its a retrospective nature and limited sample. A specific population of dogs that were both larger than the usual chondrodystrophic breeds that have TL-IVDE and also had DEEH were studied. This study was not designed as a case–control study to evaluate the effect of the presence (or lack thereof) of DEEH on outcome in medium to large breed dogs. While weight was not associated with outcome in our analysis, it is important to note that the dogs in our population were both larger than the typical dog with TL-IVDE and had DEEH. A case–controlled study of large dogs without DEEH would be required to determine the full impact of this complication on outcome. Final outcome was established by using in-house and referring veterinarian evaluations as well as telephone interviews that sometimes relied on the recollection of owners. However, while there may have been improperly recalled timelines from owner interviews, it was infrequent that this was the only method of follow-up. The data on complications were an important aspect of this project and were largely retrieved from the NCSVH medical records and owner communications; thus, complications that occurred after discharge and were managed by the local veterinarian might have been missed. In addition, imaging morphometry was performed by one of the authors (C.W.W.), who was not blinded to the outcome of these dogs.

In conclusion, surgically treated medium to large breed paraplegic dogs that had DEEH had worse outcomes than those previously reported for dogs with acute TL-IVDE. Long-term successful outcome was recorded in 77.3% of paraplegic dogs with pain perception and in 37.8% of paraplegic dogs without pain perception. Postoperative complications were common, having been reported in 14 of 59 (23.7%) dogs, with an additional three dogs that developed PMM. These outcomes partially reflect the difficulty for owners of managing large, nonambulatory dogs. Clinicians and owners should be aware of these challenges and emphasize client communication before pursuing surgery. Factors negatively associated with outcome included worse injury severity at presentation and increased HASTEi, while larger cut: HASTEi was associated with an improved outcome, providing evidence that longer decompression was beneficial. In addition, Labrador retrievers and their mixes appear to have a high incidence of DEEH. Additional studies are recommended to understand the development of DEEH, whether certain breeds of dog are more susceptible to DEEH, and how this sequela to acute TL-IVDE contributes to more severe SCI.

AUTHOR CONTRIBUTIONS

Woelfel CW, DVM: Conceived study, assisted with study design, generated data through case management and assessment, retrieved data from records, performed image analysis, generated summary data, assisted with writing of the manuscript, and reviewed and revised drafts of the manuscript; Robertson JB, MS: Performed statistical analysis, assisted with writing of the manuscript, and reviewed and revised drafts of the manuscript; Mariani CL, DVM, PhD, DACVIM (Neurology): Generated data through case management and assessment, reviewed and revised drafts of the manuscript; Muñana KR, DVM, MS, DACVIM (Neurology): Generated data through case management and assessment, reviewed and revised drafts of the manuscript; Early PJ, DVM, DACVIM (Neurology): Generated data through case management and assessment, reviewed and revised drafts of the manuscript; Olby NJ, Vet MB, PhD, DACVIM (Neurology), MRCVS: Conceived study, assisted with study design, generated data through case management and assessment, performed basic data analysis, assisted with writing of manuscript, reviewed and revised drafts of the manuscript.

CONFLICT OF INTEREST

The authors declare no conflicts of interest related to this report.

REFERENCES

1. Bergknut N, Egenvall A, Hagman R, et al. Incidence of intervertebral disk degeneration-related diseases and associated mortality rates in dogs. *J Am Vet Med Assoc.* 2012;240(11):1300-1309.
2. Granger N, Carwardine D. Acute spinal cord injury: tetraplegia and paraplegia in small animals. *Vet Clin North Am Small Anim Pract.* 2014;44(6):1131-1156.
3. Moore SA, Granger N, Olby NJ, et al. Targeting translational successes through CANSORT-SCI: using pet dogs to identify effective treatments for spinal cord injury. *J Neurotrauma.* 2017;34(12):2007-2018.
4. Moore SA, Early PJ, Hettlich BF. Practice patterns in the management of acute intervertebral disc herniation in dogs. *J Small Anim Pract.* 2016;57(8):409-415.
5. Jeffery ND, Harcourt-Brown TR, Barker AK, Levine JM. Choices and decisions in decompressive surgery for thoracolumbar intervertebral disk herniation. *Vet Clin North Am Small Anim Pract.* 2018;48(1):169-186.
6. Langerhuus L, Miles J. Proportion recovery and times to ambulation for nonambulatory dogs with thoracolumbar disc extrusions treated with hemilaminectomy or conservative treatment: a systematic review and meta-analysis of case-series studies. *Vet J.* 2017;220:7-16.
7. Tartarelli CL, Baroni M, Borghi M. Thoracolumbar disc extrusion associated with extensive epidural haemorrhage: a retrospective study of 23 dogs. *J Small Anim Pract.* 2005;46(10):485-490.
8. Olby NJ, Muñana KR, Sharp NJ, Thrall DE. The computed tomographic appearance of acute thoracolumbar intervertebral disc herniations in dogs. *Vet Radiol Ultrasound.* 2000;41(5):396-402.
9. Tidwell AS, Specht A, Blaeser L, Kent M. Magnetic resonance imaging features of extradural hematomas associated with intervertebral disc herniation in a dog. *Vet Radiol Ultrasound.* 2002;43(4):319-324.
10. Lim C, Kweon O, Choi M, Choi J, Yoon J. Computed tomographic characteristics of acute thoracolumbar intervertebral disc disease in dogs. *J Vet Sci.* 2010;11(1):73-79.
11. Mateo I, Lorenzo V, Foradada L, Muñoz A. Clinical, pathologic, and magnetic resonance imaging characteristics of canine disc extrusion accompanied by epidural hemorrhage or inflammation. *Vet Radiol Ultrasound.* 2011;52(1):17-24.
12. Cerda-Gonzalez S, Olby NJ. Fecal incontinence associated with epidural spinal hematoma and intervertebral disk extrusion in a dog. *J Am Vet Med Assoc.* 2006;228(2):230-235.
13. Rossi G, Stachel A, Lynch AM, Olby NJ. Intervertebral disc disease and aortic thromboembolism are the most common causes of acute paralysis in dogs and cats presenting to an emergency clinic. *Vet Rec.* 2020;187(10):e81.
14. Olby N, Levine J, Harris T, Muñana K, Skeen T, Sharp N. Long-term functional outcome of dogs with severe injuries of

the thoracolumbar spinal cord: 87 cases (1996-2001). *J Am Vet Med Assoc.* 2003;222(6):762-769.
15. Shaw TA, Risio LD, Laws EJ, Rose JH, Harcourt-Brown TR, Granger N. Prognostic factors associated with recovery of ambulation and urinary continence in dogs with acute lumbosacral spinal cord injury. *J Vet Intern Med.* 2017;31(3):825-831.
16. Bull C, Fehr M, Tipold A. Canine intervertebral disk disease: a retrospective study of clinical outcome in 238 dogs (2003–2004) [in German]. *Berl Munch Tierarztl Wochenschr.* 2008;121:159-170.
17. Ito D, Matsunaga S, Jeffery ND, et al. Prognostic value of magnetic resonance imaging in dogs with paraplegia caused by thoracolumbar intervertebral disk extrusion: 77 cases (2000-2003). *J Am Vet Med Assoc.* 2005;227(9):1454-1460.
18. Levine JM, Fosgate GT, Chen AV, et al. Magnetic resonance imaging in dogs with neurologic impairment due to acute thoracic and lumbar intervertebral disk herniation. *J Vet Intern Med.* 2009;23(6):1220-1226.
19. Castel A, Olby NJ, Ru H, Mariani CL, Muñana KR. Early PJ. Risk factors associated with progressive myelomalacia in dogs with complete sensorimotor loss following intervertebral disc extrusion: a retrospective case-control study. *BMC Vet Res.* 2019;15(1):433.
20. Fehlings MG, Rao SC, Tator CH, et al. The optimal radiologic method for assessing spinal canal compromise and cord compression in patients with cervical spinal cord injury. Part II: results of a multicenter study. *Spine.* 1999; 24(6):605-613.
21. Evans HE, de Lahunta A, Miller ME. *Miller's Anatomy of the Dog*. St. Louis, MO: Elsevier Saunders; 2013.
22. Batson OV. The function of the vertebral veins and their role in the spread of metastases. *Ann Surg.* 1940;112(1):138-149.
23. Vernon JC, Durand A, Guevar J, et al. Vertebral venous system abnormalities identified with magnetic resonance imaging in sighthounds. *Vet Radiol Ultrasound.* 2017;58(4):399-410.
24. De Risio L, Adams V, Dennis R, McConnell FJ. Association of clinical and magnetic resonance imaging findings with outcome in dogs with presumptive acute noncompressive nucleus pulposus extrusion: 42 cases (2000-2007). *J Am Vet Med Assoc.* 2009;234(4):495-504.
25. Boekhoff TM, Flieshardt C, Ensinger E, Fork M, Kramer S, Tipold A. Quantitative magnetic resonance imaging characteristics: evaluation of prognostic value in the dog as a translational model for spinal cord injury. *J Spinal Disord Tech.* 2012;25(3):81.
26. Griffiths IR. The extensive myelopathy of intervertebral disc protrusions in dogs ('the ascending syndrome'). *J Small Anim Pract.* 1972;13(8):425-437.
27. Lucke-Wold BP, Logsdon AF, Manoranjan B, et al. Aneurysmal subarachnoid hemorrhage and neuroinflammation: a comprehensive review. *Int J Mol Sci.* 2016;17(4):497.
28. Cudia SP, Duval JM. Thoracolumbar intervertebral disk disease in large, nonchondrodystrophic dogs: a retrospective study. *J Am Anim Hosp Assoc.* 1997;33(5):456-460.
29. Aikawa T, Fujita H, Kanazono S, Shibata M, Yoshigae Y. Long-term neurologic outcome of hemilaminectomy and disk fenestration for treatment of dogs with thoracolumbar intervertebral disk herniation: 831 cases (2000-2007). *J Am Vet Med Assoc.* 2012;241(12):1617-1626.
30. Olby N, Harris T, Burr J, Muñana K, Sharp N, Keene B. Recovery of pelvic limb function in dogs following acute intervertebral disc herniations. *J Neurotrauma.* 2004;21(1):49-59.
31. Levine JM, Budke CM, Levine GJ, Kerwin SC, Hettlich BF, Slater MR. Owner-perceived, weighted quality-of-life assessments in dogs with spinal cord injuries. *J Am Vet Med Assoc.* 2008;233(6):931-935.
32. Freeman PM, Holmes MA, Jeffery ND, Granger N. Time requirement and effect on owners of home-based management of dogs with severe chronic spinal cord injury. *J Vet Behav.* 2013;8(6):439-443.
33. Bauer M, Glickman N, Glickman L, Toombs J, Golden S, Skowronek C. Follow-up study of owner attitudes toward home care of paraplegic dogs. *J Am Vet Med Assoc.* 1992;200(12): 1809-1816.
34. Brown EA, Dickinson PJ, Mansour T, et al. FGF4 retrogene on CFA12 is responsible for chondrodystrophy and intervertebral disc disease in dogs. *Proc Natl Acad Sci U S A.* 2017;114(43): 11476-11481.
35. Pease A, Sullivan S, Olby N, et al. Value of a single-shot turbo spin-echo pulse sequence for assessing the architecture of the subarachnoid space and the constitutive nature of cerebrospinal fluid. *Vet Radiol Ultrasound.* 2006;47(3):254-259.
36. Gilmour LJ, Jeffery ND, Miles K, Riedesel E. Single-shot turbo spin echo pulse sequence findings in dogs with and without progressive myelomalacia. *Vet Radiol Ultrasound.* 2017;58(2):197-205.
37. Wang-Leandro A, Siedenburg JS, Hobert MK, et al. Comparison of preoperative quantitative magnetic resonance imaging and clinical assessment of deep pain perception as prognostic tools for early recovery of motor function in paraplegic dogs with intervertebral disk herniations. *J Vet Intern Med.* 2017;31(3):842-848.
38. Corse MR, Renberg WC, Friis EA. In vitro evaluation of biomechanical effects of multiple hemilaminectomies on the canine lumbar vertebral column. *Am J Vet Res.* 2003;64(9):1139-1145.
39. Fenn J, Laber E, Williams K, et al. Associations between anesthetic variables and functional outcome in dogs with thoracolumbar intervertebral disk extrusion undergoing decompressive hemilaminectomy. *J Vet Intern Med.* 2017;31(3):814-824.
40. Fenn J, Ru H, Jeffery ND, et al. Association between anesthesia duration and outcome in dogs with surgically treated acute severe spinal cord injury caused by thoracolumbar intervertebral disk herniation. *J Vet Intern Med.* 2020.
41. Upchurch DA, Renberg WC, Turner HS, McLellan JG. Effect of duration and onset of clinical signs on short-term outcome of dogs with Hansen type I thoracolumbar intervertebral disc extrusion. *Vet Comp Orthop Traumatol.* 2020;33(3):161-166.
42. Jeffery ND, Barker AK, Hu HZ, et al. Factors associated with recovery from paraplegia in dogs with loss of pain perception in the pelvic limbs following intervertebral disk herniation. *J Am Vet Med Assoc.* 2016;248(4):386-394.

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