

## Magnetic resonance findings and outcome in ten cats with traumatic spondylomyelopathy

*MRI-bevindingen en klinische uitkomst bij tien katten met traumatische spondylomyelopathie*

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### A BSTRACT

In this retrospective study, the MR findings of ten cats with acute post-traumatic spondylomyelopathy were described and the most useful MR sequences were determined. Spinal cord injury (SCI), bone and muscle trauma were compared with the clinical outcome (recovery or euthanasia). The extension of spinal cord injury (SCI) was measured in vertebral body length (VBL). Of the ten cats, only five fully recovered. In the recovery group, no SCI (n=1) or SCI <1 VBL (n=4) were found. In the group of euthanized dogs, SCI > 2 VBLs (n=4) or spinal cord transection (n=1) were found. Lesions were best seen on T2WSE (spinal cord injury), STIR (soft tissue trauma) and T1WSE (bone injury). Low-field MR was therefore helpful to assess feline spinal trauma and may prove helpful to predict the clinical outcome, although a larger case series is needed. The authors suggest that protocols with low-field MR should include T1WSE, T2WSE and STIR sequences.

### SAMENVATTING

In deze retrospectieve studie werden de laagveld-magnetic resonance imaging (laagveld-MRI)-bevindingen beschreven bij tien katten met acute traumatische spondylomyelopathie en werden de meest bruikbare MRI-sequenties om dit in beeld te brengen, besproken. De uitgebreidheid van ruggenmerg-, spier- en bottrauma werd vergeleken met de klinische uitkomst, ie. klinisch herstel of euthanasie. Van de tien katten herstelden vijf dieren volledig (de 'herstelgroep'). In deze herstelgroep werd er geen ruggenmergletsel gevonden, of als er een letsel aanwezig was dan was de lengte hiervan minder dan de lengte van een wervellichaam. In de groep met geëthanaseerde dieren was de lengte van het ruggenmergletsel langer dan twee wervellichamen of er was transectie van het ruggenmerg zichtbaar. De meest bruikbare sequenties waarop de afwijkingen van de wervelkolom het meest naar voren kwamen, waren STIR (wekedelentrauma) T2WSE (ruggenmergletsel) en T1WSE (bottrauma). Laagveld-MRI is een bruikbare techniek om trauma van de wervelkolom van de kat in beeld te brengen en de klinische uitkomst te voorspellen. De auteurs stellen voor dat het onderzoeksprotocol ten minste T1WSE, T2WSE en STIR-sequenties omvat.

### INTRODUCTION

Acute spinal cord injuries (SCIs) caused by exogenous traumas, mainly road traffic accidents (RTA), are the fourth most common cause of feline death (Rochlitz, 2004). Other causes of acute spinal trauma include falls, gunshots, falling objects and accidental owner-induced injuries (Rochlitz, 2004; Marioni et al., 2004; Adamantos et al., 2007; Eminaga et al., 2011). In cats, vertebral fractures and/or luxations account for 6% of all spinal cord disorders (Marioni

et al., 2004). Traumatic SCIs are considered critical emergencies that must be recognized and treated rapidly to increase the chances of preventing permanent loss of function (Whitney et al., 1987; Glick et al., 1998; Arce et al., 2001; Pratschke et al., 2002; Cruz-Arámbulo et al., 2012). The effects of SCI depend on the severity of the injury: in a complete SCI, there is absence of neurotransmission below the level of the injury, while in an incomplete SCI, some functional axons remain with a reduced or temporary loss of neurotransmission (Dumont et al., 2001).

**Table 1. Modified Matthiesen neurological assessment score used.**

Grade	Neurological status
0	Normal
1	Hyperesthesia and no neurological deficits
2	Ambulatory paraparesis or ataxia
3	Non-ambulatory paraparesis
4	Paraplegia without loss of deep pain sensation
5	Paraplegia with loss of deep pain sensation

Diagnostic imaging plays a key role in the evaluation of spinal trauma (Besalti et al., 2002; Gramueck et al., 2004; Voss et al., 2004; Bali et al., 2009; Eminaga et al., 2011; Marioni et al., 2010). Lateral radiographs of the whole spine to detect vertebral luxations or fractures have been recommended for initial evaluation (Dennis, 1987; Sande, 1990; Bagley, 2000); however radiographic studies in dogs carry a low negative predictive value for the presence of vertebral canal narrowing (51%) and fracture fragments in the vertebral canal (58%) (Kinns et al., 2006).

More recently, computed tomography (CT) and magnetic resonance (MR) imaging have been increasingly used as the first-line imaging technique for the evaluation of spinal trauma (Jeffery, 2010; Da Costa et al., 2010; Park et al., 2012). CT is the cross sectional imaging modality with the best spatial resolution and allows accurate determination of the presence of vertebral fractures and bony fragments within the vertebral canal (Kinns et al., 2006; Da Costa et al., 2010). However, because MR provides superior contrast resolution and diagnostic sensitivity, it has been found to be significantly superior to CT in the diagnosis of soft tissue trauma, especially for ligamentous, discal, vascular and neural injuries (Ramon et al., 1997; Saifuddin, 2001; Muchow et al., 2008; Lundberg, 2008; Da Costa et al., 2010; Johnson et al., 2011; Morais et al., 2013). Low-field MR is a valid technique for assessing poly-traumatized humans (Silberstein et al., 1992) and dogs (Schouman-Claeys et al., 1990).

There is a paucity of published reports on the use of MR for the assessment of traumatic spinal injuries in small animals. The aims of this retrospective study were to describe the MR findings in a series of 10 cats with post-traumatic spondylomyelopathy, correlate these MR findings with clinical outcome, and determine the sequences that were found most useful in identifying pathology. To the best of the authors' knowledge, this article is the first to investigate a correlation between MR findings and the outcome in cats with acute spinal trauma.

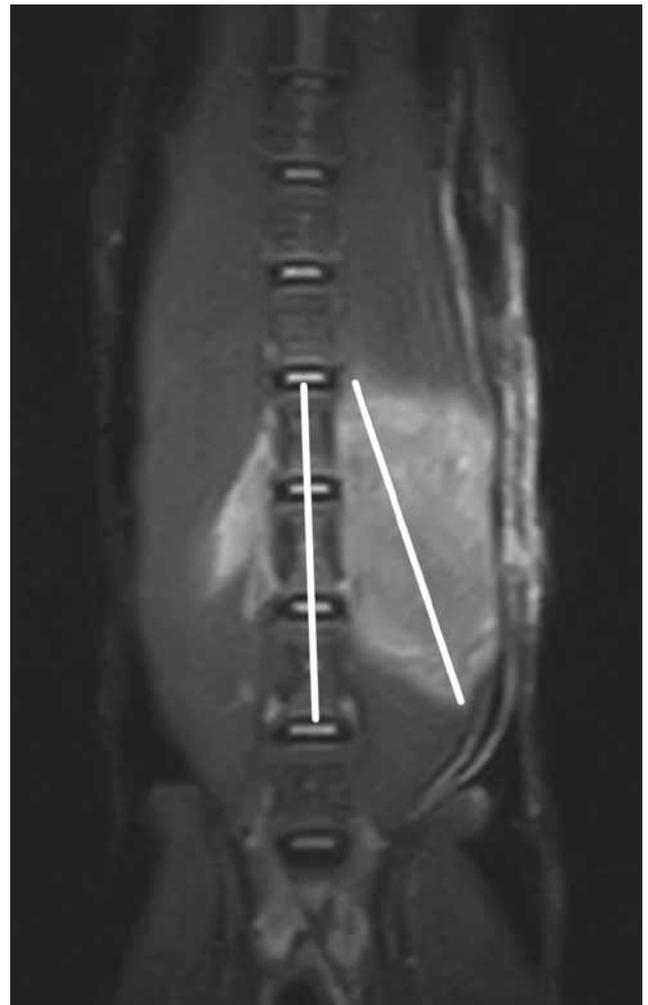
## MATERIALS AND METHODS

Medical records were reviewed retrospectively to identify cats with acute neurological deficits following a traumatic event, which were referred to Dick

White Referrals (Cambridgeshire, England) between 2010 and 2013. The cats included in the study were those diagnosed with traumatic spondylomyelopathy localized T3-S3 spinal cord segments, undergoing MR and with a follow-up or contact with the owners for at least six months post-discharge.

The neurological examination was performed by a board-certified neurologist or by a supervised resident in neurology. Neurological status was graded using a five-point scale adapted from Matthiesen (1983) (Table 1). All cats underwent a MR examination within 6 days (mean 2.5 days) of injury, which was within 6 hours of the admission in the referral centre. The following information was retrieved from the medical records: age, sex, breed, presenting clinical signs, results of physical, neurological and diagnostic imaging examinations, laboratory data (hematology, serum biochemistry and CSF analysis), treatment, duration of hospitalization and outcome (two groups were assigned for outcome: recovered and euthanized).

The MR imaging was performed under general anesthesia using a 0.4 Tesla open magnet (Hitachi Ap-



**Figure 1. Extension of the soft tissue injuries measured in vertebral body lengths on a dorsal STIR image. Note the severe paraspinal soft tissue injury, seen as a bilateral heterogeneous hyperintense signal more marked on the left and measuring up to 3 vertebral body lengths.**

erto, Tokyo, Japan). T2-weighted spin echo (T2WSE) and Short Tau Inversion Recovery (STIR) images were acquired in the sagittal, transverse and/or dorsal planes for all cats. T1-weighted spin echo (T1WSE) sequences were acquired in nine cases and T1WSE post-administration of gadoterate meglumine (Dotarem, Guerbert, France) at 0.1 mmol/kg body weight, were acquired in eight cats; T2\* gradient recalled echo (GRE) sequences were acquired in two cases.

All MR images were retrospectively reviewed by a board-certified radiologist and a resident in radiology, both unaware of the clinical outcome. The anatomic location and extension of the lesions were identified and noted for each cat. The lesions were divided into three groups: soft tissue injury (muscle contusion and hemorrhage), bone injury (fractures and luxations) and spinal cord injury (intramedullary pathology including contusion and cord compression). The soft tissue or spinal cord injury with the greatest cranio-caudal extension of the abnormal signal in a single slice was measured in vertebral body lengths in sagittal or dorsal planes (Figure 1). In addition to the signal characteristics of the lesions, the most sensitive MR sequence for each lesion was noted.

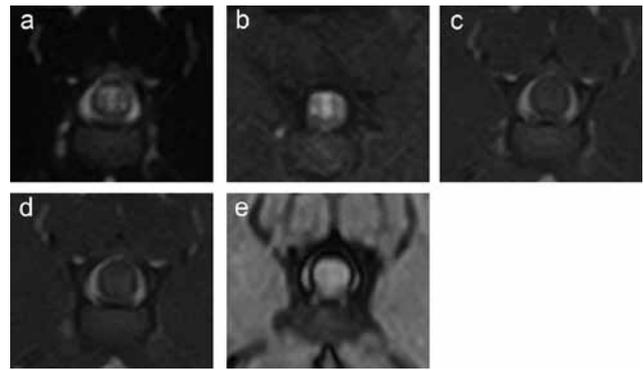
The outcome for each case was determined based on the information from a follow-up examination or by contacting the owner at the time of the study. Follow-up data were available from 6 months to 3 years following the traumatic event. Based on the outcome, the patients fell into one of two categories: recovered or euthanized (recovery group or euthanized group).

## RESULTS

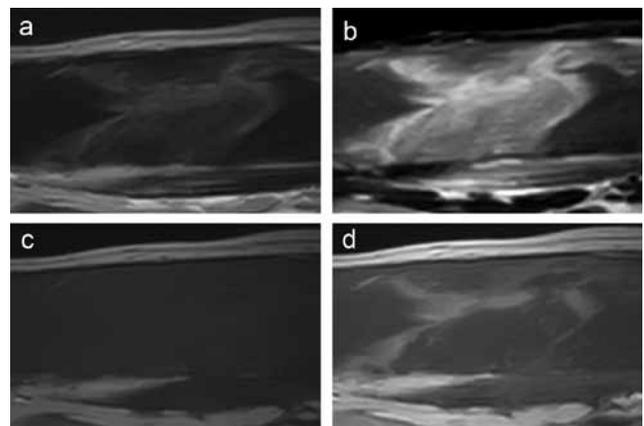
Ten cats were included in the study. Seven were males and three females, all neutered except for one young male. Eight were non-pedigree (Domestic Short/Long Hair) and two were pedigree (one Ragdoll and one Oriental Short Hair) cats. Their age ranged from 9 months to 7 years (mean age: 2.8 years). Nine cats were suspected to be involved in a RTA, and one cat was injured by a treadmill. The main neurological signs were ataxia (2), ambulatory paraparesis (2), non-ambulatory paraparesis (1), paraplegia with deep pain sensation (2) and paraplegia with loss deep pain sensation (3). The neurolocalization was T3-L3 in four cats, L4-S3 in four cats and T3-S3 in four cats. Detailed information about individual cases is given in Table 2.

### MR findings

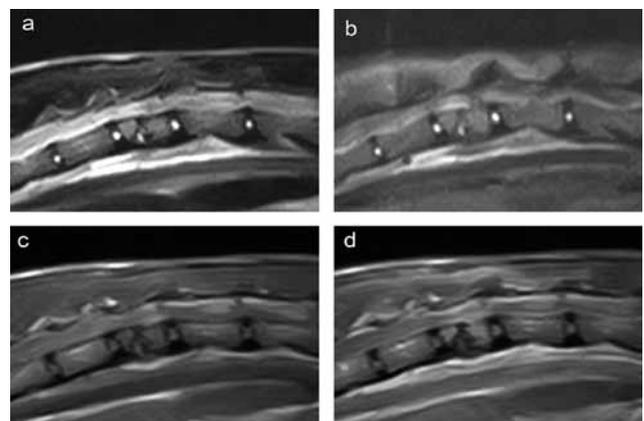
Nine cats had intramedullary spinal cord lesions identified on MR images as intramedullary high intensity signal on T2WSE images (Figure 2) extending between 0.5 and 6 vertebral body lengths (average 2.4 vertebral body lengths). In addition to these intramedullary lesions, one cat had a suspected laceration/



**Figure 2.** Transverse image of a SCI on: (a) T2WSE, (b) STIR, (c) T1WSE, (d) T1WSE post-contrast and (e) T2\* GRE sequences. Note the intramedullary lesions are best seen on T2WSE and STIR images as hyperintensities. There is no contrast enhancement in post-contrast T1WSE.



**Figure 3.** Sagittal images of an epaxial muscle injury on T2WSE (a), STIR (b), T1WSE (c) and T1WSE post-contrast (d) sequences. Note: the lesion is best seen on STIR and then on T2WSE image, as a heterogeneous hyperintense signal. There is contrast enhancement in post-contrast T1WSE.



**Figure 4.** Midline sagittal image showing a compression fracture of the 12<sup>th</sup> thoracic vertebrae on (a) T2WSE (b) STIR (c) T1WSE and T1WSE post-contrast sequences. This patient was euthanized shortly after the MR examination.

transection of the spinal cord. The greatest number of intramedullary SCI were identified on T2WSE (9/9); with 6/9 identified on STIR. SCIs were identified on pre-contrast T1WSE images in 2/9 cats; the lesions were contrast enhancing in only 3/8 cats.

Soft tissue injuries were detected in all cases and were identified by altered MR signal intensity of the muscles and/or subcutaneous tissues (Figures 1 and 3). Hyperintensity compared to normal muscle was identified on STIR sequences in all cats (10/10); and on T2WSE sequences in 8/10 cats, and was identified as contrast uptake in T1WSE post-contrast sequences in 5/8 cats. MR abnormality was seen in the paraspinal muscles in all cats (epaxial in 10/10 and hypaxial muscles in 8/10), pelvic muscles in 3/10 and abdominal muscles in 3/10. The epaxial muscles showed pathology that extended on average over 2.8 (range: 1-5) vertebral body lengths while the hypaxial injuries, when present, extended for a shorter distance - on average over 2 (range: 1-4) vertebral body lengths.

Bone injuries were identified in 6/10 cats. Four cats had fractures of the vertebrae affecting the vertebral bodies, articular facets and spinous processes. Of these, three out of four cats were considered unstable according to a three vertebral compartments model (Denis, 1984). Two of the vertebral fractures were at the thoracolumbar spine between T12 and L2 (Figure 4) and the other two were at the caudal aspect of the lumbar spine between L6 and L7. Two cats had pelvic fractures. In all the cases, T1WSE made the bone injuries most conspicuous; sagittal planes were preferred for vertebral luxations and transverse planes for vertebral fractures, particularly when the articular facets were involved.

### Outcome

Of the ten cats with SCIs, five had a good recovery and five were euthanized, and so were divided into

**Table 2. Case details of the ten cats with acute spondylomyelopathy according to their neurological grade.**

Signalment	Cause of trauma	Ambulation	Pain perception	Neurological grade	Neuro-localization	SCI length (VBL)	Epaxial muscle injury length (VBL)	Bone lesions	Treatment	Outcome
DSH, 9 m, Fn,	Treadmill	Ataxia	Present	2	T3-L3	-	4.8	-	Meloxicam and Gabapentin	Good
Ragdoll, M, 9 m	RTA	Ataxia	Present	2	T3-S3	0.5	2.3	Multiple pelvic fractures	Meloxicam and Gabapentin	Good
DSH, Mn, 3 y	RTA	Ambulatory Paraparesis	Present	2	T3-L3	1	-	-	Meloxicam and Gabapentin	Residual ataxia
DSH, Mn, 5.25y	RTA	Ambulatory Paraparesis	Present	2	L4-S3	1	1.5	L6 Fracture	Surgery and Meloxicam and Gabapentin	Good
DSH, Mn, 2 y	RTA	Non ambulatory paraparesis	Present	3	L4-S3	1	1.5	L6-7 Fracture/luxation	Surgery and Meloxicam and Gabapentin	Good
DSH, Mn, 2 y	RTA	Paraplegia	Present	4	L4-S3	2	2.4	-	Meloxicam and Gabapentin	Delayed 3 m euthanasia
DSH, Fn, 9 m	RTA	Paraplegia	Present	4	T3-S3	6	4.6	-	Meloxicam and Gabapentin	Delayed 6 m euthanasia
Oriental, Mn, 3y	RTA	Paraplegia	Absent	5	T3-L3	5	2.8	T12 Fracture	-	Immediate euthanasia
DSH, Mn, 7y	RTA	Paraplegia	Absent	5	L4-S3	2.5	5	Multiple pelvic fractures	-	Immediate euthanasia
DSH, Fn, 4y	RTA	Paraplegia	Absent	5	T3-L3	1.5 *	2.2	T13-L1-2 Fractures	-	Immediate euthanasia

\*suspected spinal cord transection/laceration.

DSH: domestic shorthaired cat, M: male, Mn: male neutered, Fs: female neutered, m: month, y: year, SCI spinal cord injury, VBL vertebral body length

**Table 3. Correlation between the neurological grade, the SCI length and the outcome.**

Neurological grade	SCI length in VBL (range)	Outcome
2 (n=4)	0.6 (0.5-1)	Good (except for one residual ataxia)
3 (n=1)	1	Good
4 (n=2)	4 (2-6)	Delayed euthanasia
5 (n=3)	3.75 * (2.5-5)	Immediate euthanasia

\*(Excluding the cat with transected spinal cord n=2)

two groups for assessment of outcome: recovery and euthanized. Three were euthanized immediately because of the severity of the primary lesions and two at a later date due to the lack of recovery of the normal neurological status.

The cats in the recovered group did not have evidence of neurological signs at 6 months after the traumatic event, except for one that had a residual ataxia. All cats in the recovery group scored 2 and 3 on the modified Matthiesen neurological assessment. Table 3 shows the correlation between SCI length and outcome according to the neurological grade. One cat had only soft tissue injury, despite clinical signs of spondylomyelopathy. SCIs were seen in the remaining four patients; extending maximally one vertebral body length (range from 0 to 1; mean 0.7 vertebral body length). Epaxial muscle injuries were seen in all five cats in the recovery group, extending between 1 and 4.8 with an average of 2.2 vertebral body lengths. Bone injury was seen in three cats: one cat had vertebral fractures of L6, one a fracture/luxation of L6-L7, and the third had multiple pelvic fractures. All underwent surgical repair.

Of the euthanized group, all cats had a Matthiesen neurological assessment score of 4 or 5. Those with a score of 4 (n=2) had a poor recovery and were euthanized 3 and 6 months post-discharge, and those with a score of 5 (n=3) were euthanized shortly after imaging. Four of the euthanized patients had SCIs that extended at least 2 vertebral body lengths (range from 2 to 6, average 3.9) while the remaining patient was suspected of having a transected/lacerated spinal cord. Epaxial muscle injuries in the five cats were also more extensive than in the groups with lower scores, being over 2.2 vertebral body lengths and with an average of 3.4 vertebral body lengths. Three cats in this group had bone injuries. Two cats had vertebral fractures; one at T12 and the other had multiple vertebral fractures affecting T13, L1 and L2; these cats were euthanized without repair. The third cat with bone injuries had multiple pelvic fractures, which required surgical repair.

## DISCUSSION

Nine of the ten cats presented with post-traumatic neurological deficits were suspected to be involved in a

RTA. They were predominantly young adults (median age 2.8 years old), males (7/10) and non-pedigree cats (8/10). Only five cats survived 6 months after the traumatic event. The survival rate of 50% in the present study is similar to the reported rate in a larger study of thirty cats (Gramueck et al., 2004). In the small population of ten cats of the present study, there is a clear correlation between clinical outcome and initial neurological grading according to the Matthiesen grading system. All the patients with grade 2 (four cats) and 3 (one cat) survived, and had a complete recovery except for one cat with grade 2 that remained ataxic. Two cats with grade 4 were discharged, but deterioration of their condition lead to their euthanasia 3 and 6 months post-discharge. The three cats with grade 5 were immediately euthanized due to the severity of the lesions. Furthermore, all the cats in the study without deep pain sensation had a fatal outcome, in concordance with the literature (Gramueck et al., 2004).

Unsurprisingly, findings consistent with SCIs on MR imaging were found to have a negative influence on the outcome, with five out of nine patients having cord injury visible on MR imaging, being euthanized. The length of the SCI on MR imaging was observed to correlate with the survival of the patients; with the five cats with SCIs extending 1 vertebral body length or less making a full recovery. On the other hand, in four of the five fatal cases, the SCIs were 2 vertebral body lengths or more, with the remaining fatal case a suspected transected spinal cord. No significant differences in SCI extension could be made between the grade 2 and 3 and between the grade 4 and 5. Other authors have used the extension of the SCI in MR examinations to assess the prognostic value in the canine population in other types of SCI (Ito et al., 2005; Bruce et al., 2008; Levine et al., 2009; De Risio et al., 2009). The vertebral length ratio of T2WSE intramedullary hyperintensity appeared to be predictive of long-term ambulatory status in dogs with acute disc herniation (Levine et al., 2009; Ito et al., 2005). A cut-off value of 1.28 vertebral body lengths to predict an unsuccessful outcome in dogs with non-compressive disc extrusion resulted in 57% sensitivity and 82% specificity (De Risio et al., 2009). In another study by Ito et al. (2005), all paraplegic dogs following a thoracolumbar disk extrusion, with an SCI longer than 3 times L2 vertebra had a fatal outcome. Compared to canine vertebrae, feline vertebrae are rela-

tively more elongated. The authors postulate that the relatively elongated feline vertebra represents a longer spinal cord segment and the different mechanism of injury external trauma versus internal secondary to intervertebral disc, could contribute to the difference in length associated with non-survival in the present study compared to others. A study by Gramueck et al. (2004) established that cats with loss of deep pain sensation had a high incidence of myelomalacia at surgery or post-mortem examination. Unfortunately, myelomalacia has no specific characteristic appearance on MR, and since no post-mortem examinations were performed in the present study, it was impossible to correlate the findings of length of cord abnormality with presence or absence of myelomalacia.

In general, T2\* GRE sequences are most valuable for their increased ability to detect the paramagnetic blood degradation products associated with hemorrhage compared to conventional spin echo sequences (Atlas et al., 1988). In the present study, only two patients suspected of acute hemorrhage had T2\* GRE sequences, and these showed no susceptibility artefact (indicated by signal void), hence, it was not helpful in distinguishing hemorrhage from edema. In the authors' experience, T2\* GRE sequences have a limited use in feline spinal imaging because of the small cord size and relative lack of sensitivity of susceptibility artefact in low-field MR (Farahani et al., 1990); however these sequences may be more beneficial in larger patients or in different magnets. Contrast enhancement on T1WSE sequences indicates extravasation of contrast-enhanced blood into the interstitial space (Terae et al., 1997). Furthermore, a sizeable enhancement in the hyperacute stage might indicate continued bleeding (Nawashiro et al., 2001). Contrast enhancement was seen in three cats only; each with grade 4 and 5 SCIs and were subsequently euthanized. The significance of contrast enhancement with SCIs was difficult to interpret due to the low number of cats in the study. Further studies will be needed to establish if this is indeed a negative predictive factor.

In the present study, one cat had no SCI on MR despite evidence of spondylomyelopathy on neurological examination. Interestingly, the soft tissue damage in this patient was very extensive, with the second longest epaxial muscle injury (4.8 vertebral body lengths) of all cases. This cat was the only one cat not involved in a RTA but had a treadmill injury, which is likely to have a different physical mechanism of trauma, and therefore may have a different pattern of injury. Spinal cord injury without radiologic abnormality (SCIWORA) is documented in humans and is attributed to "cord concussion", where the biochemical alterations within the cord that led to the initial paralysis did not generate abnormal MR signals (Pang et al., 1982; Pang, 2004). More recently, diffusion-weighted MR (DWI) has been proposed as a method to evaluate the integrity of the spinal cord in SCIWORA cases (Shen et al., 2007). The authors of the present study have not assessed this, but it is

possible that DWI will further help elucidating cases of SCIWORA in cats, which would previously have been considered to have a normal MR investigation.

Epaxial muscle injuries were present in all the cats. In the euthanized group, the epaxial injuries were notably more extensive (extending for a mean of 3.4 (euthanized group) versus 2.2 (recovery group) vertebral body length suggesting that a greater trauma had occurred with more devastating injuries leading to poorer outcome.

Vertebral fractures were present in four cases, of which two fully recovered after surgical repair. In the recovery group, both cats suffered fractures of the caudal lumbar spine at the level of L6-7, and had small concurrent SCIs extending over 1 vertebral body length. In the euthanized group, both cats had vertebral fractures affecting the thoracolumbar region but the concurrent SCI was more severe: one cat was suspected to have a transected/lacerated spinal cord and the other had an extensive SCI over 5 vertebral body lengths. The presence of vertebral fracture did not have a detrimental effect on outcome when surgically repaired; however the presence of an extensive concurrent SCI and possibly the fracture location may be more relevant to the prognosis.

Of all the MR sequences that were used, STIR detected the greatest extension of paravertebral muscle trauma and on two occasions detected lesions that would have been missed on T2WSE or on T1WSE post-contrast. In human medicine, STIR sequences are widely used for excluding spinal trauma in adults (Richards, 2005) and are also highly sensitive in pediatric patients (Henry et al., 2013). Therefore, the authors suggest including STIR sequences in the MR protocol for acute spinal trauma in cats, in addition to standard T2WSE and T1WSE sequences. T2\* GRE sequences were not helpful in the present case, and the utility of post-contrast images is as yet unestablished.

There are limitations to the present study. It is a retrospective review of patients and as such has variations in the imaging protocol. Furthermore, the low number of cases, the variability of the injuries and the lack of post-mortem examination of the euthanized cats decrease the power of this study.

## CONCLUSION

Low-field MR imaging was useful to assess spinal trauma in cats and helped to predict the clinical outcome, although a larger case series is needed to evaluate this further. In the authors' opinion, protocols with low-field MR should include T1WSE, T2WSE and STIR images, ideally in two or more planes. The use of post-contrast sequences may be helpful; however, the low number of cats with contrast enhancement precludes conclusion. Cats with intramedullary hyperintensity on T2WSE over 2 vertebral body lengths or more had a 100% mortality rate, while patients with-

out spinal cord injury visible on MR or with intramedullary hyperintensity on T2WSE of 1 vertebral body length or less made a complete recovery, suggesting that MR features may prove to be useful in establishing a prognosis for cats with spinal trauma.

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