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Recovery times for dogs undergoing thoracolumbar hemilaminectomy with fenestration and physical rehabilitation: A review of 113 cases

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This study aimed to determine if physical rehabilitation, in the form of neuromuscular electrical stimulation, hospital/home exercises, and/or underwater treadmill therapy, improved recovery times for dogs undergoing thoracolumbar hemilaminectomy and fenestration for Type I intervertebral disc disease. The initial recovery time was established as time from surgery to 3 unassisted steps to fall. A modified Frankel score for stage of intervertebral disc disease was assigned at intake into physical rehabilitation and at release. The study also examined variables including age, sex, amount of time in rehabilitation, and duration of signs before surgery. Retrospective study design was used. A total of 113 dogs undergoing hemilaminectomy with fenestration for T3-L3 Type I intervertebral disc disease was used. Dogs exhibiting signs of Type I intervertebral disc disease underwent advanced diagnostics before hemilaminectomy with fenestration was performed. In hospital, physical rehabilitation included neuromuscular electrical stimulation, range of motion and sling walking. The owners received home care instructions for exercise, handling, sling walking, elimination management, and what was not allowed from the dogs. Underwater treadmill therapy was initiated 10 to 14 days postoperatively and done on a weekly basis. Additional exercises were progressively added to the program for strength and balance. The average recovery time in this study was 16 days and dogs spent an average of 40 days in formal physical rehabilitation. 23 dogs improved 1 full modified Frankel score (MFS) and 89 dogs did not have a full increase of 1 MFS. More time in formal rehabilitation ($P < 0.001$) and more underwater treadmill sessions ($P < 0.001$) increased the dog's chances of improvement. Physical rehabilitation improves the recovery in a portion of patients undergoing hemilaminectomy with fenestration for Type I thoracolumbar intervertebral disc disease.

Key words: Physical rehabilitation, neuromuscular electrical stimulation, intervertebral disc disease, underwater treadmill, modified Frankel score, nociception.

INTRODUCTION

Hansen type I intervertebral disc disease is typically associated with chondroid disc degeneration and has an

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acute onset. The disc extrudes through the dorsal annulus causing dorsal, dorsolateral, or circumferential compression of the spinal cord. Hansen type I is herniation of the nucleus pulposus through the annular fibers and extrusion of the nuclear material into the spinal canal. Acute disc extrusion is characterized by the presence of soft or firm fibrous disc material within the vertebral canal and extradural hemorrhage. The thoracolumbar junction accounts for the highest incidence of disc lesions (T12-13 to L1-L2). Clinical signs range from pain (hyperesthesia), postural deficits, to paraplegia of the pelvic limbs with or without nociception (Coates, 2004).

The two most common types of decompressive surgery are the dorsal laminectomy and hemilaminectomy. The hemilaminectomy is considered the superior technique because of decreased destabilization, improved visualization for removal of disc debris, less associated with a post-surgical compressive laminectomy membrane and decreased manipulation of the spinal cord. The dorsolateral approach allows for access to the disc spaces for prophylactic fenestration. One study reported retrieval of disc material in 93% of dogs that had hemilaminectomy compared with 40% with dorsal laminectomy (McKee, 1992).

Physical rehabilitation has many modalities that aid in the recovery of dogs that have undergone hemilaminectomy for Hansen's Type I intervertebral disc disease in the thoracolumbar vertebral column (T3-L3). These include neuromuscular electrical stimulation, exercises such as supported standing, range of motion, side bends, sling walking, underwater treadmill, and strengthening/balance exercises such as walks, circles, weaves and low step-overs. Neuromuscular electrical stimulation can make the muscles of the pelvic limbs go through an aerobic workout (to muscle fatigue) even though the muscles of the hind limbs are not getting the nervous impulses in order to flex and extend (Krauspe et al., 1992; Low and Reed, 2000; Crognale et al., 2013). Exercises that are started within 12 h of surgery and also done at home, such as range of motion, help to bring blood flow to the joints when the limbs are not moving during the recovery period (Brody, 1999; Shumway, 2007). Standing exercises utilize the upper motor neuron extensor tone and helps maintain the animal's extensor strength until the limb begins to sequence (Millis et al., 2004). Side bends aid the dog to keep flexibility in the paraspinal muscles as well as teaching early weight shifting (Millis et al., 2004). Underwater treadmill aids in gait training by providing buoyancy to make it easier to stand, resistance to help keep the animal's strength, warm water to help the tight UMN spastic muscles relax so that the handler or animal can sequence the hind legs in a series that mimics walking (Geigle et al., 1997).

Straight line walking aids the body in strength and gait. Circles and weavings allow for either subtle or direct weight shifting (Millis et al., 2004). Low height step-overs retrain proprioception using visual and audible clues such as toenails tapping on wood or rattling on hula hoops (Millis et al., 2004). Balance board exercises allow the dog an opportunity to shift weight and work on proprioception and balance (Millis et al., 2004). The goal of this study was to give an average recovery time (from surgery to 3 unassisted walking steps to fall or better) when a dog receives physical rehabilitation directly after surgery and the amount of time in formal rehabilitation. Comparisons were made based on age, weight, sex, modified Frankel score at time of surgery, disc(s) affected, presentation, days from surgery to therapy, number of therapy sessions, number of underwater treadmill sessions, and days in formal physical rehabilitation.

MATERIALS AND METHODS

One hundred thirty three cases from the January 2010 to December, 2014 period were reviewed for this retrospective study. Twenty dogs were not included in this study because they did not enter formal physical rehabilitation or information pertaining to when they walked was not obtained. The decision to go to surgery was based on physical exam by a board-certified veterinary surgeon in consultation with the owners. Dogs of any size, sex, age, breed, or any length of time with paresis/paralysis were allowed in the study. Dogs were categorized as either presented to the surgeon less than 24 h from onset of neurologic signs, between 24 to 48 h post onset of signs or greater than 72 h from onset of signs. Duration of clinical signs prior to surgery was not available in 16/113 dogs. Dogs either had a myelogram using iohexol as the contrast agent before surgery, computed tomography/myelogram or magnetic resonance imaging to determine the location of the ruptured disc(s). Diagnostics were performed either by a boarded veterinary neurologist or sugeon and the surgeries were performed by one of seven boarded veterinary surgeons.

The hemilaminectomies were performed by using a dorsal midline incision, elevating the epaxial muscle attachments off the lateral aspect of the dorsal spinous processes, lamina, articular facets and the pedicle to the level of the accessory process and keeping the muscles retracted with a Gelpi retractor. A high speed drill was used to make a rectangular area from the base of the dorsal spinous processes dorsally, the accessory processes ventrally, and the articular facet of the caudal vertebrae. The area was drilled cranial to caudal using a back and forth action once the cortical layer was reached to reveal the soft inner periosteum (Figure 1). The vertebral canal was carefully entered, and much of the herniated disc material was removed as possible with special care taken not to damage the spinal cord. Prophylactic fentestration (making a small rectangular window in the annulus fibrosis) using a number 11 scapel blade was also performed at the level of the affected disc, and at times, the cranial and/or caudal disc. Hemorrhage from soft tissue was controlled with cautery or Gel Foam[1]. A thin subcutaneous fat pad was placed over the hemilaminectomy site and the muscles and surrounding tissues were closed in three layers (Fossum et al., 2013).

Standard anesthetic protocols were followed for the dogs, an intraoperative antibiotic was given intravenously, and a continuous rate infusion of fentanyl (2 to 4 micrograms per kilogram per hour) was administered for a minimum of 18 h post surgery. Seventy five percent of the dogs were started on oral famotidine and sucralfate

[1]Gelfoam, Pharmacia, Kalamazoo, Mich.

as soon as possible after surgery. A fentanyl patch, tramadol, a non-steroidal anti-inflammatory drug (not given if a steroid was given before or during surgery), and/or gabapentin were included in the postoperative pain management.

Three quarters of the dogs had a Foley urinary catheter system placed at the time of surgery and removed when the dog showed signs of sequencing or when the bladder could be manually expressed with or without the aid of urinary drugs (such as diazepam, phenoxybenzamine or prazocin). One quarter of the dogs did not have a urinary catheter placed and were expressed by hospital staff with or without the aid of drugs that relax the urethral sphincter.

Physical rehabilitation for the dogs during their hospital stay was conducted by a DVM/CCRP, or rehabilitation assistant, and/or trained surgery technician. Each dog had a physical exam 1 day to 2 weeks after the surgery at the hospital where the surgery was performed by the same DVM/CCRP which included a body system exam, 70% thigh circumference, notes about any pain, postural deficits, nociception, ability to stand and if the animal could initiate volitional movement when supported. The DVM/CCRP then prepared a written set of home care instructions for the owner or rehabilitation assistant which included massage of the hind legs and feet, range of motion exercises, wide arc side bends, sling walks and standing exercises in addition to the home care instructions provided by the surgeons. Home care instructions from the surgeons emphasized range of motion exercises in the form of bicycles or on the hind legs or flexion and extension of each pelvic limb focusing on the stifle, towel/sling assisted walks, supporting spine when picking the dog up and keeping the spine level, continuation of medications, exercise restriction including confinement, no running, jumping, or explosive activity or playing with other dogs, and a recommendation for continued formal physical rehabilitation.

NMES was started at the first visit after the examination. One of two commercial hand held NMES machines was utilized[2,3]. The hair was clipped in specific muscle areas of the pelvic limbs of the dogs and cleaned with a paper towel moistened with tap water. For dogs less than 10 kg, 3.125 cm round pediatric disposable gel-lined electrodes were used. For dogs over 10 kg, 3.375 cm square electrodes were used. For channel one, one electrode was applied to two stifle extensor muscles – the sartorius and vastus lateralis. For channel two, one electrode was applied to one stifle flexor (caudal biceps femoris) and one electrode to a tarsal flexor (cranial tibial muscle). The electrodes were placed as close to the motor point as possible to achieve the best muscle contraction. An alternating current was used (15 s on channel one and fifteen seconds of rest for channel one while channel two was on for fifteen seconds). A 200 microsecond (μs) pulse width was utilized with a ramp of 3 s and 45 Hz of pulse rate was used. The fine adjustment for each animal was the amperage, which was 10 to 20 milliamperes or less for dogs less than 10 kg and 20 to 40 milliamperes for dogs over 10 kg.

Each pelvic limb was stimulated separately for fifteen minutes with the dog in lateral recumbency or as close as possible and good contractions were obtained as in Figure 2. Neuromuscular electrical stimulation was performed as close to every other day while in the hospital as possible. If the dogs did not have early volitional (motor) movement in the pelvic limbs at the time of discharge from the hospital, the owner or caretaker was rented and specifically demonstrated instructions on how to use the NMES machine at home. Home care instructions were given and demonstrated to the owner at the go home appointment. Each family was given a soft lined sling for sling walking to take out for elimination 4 times per day. Massage of the hind legs included gentle kneading down and up the legs as well as tickling of the toes. Hair brushing (staying away from the incision) for sensory stimulation was also recommended. Range of motion of the stifles either slowly in lateral recumbency or standing with hand support and bicycling one hind leg at a time for 10 to 25 repetitions was always recommended. Side bends included a treat offered from the nose to each side (about shoulder arc) which allowed for a good balanced stretch of the spine and weight shifting to each hind leg as in Figure 3. Having the dog stand to eat while offering a small amount of food at a time and watch TV with gentle hand support between the legs or propped up on a leg or pillow was the final exercise.

Underwater treadmill[4] therapy was initiated on the first appointment (minimum of 10 to 14 days post-op) when the dog began walking or sequencing when sling walked. The dogs were fashioned with a loose fitting harness and placed in the UT with the DVM/CCRP or her assistant (for the 1st two times on dogs >10 kg and every time with dogs < 10 kg). The water level was raised to the upper thigh. A minimal speed was set for the size of the dog (dogs < 20 kg at 0.48 kilometers per hour and dogs > 10 kg starting at 0.97 kilometers per hour) for the first minute. If a dog could sequence the pelvic limbs without help, the speed was then increased by 0.16 or 0.32 kilometers per hour. For dogs that sequenced on land, but not in the water, the hind limbs were manually sequenced trying to mimic natural gait as in Figure 4. The time of the first UT session was generally 3 to 5 min. Dogs were towel dried after the session.

At the end of each underwater treadmill session, a new exercise was shown to the owner to be performed daily and added to the home exercise program. These exercises were circles, weaves, step-overs and balance boards added in a progressive order. The number of repetitions was set at 5 to each direction for circles and 3 to 4 reps back and forth for weaves. Circles were to be wide (1.21 to 1.82 m in diameter) and the spaces between weaves were to be just slightly longer than the dog 30.5 to 45.7 cm for dogs < 10 kg as in Figure 5 and 0.6 to 1.21 m for dogs > 10 kg. Step-overs were to be objects 2.54 to 5.08 cm high (such as broomsticks, rolled towels or hula hoops) for dogs < 10 kg as in Figure 6, and 0.08 to 10.18 cm (boards or rolled blankets) for dogs > 10 kg. The height was chosen based on the ability of the dog to flex the stifle as the object was crossed. The step-overs were spaced at 30.48 cm for dogs < 10 kg and 60.96 to 91.44 cm for dogs > 10 kg. Appropriate balance boards were loaned out for 1 to 2 weeks according to patient size. Balance boards of 0.60 × 0.60 m were loaned out for dogs < 10 kg and 0.61 × 0.61 m or 0.91 × 0.91 m were loaned out for dogs > 10 kg. The dog was to walk across the board 10 times to get used to the wobble and then kept on for 10 reps at 10 s wobble intervals as in Figure 7. Two factors contributed to the release of the dog from the formal physical therapy program. The first was how well the dog was walking (near normal strides with little ataxia was the goal) and the second was client desire for the dog to stay in rehabilitation therapy.

A MFS (Levine et al., 2009) was assigned at the time the dog presented to surgery, when the dog started physical rehabilitation and when the dog finished physical rehabilitation. A zero score was paraplegia without nociception. A score of 1 indicated paraplegia without superficial pain sensation. A score of 2 indicated paraplegia with deep and superficial pain sensation. A score of 3.25 indicated no volitional movement and no weight bearing was present. A score of 3.5 indicated no volitional movement, but weight bearing was present.

This was a modification of the MFS made specifically for this study so that a progressive numerical value could be attached to the a and b subclasses of the 3 group. A score of 4 indicated volitional movement with ataxia. A score of 5 indicated volitional movement with spinal hyperesthesia only.

[2]Respond Select, EmpiCo., St. Paul, MN, 55126 USA
[3]Perfect Stim, Lead-lok Inc., Sandpoint, ID 83864 USA
[4]Ferno Underwater Treadmill, Ferno Pools, Wilmington, OH, 45177 USA

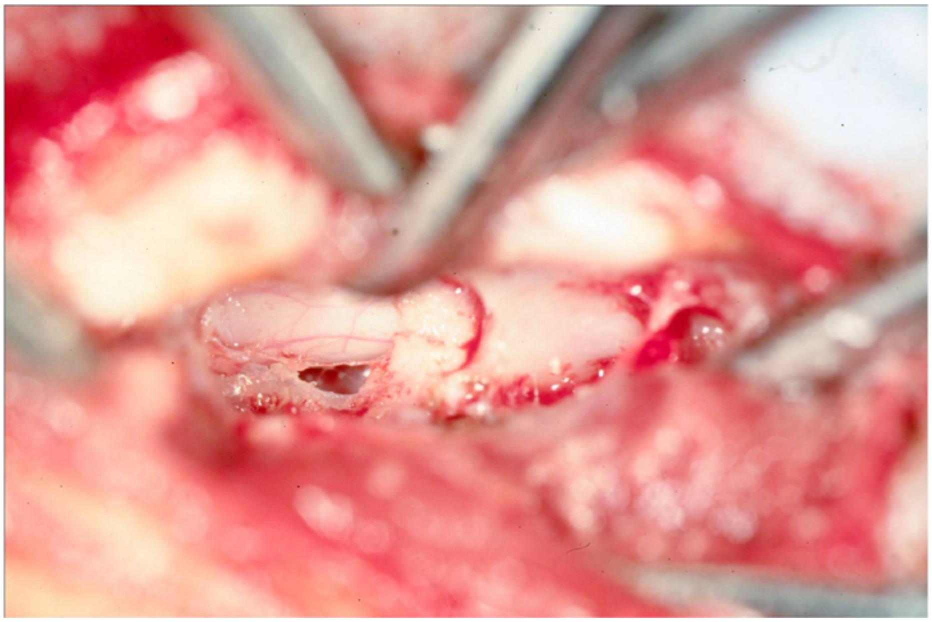

Figure 1. Photo of thoracolumbar hemilaminectomy procedure. Courtesy of KH Krause.

Figure 2. Photo of Dachshund cross dog receiving pelvic limb neuromuscular electrical stimulation.

Statistical analysis

Categorical data were described as proportions and 95% mid-P exact confidence intervals (CI). Quantitative data were described as medians and interquartile ranges (IQR). Clinic improvement during physical rehabilitation was defined as an increase of at least one modified Frankel score (MFS) unit from the post-surgery value. Categorical variables were compared between outcome groups using the chi-square or Fisher exact tests. Quantitative variables were compared between outcome groups using Mann-Whitney U

Figure 3. Side bending exercise on a Jack Russell Terrier. Note the paraspinal muscle stretch and weight shifting.

Figure 4. Beagle gaiting in underwater treadmill.

tests. Quantitative variables were categorized based on percentiles of the distribution when biologically relevant categories could not be determined. Univariate associations between successful physical rehabilitation and potential predictors were estimated using binary logistic regression. Univariate associations between time to successfully taking the first steps after surgery and potential predictors were estimated using Cox proportional hazards regression. Multivariable models were built using a backwards stepwise approach starting with all main effects that had P-value less than or equal to 0.20 in the univariate screening models. Variables were removed one-by-one based on the largest Wald P-values. Interaction terms were not evaluated in the multivariable models. The fit of the final logistic regression model was assessed using the Hosmer and Lemeshow test. Categorical data analysis

Figure 5. Chihuahua weaving between cones working on weightshifting and balance.

Figure 6. Jack Russell Terrier working on proprioception and gaiting.

was performed in available freeware[5] and other analyses performed using commercially available software.[6] Significance was set as P < 0.05.

RESULTS

One hundred and thirteen dogs met the criteria for

[5]Epi Info, version 6.04, Atlanta, GA, USA

[6]IBM SPSS Statistics Version 22. International Business Machines Corp., Armonk, NY, USA

Figure 7. Golden Retriever mix working on proprioception, balance and core strength on a wobble board.

inclusion into the study. Approximately 50% of the dogs were Dachshunds, 8.5% were Chihuahuas, and 4% each were Beagles, Corgis, Shih Tzus and terriers (or terrier crosses). The other breeds included in the study were both large and small breeds. Average body weight for this study was 10 kilograms (range 3 to 50 kg). Included were 53 spayed females (46%), 47 were neutered males (42%), females were sexually intact (4%) and 8 males were sexually intact (7%). Mean age was 6 years (range 2 to14 years). There were 16 lesion localization categories and some had a hemilaminectomy over more than one disc space. Twenty-four dogs had a T13 to L1 disc (21%), 20 dogs had a T12 to T13 disc (17.7%), 13 dogs had an L1 to L2 disc (11.5%), 11 dogs had a T11 to T12 disc (9.7%), 6 dogs had an L2 to L3 disc (5.3%), 3 dogs had a T10 to T11 disc (2.7%), and 3 dogs had an L3 to L4 disc (2.7%). Eleven dogs had two discs from T11 to T13 (9.7%) and the rest had a combination of either thoracic, lumbar (L1 toL3) or a combination of thoracolumbar discs.

Dogs took an average of 16.8 days (range of 1 to 270 days) to take 3 steps of ambulation by themselves and spent 40.7 days in formal physical rehabilitation (with visits every 1 to 7 days). Dogs received an average of 6.6 neuromuscular electrical stimulation sessions and 3.6 underwater treadmill sessions. Modified Frankel scores from intake to release from formal physical rehabilitation increased anywhere from a 0 (no nociception) to a 5 (ambulatory with spinal hyperesthesia only). Most of the increases were from a Modified Frankel score of 3.5 (no motor with non weight bearing) to a 4 (motor function to limbs with ataxia). Only 8/16 (50%) of dogs with loss of deep pain (nociception) improved with physical rehabilitation. Variables that were not affected by physical rehabilitation included breed, body weight and time to presentation to surgeon from the onset of signs. Spayed females had larger improvement ($P = 0.054$) than intact males ($P = 1.0$). Number of days in formal physical rehabilitation and number of therapy sessions each had a P-value of 0.001. Shorter days until successful steps also had a larger increase in MFS and a P-value of 0.001.

DISCUSSION

The present study gave a baseline recovery time for dogs undergoing thoracolumbar hemilaminectomy with fenestration and physical rehabilitation. Previous studiesreported that 90% of dogs were ambulatory 10, 12.9 and 10.8 days after hemi-laminectomy surgery alone (Davis and Brown, 2002; Ferreira et al., 2002; Ruddle et al., 2006). However, the dogs in the 10 day recovery were those that were ambulatory before surgery (Davis and Brown, 2002). One study where 90% of dogs walked 10 days after surgery did not include dogs with greater

Table 1. Descriptive statistics and comparison of categorical variables between dogs with improvement during physical therapy (increase of at least 1 modified Frankel score unit) and those without a substantial improvement post IVDD surgery.

Variable	Improvement		No improvement		P value*
	n	Proportion (95% CI)	n	Proportion (95% CI)	
Dachshund	23	0.43 (0.25, 0.64)	89	0.52 (0.41, 0.62)	0.483
Chondrodystrophic breed	23	0.61 (0.40, 0.79)	89	0.73 (0.63, 0.81)	0.254
Intact male	23	0.09 (0.01, 0.26)	89	0.08 (0.04, 0.15)	1.0
Neutered male	23	0.22 (0.08, 0.42)	89	0.46 (0.36, 0.56)	0.035
Intact female	23	0.04 (0.00, 0.20)	89	0.03 (0.01, 0.09)	1.0
Neutered female	23	0.65 (0.44, 0.82)	89	0.43 (0.33, 0.53)	0.054
T10-T11 affected	23	0.09 (0.01, 0.26)	89	0.04 (0.01, 0.10)	0.601
T11-T12 affected	23	0.22 (0.08, 0.42)	89	0.25 (0.17, 0.34)	0.766
T12-T13 affected	23	0.39 (0.21, 0.60)	89	0.36 (0.27, 0.46)	0.778
T13-L1 affected	23	0.43 (0.25, 0.64)	89	0.33 (0.23, 0.43)	0.328
L1-L2 affected	23	0.26 (0.11, 0.47)	89	0.21 (0.14, 0.31)	0.627
L2-L3 affected	23	0.09 (0.01, 0.26)	89	0.08 (0.04, 0.15)	1.0
L3-L4 affected	23	0.04 (0.00, 0.20)	89	0.03 (0.01, 0.09)	1.0
Presented < 24 h	18	0.56 (0.33, 0.77)	77	0.49 (0.38, 0.60)	0.635
Presented 24-72 h	18	0.33 (0.15, 0.57)	77	0.39 (0.29, 0.50)	0.658
Presented > 72 h	18	0.11 (0.02, 0.32)	77	0.12 (0.06, 0.20)	1.0

*Comparison between groups using chi-square or Fisher exact tests.

than 15 kilograms (Bush, et al., 2007).Also, dogs that did not enter formal physical rehabilitation were not included in this study, and so this may have skewed the time to ambulation when compared to other studies. One study reviewed 831 cases and placed dogs into recovery groups based on a neurologic grading scale of 0 to 5 with 0 being clinical normal dog and 5 representing paraplegia with absent nocicieption in both pelvic limbs and tail. Time to ambulation was reported for each grade along with the complications. 86.7% of dogs with grades 1 (thoracolumbar spinal pain without neurologic deficits) and 2 (ambulatory paraparesis) signs became ambulatory within 14 days. 81.9% of dogs became ambulatory within 14 days. 74.4% of dogs with grade 4a signs (paraplegia with intact nociception in both pelvic limbs and tail became ambulatory in 14 days. 69.7% of dogs with grade 4b signs (paraplegia with intact or decreased deep nociception in at least one of the pelvic limbs or tail) became ambulatory within 14 days. 36.4% of dogs with grade 5 signs (paraplegia with absent deep nociception in both pelvic limbs and tail within 14 days (Aikawa et al., 2012). However, the physical rehabilitation was limited to massage, passive range of motion, supported standing and encouragement of walking on non-slick surfaces by the owners when discharged.

Three factors could contribute to the longer recovery times in the present study. The first is if the dogs had volitional motor movement before surgery and having a grading scale is important to classify what the patient's clinical signs were prior to surgery, after surgery and before starting formal physical rehabilitation and at the end of formal physical rehabilitation. The scale can correlate the amount of spinal cord damage (Levine et al., 2009). However, it gives more objective data for comparison between groups of patients and research studies. The second is if the animal had deep pain perception (nociception) after surgery as this lowers the chance for becoming ambulatory (Levine et al., 2009). The last factor was the length of time between start of pain and loss of function until the time that the dog had surgery.

Four major findings were apparent from the data. The first is that fewer neutered males improved and that spayed females tended to have better recoveries (Tables 1, 2 and 3). The P-value was not less than 0.05, but equal to 0.054 (Tables 1 and 2). Older dogs were more likely to have an increased MFS (Table 3). More severe signs at presentation (a lower MFS) resulted in a larger increase in the MFS. The more affected number of discs also had a larger increase in the MFS (Table 2). More physical rehabilitation sessions, underwater treadmill sessions and longer amount of formal time in physical rehabilitation meant a better chance of improvement (Table 2). Dogs with more than 7 physical rehabilitation sessions were more likely to show improvement relative to fewer sessions (Table 4). Less severely affected dogs (larger MFS at start) were less likely to have a larger increase in improvement (Table 3). Those with a greater increase in MFS had longer days until taking steps, but this is a function of the fact that they were more severely

Table 2. Descriptive statistics and comparison of quantitative variables between dogs with improvement during physical therapy (increase of at least 1 modified Frankel score unit) and those without a substantial improvement post IVDD surgery.

Variable	Improvement		No improvement		P value*
	n	Median (IQR)	n	Median (IQR)	
Age (yrs)	23	7 (4, 9)	89	5 (4, 8)	0.178
Body weight (kg)	20	7.6 (6.4, 14.3)	88	7.0 (5.5, 9.9)	0.174
Modified Frankel score at presentation	23	1 (0, 2)	89	2 (2, 2.6)	0.004
Number of affected disks	23	1 (1, 1)	89	1 (1, 1)	0.042
Days post-op at therapy start	23	2 (1, 2)	89	2 (1, 3)	0.303
Days of physical therapy	23	41 (20, 79)	88	23 (13, 35)	0.006
Number of therapy sessions	23	7 (2, 25)	89	1 (1, 7)	<0.001
Number of treadmill sessions	23	3 (2, 7)	89	2 (1, 3)	0.023
Days until successful steps	23	21 (9, 50)	89	7 (4, 15)	0.001

MFS = modified Frankel score. *Comparison between groups based on Mann-Whitney U tests.

Table 3. Univariate logistic regression for the prediction of a successful physical therapy as defined as an increase of at least 1 modified Frankel score after surgery.

Variable	Parameter estimate ($\hat{\beta}$)	P-value (Wald)	Odds ratio (95% CI)
Age ≥ 6 yrs	0.984	0.049	2.68 (1.00, 7.14)
Weight < 10 kg	-0.693	0.181	0.50 (0.18, 1.38)
Female	0.984	0.049	2.68 (1.00, 7.14)
Neutered	-0.170	0.810	0.84 (0.21, 3.36)
Dachshund	-0.330	0.484	0.72 (0.29, 1.81)
Chondrodystrophic breed	-0.555	0.257	0.57 (0.22, 1.50)
MFS at surgery	-0.697	0.003	0.50 (0.32, 0.79)
More than 1 disk affected	1.027	0.034	2.79 (1.08, 7.21)
Presented < 24 h	0.249	0.636	1.28 (0.46, 3.60)
Days from surgery to therapy	-0.267	0.177	0.77 (0.52, 1.13)
Number of therapy sessions	0.080	0.001	1.08 (1.03, 1.14)
Number of treadmill sessions	0.063	0.103	1.07 (0.99, 1.15)
Days of physical therapy	0.004	0.183	1.00 (1.00, 1.01)

affected at intake and stayed in rehabilitation until they were walking (Tables 1, 5 and 6).

This author has found that two criteria that are important for a dog to walk again. First, the dog must be able to stand 10 to 30 s by itself or with gentle hand support. The dog must be able to paddle the hind legs in sequence when sling walked. Physical rehabilitation through electrical stimulation, exercises and underwater treadmill therapy helps to combine the two criteria so that the dog can gait by itself. In humans, 3 criteria must be present to achieve a normal or functional gait. The criteria are an adequate range of joint mobility, appropriate timing of muscle activation across the gait cycle, and unimpaired sensory input from the visual, somatosensory, and vestibular systems (Griggs et al., 2007). Although improvement for this study was considered to be an increase of one full MFS, the difference between a 3.25 or a 3.5 MFS is the difference between standing and walking.

Neuromuscular electrical stimulation provided in the early recovery period helped with muscle memory until the hind leg flexor muscles received innervation (Kanaya and Tajima, 1992). NMES may also decrease pain via the Gate Theory (Melzack and Wall, 1965). During NMES sessions, dogs were allowed to lie in a quiet room with music, have their hair coats brushed, and given lean turkey and water. For the dogs that appeared to have a slower recovery, daily electrical stimulation sessions with the owners were beneficial. Communicating with the owner after the surgery (within a day after surgery and a day after going home) about prognosis and recovery times was beneficial for the owners in what to expect and what was needed to be done as well as answering the many questions that they had in mind. Weekly follow-up

Table 4. Multivariable logistic regression for the prediction of a successful physical therapy (PT) as defined as an increase of at least 1 MFS after surgery.

Variable*	Parameter estimate ($\hat{\beta}$)	P-value (Wald)	Odds ratio (95% CI)
Female	1.246	0.038	3.48 (1.07, 11.3)
Male	Referent	-	-
Number of PT sessions	-	0.024	-
0 or 1 session	Referent	-	-
2 – 7 sessions	0.820	0.212	2.27 (0.63, 8.23)
> 7 sessions	2.080	0.006	8.00 (1.80, 35.6)
MFS at time of surgery	-	0.012	-
0-1	Referent	-	-
2	-1.938	0.003	0.14 (0.04, 0.52)
> 2	-1.291	0.097	0.28 (0.06, 1.27)

Hosmer and Lemeshow $\chi^2 = 5.357$, df = 7, P = 0.617.

Table 5. Univariate Cox proportional hazard regression for the rate of taking first successful steps.

Variable	Parameter estimate ($\hat{\beta}$)	P-value (Wald)	Hazard ratio (95% CI)
Age ≥ 6 yrs	-0.118	0.542	0.89 (0.61, 1.30)
Weight < 10 kg	0.246	0.258	1.28 (0.83, 1.96)
Female	0.051	0.791	1.05 (0.72, 1.54)
Neutered	-0.245	0.409	0.78 (0.44, 1.40)
Dachshund	-0.175	0.369	0.84 (0.57, 1.23)
Chondrodystrophic breed	-0.195	0.353	0.82 (0.55, 1.24)
MFS at surgery	0.451	<0.001	1.57 (1.32, 1.86)
T10-T11 affected	-0.466	0.272	0.63 (0.27, 1.44)
T11-T12 affected	-0.202	0.370	0.82 (0.53, 1.27)
T12-T13 affected	-0.290	0.151	0.75 (0.50, 1.11)
T13-L1 affected	0.119	0.554	1.13 (0.76, 1.67)
L1-L2 affected	0.006	0.979	1.01 (0.64, 1.59)
L2-L3 affected	-0.294	0.424	0.75 (0.36, 1.53)
L3-L4 affected	0.195	0.704	1.22 (0.45, 3.32)
More than 1 disk affected	-0.461	0.032	0.63 (0.41, 0.96)
Presented < 24 hrs	-0.083	0.696	0.92 (0.61, 1.39)
Days from surgery to therapy	-0.011	0.737	0.99 (0.93, 1.05)
Number of therapy sessions	-0.090	<0.001	0.91 (0.88, 0.95)
Number of treadmill sessions	-0.121	<0.001	0.89 (0.84, 0.94)
Days of physical therapy	-0.017	<0.001	0.98 (0.98, 0.99)

appointments helped detect post-operative problems such as residual pain, regression in nerve function and bladder maintenance problems such as urine retention and infection.

Underwater treadmill therapy is useful for patterning gait and encouraging use of the limbs (Millis and Levine, 2014). A residual, temporary improved gait is often noted after treadmill therapy. At these appointments, dogs could be assessed in their improvement as they went on to learn a new exercise. Owners were encouraged to

Table 6. Multivariable Cox proportional hazard regression for the rate of taking first successful steps.

Variable*	Parameter estimate ($\hat{\beta}$)	P-value (Wald)	Hazard ratio (95% CI)
MFS at time of surgery	-	0.001	-
0-1	Referent	-	-
2	1.110	0.001	3.04 (1.55, 5.96)
> 2	1.331	<0.001	3.78 (1.82, 7.87)
Physical therapy sessions	-	<0.001	-
0-1	Referent	-	-
2-7	-0.559	0.022	0.57 (0.35, 0.92)
> 7	-1.828	<0.001	0.16 (0.07, 0.36)
Number of treadmill sessions			
0-3	Referent	-	-
> 3	-0.653	0.022	0.52 (0.30, 0.91)

keep activity to 5 min or less when the dog began walking. Running, jumping or sharp turns were discouraged. Crate rest was recommended when the owners were not home or in direct supervision of the dog.

Further studies need to be conducted to look at which groups of patients benefit the most from physical therapy. If a dog recovers within 3 days after surgery, recovery was almost completely to the surgery. Dogs that do not ambulate within a week of surgery or those that have lost deep pain perception would intuitively be the group that would benefit from physical rehabilitation the most. Although only 50% of the dogs that had no deep pain (nociception) at the time of intake improved, 10/16 (63%) presented to the surgeon less than 24 h from the onset of clinical signs which may indicate a more severe lesion. One study demonstrated that dogs with deep pain perception present at 2 weeks postoperatively had significantly higher success rate (8/12, 66.7% recovered) than dogs without deep pain perception at this time period (1/10, 10.0% recovered) (Laitinen and Puerto, 2005).

Four weaknesses are present in this study. The first is inconsistent long-term follow up (greater than 3 months) in all of the patients compared to a previous study (Aikawa et al., 2012). The second is trying to put a numerical value on the two subclasses of non-ambulatory paraparesis with or without weight bearing within modified Frankel spinal cord injury score. There may be a better overall scoring system such as the Texas spinal cord injury scale (Levine et al., 2009). Also, there is no control group within the study to compare dogs receiving hemilaminectomy and fenestration alone versus those that received formal physical rehabilitation. Finally, the current study did not look at electrical stimulation, underwater treadmill therapy or home exercise modalities separately or as separate combined groups. A previous study reported faster recovery times (5 days versus 12 days in the control group); however, both were also given polyethylene glycol (PEG), which has been shown to decrease recovery times (Draper, 2012; Laverty, 2004). Therefore, further controlled studies are needed to compare different rehabilitation modalities to see which one or combination is most effective at shortening and improving quality of recovery after thoracolumbar hemilaminectomy with fenestration.

Conflict of Interest

The authors have not declared any conflict of interest.

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Abbreviations: DVM/CCRP, Doctor of veterinary medicine/certified canine rehabilitation practitioner; **IVDD,** intervertebral disc disease; **MFS,** modified Frankel score; **NMES,** neuromuscular electrical stimulation; **UMN,** upper motor neuron; **UT,** underwater treadmill therapy.

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