TITLE: Acute Herniation of Nondegenerate Nucleus Pulposus: Acute Noncompressive Nucleus Pulposus Extrusion and Compressive Hydrated Nucleus Pulposus Extrusion

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JOURNAL: Veterinary Clinics of North America: Small Animal Practice

PUBLISHER: Elsevier

PUBLICATION DATE: January 2018

DOI: 10.1016/j.cvsm.2017.08.004

Acute herniation of non-degenerate nucleus pulposus: acute non-compressive nucleus pulposus extrusion and compressive hydrated nucleus pulposus extrusion

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Keywords: High-velocity low-volume disc extrusion, traumatic disc extrusion, ANNPE, HNPE, spinal cord contusion

The authors have no competing interests to declare.

SYNOPSIS

Acute herniation of non-degenerate nucleus pulposus material is an important and relative common cause of acute spinal cord dysfunction in dogs. Although there is some discussion about the most appropriate terminology, two types of herniation of non-degenerate or hydrated nucleus pulposus have been recognized; acute non-compressive nucleus pulposus extrusion (ANNPE) and acute compressive hydrated nucleus pulposus extrusion (HNPE). Spinal cord contusion plays an important role in the pathophysiology of both conditions. Sustained spinal cord compression is not present in ANNPE, while varying degrees of compression are present in HNPE. Both conditions typically affect older dogs and affected animals can present with a characteristic clinical presentation. Magnetic resonance imaging (MRI) is the diagnostic modality of choice and specific MRI findings have been described to obtain a reliable clinical diagnosis. Although affected animals often present with severe neurological signs, good outcomes can be achieved if appropriate treatment is initiated.

Key Points

- Acute non-compressive nucleus pulposus extrusion is characterized by a sudden extrusion of non-degenerate nucleus pulposus without remaining spinal cord compression
- Hydrated nucleus pulposus extrusion is characterized by a sudden extrusion of hydrated nucleus pulposus, which results in varying degrees of spinal cord compression
- Dogs with acute non-compressive nucleus pulposus extrusion, and to a lesser extent dogs with hydrated nucleus pulposus extrusion, can present with characteristic clinical signs
- Magnetic resonance imaging (MRI) is the diagnostic modality of choice for both conditions. Specific MRI findings have been described for both conditions
- While there is consensus about the best treatment for acute non-compressive nucleus pulposus extrusion, the ideal treatment for hydrated nucleus pulposus extrusion is unknown

INTRODUCTION

Acute intervertebral disc herniation is the most common spinal emergency in dogs and can be defined as a localized displacement of intervertebral disc material beyond its normal anatomical boundaries.[1] "Hansen type I" intervertebral disc disease or "intervertebral disc extrusion" is the most common and best characterized spinal cord condition in dogs.[2-4] In this condition, acute extrusion of dehydrated and calcified nucleus pulposus through a fully ruptured annulus fibrosus is preceded by advanced chondroid degeneration of the intervertebral disc (IVD) and the nucleus pulposus in particular.[2] Acute spinal cord injury (SCI) in dogs with "Hansen type I" intervertebral disc disease is caused by a combination of spinal cord contusion and varying degrees of sustained spinal cord compression.[4-6] However, following continuous developments and increased availability of magnetic resonance imaging (MRI) in veterinary medicine, it is increasingly recognized that acute extrusions can also occur of non- or minimally degenerate nucleus pulposus. Although there is some discussion concerning the most appropriate terminology, two types of acute herniation of non-degenerate nucleus pulposus are currently recognized; acute non-compressive nucleus pulposus extrusion (ANNPE) and hydrated nucleus pulposus extrusion (HNPE). Differentiation and diagnosis is based on well-reported clinical characteristics and diagnostic imaging findings.[7,8] Several reports have now explored the typical clinical presentation, diagnostic findings and management of ANNPE and HNPE, revealing some stark contrasts with traditional "Hansen Type I" IVD extrusions and emphasizing the need for an accurate diagnosis in such cases.[7-14] Although both ANNPE and HNPE refer to an acute extrusion of non-degenerate nucleus pulposus and subsequent

acute SCI, there are also important differences that might influence clinical decision-making regarding management and prognosis.

INTERVERTEBRAL DISC ANATOMY

Although a detailed description of canine IVD anatomy is beyond the scope of this manuscript, an understanding of the basic anatomical concepts is desirable to understand the clinical characteristics and treatment recommendations for dogs with ANNPE and HNPE. All vertebral bodies, with the exception of the first and second vertebrae and the fused sacral vertebrae, are interconnected by an IVD.[15] The IVD is composed of a centrally located nucleus pulposus, an outer annulus fibrosus, the transitional zone and adjacent vertebral endplates.[5] The healthy and non-degenerate nucleus pulposus is a mucoid, translucent, gelatinous structure **(Figure 1)**. It is well hydrated and is mainly composed of water.[16] The nucleus pulposus is surrounded by the annulus fibrosus, which consists of a network of concentrically organized collagen layers forming fibrous lamellae. The annulus fibrosus is thicker ventrally than dorsally, which results in an eccentric localization of the nucleus pulposus in the IVD.[15] The thinner dorsal annulus fibrosus in combination with the eccentric location of the nucleus pulposus are believed to predispose the nucleus pulposus to extrude in a dorsal direction towards the vertebral canal and spinal cord.[15] The most central part of the annulus fibrosus is more cartilaginous and forms the interconnection between the nucleus pulposus and annulus fibrosus. This well-demarcated region is called the transitional zone.[2,5] The dorsal and ventral borders of the IVD are formed by respectively the dorsal and ventral longitudinal ligament, while the cranial and caudal borders are formed by the cartilaginous vertebral endplates.[15] These vertebral endplates

have an important role in supplying the IVD with nutrients. Small molecules can reach the different components of the IVD through diffusion and osmosis from the capillary buds through the vertebral endplates.[17] The nucleus pulposus is a remnant of the embryological notochord and the predominant cell type of the non-degenerate nucleus pulposus is therefore the notochordal cell. The transitional zone contains chondrocyte like cells, the outer layer of the annulus fibrosus contains fibrocyte-like cells and the more central layers of the annulus contain a mixed population of fibrocytes and chondrocyte-like cells.[18] Intervertebral disc degeneration is a complex and multifactorial process and is associated with changes in the composition of these cells and their associated extracellular matrix. Early IVD degeneration is characterized by histological changes in the nucleus pulposus, which can be summarized as a gradual replacement of notochordal cells by chondrocyte-like cells.[5,18] Clinically irrelevant degenerative changes of the IVD however also occur during the physiologic process of aging[19] and changes seen in early pathological IVD degeneration can be indistinguishable from age-related changes.[5]

ACUTE NON-COMPRESSIVE NUCLEUS PULPOSUS EXTRUSION

There have been several terms used historically to describe this condition, with the current consensus of ANNPE used as it describes the key features of a sudden extrusion of non-degenerate nucleus pulposus, causing spinal cord contusion without significant compression.[7,13] Previous terms used have included traumatic disc extrusion, high-velocity low-volume disc extrusion, traumatic disc prolapse and Hansen Type III intervertebral disc disease.[2,20-22] ANNPEs have been diagnosed in dogs and less frequently in cats [23,24], and typically present with a very characteristic peracute onset of clinical signs during exercise

or following trauma.[7,13,24] Clinical signs are distributed according to the neuroanatomical location and extent of the lesion, and typically stabilize within 24 hours before improving or remaining static depending on the SCI severity.[7,13]

Pathophysiology

Understanding the pathogenesis of ANNPE requires an appreciation of the normal canine IVD anatomy outlined above. The strong osmotic gradient within the normal, non-degenerate nucleus pulposus acts to draw water into the nucleus pulposus and therefore create a naturally high intradiscal pressure.[5] The combination of this healthy hydrated nucleus pulposus surrounded by a dense and fibrous annulus fibrosus, allows mobility as well as great stability.[5] The normal IVD is therefore able to withstand marked variations of physiological loading and biomechanical stress without suffering structural compromise. However, in circumstances whereby the vertebral segment and IVD are subjected to supraphysiological forces, such as during intense exercise or trauma, structural integrity may fail.[22] In such a scenario, a small tear may occur in the complex lamellar structure of the annulus fibrosus, leading to a sudden extrusion of non-degenerate nucleus pulposus material dorsally into the vertebral canal (an ANNPE). It has been suggested that the annular lamellae in dogs are more vulnerable to such tears with increasing age.[25] In ANNPE the nuclear material is hypothesized to extrude with great force, causing a focal contusive injury to the adjacent spinal cord.[7] As the extradural material is non-degenerate and therefore highly hydrated, it typically rapidly dissipates or is resorbed, leaving minimal to no spinal cord compression.[7,22]

142 This hypothesis is supported by post-mortem findings in affected dogs of small tears in the
143 dorsal annulus, as well as non-degenerate nucleus pulposus material extradurally in the
144 vertebral canal.[26] The adjacent region of spinal cord may demonstrate evidence of focal
145 contusive injury, haemorrhage and necrosis.[26]
146
147 **Clinical presentation and differential diagnosis**
148 Dogs with ANNPE often have a characteristic clinical presentation and present with a
149 peracute onset of often severe neurological deficits, clinical signs are lateralized in up to
150 90% of affected cases[13] and are non-progressive after the initial 24 hours.[7,10,13] Although
151 dogs often vocalize at onset of clinical signs and a moderate degree of spinal hyperesthesia
152 can be noted on initial clinical examination, this condition is typically not associated with
153 severe or sustained spinal pain.[7,13] A study has indicated that these specific clinical
154 characteristics are indeed significantly associated with a diagnosis of ANNPE and that they
155 can be used to raise a high clinical index of suspicion for this particular disorder.[1] Clinical
156 signs are associated with intense exercise, such as running, in approximately 60% of cases
157 and external trauma in up to 40% of affected animals.[7] Although any breed can be affected,
158 older large breed dogs, and especially Border collies, seem vulnerable for this condition.[13]
159 This clinical presentation is very similar and almost indistinguishable from dogs with
160 ischemic myelopathy or fibrocartilaginous embolic myelopathy.[22] Ischemic myelopathy
161 should therefore be considered the most important differential diagnosis for ANNPE.
162 Although both conditions can be differentiated by MRI [27,28], a recent study identified
163 differences in clinical presentation between dogs with ANNPE and ischemic myelopathy.[13]
164 Dogs with ANNPE were significantly older (mean age of 7.0 years for dogs with ANNPE),

were more likely to have a history of vocalization at onset of clinical signs (in 62% of dogs with ANNPE), had more often spinal hyperesthesia (48% of dogs with ANNPE) during initial examination and had more often a lesion affecting the C1-C5 spinal cord segments compared to dogs with ischemic myelopathy.[13] Dogs with ischemic myelopathy more likely had a lesion affecting the L4-S3 spinal cord segments compared to dogs with ANNPE.[13] Compared to the general hospital population, Border collies were overrepresented for ANNPE, while English Staffordshire Bull terriers were overrepresented for ischemic myelopathy.[13] As outlined above, onset of clinical signs is associated with external trauma in up to 40% of dogs with ANNPE.[7] This is also reflected in earlier reports referring to this condition as "traumatic disc extrusion".[21] This highlights that ANNPE should be considered in animals suffering from spinal cord dysfunction immediately after external trauma and that ANNPE should be considered an important differential diagnosis for vertebral fracture and luxation.

Although "Hansen type I" intervertebral disc disease is the most common canine spinal emergency, affected animals often present with a different clinical presentation compared to dogs with ANNPE.[1] Dogs with "Hansen type I" intervertebral disc disease most commonly present with an acute instead of peracute onset of clinical signs, clinical signs are often progressive beyond the first 24 hours after their onset, affected animals more commonly display spinal hyperesthesia and clinical signs are not often obviously lateralized.[3]

Diagnosis

187 It is often possible to reach a high clinical index of suspicion for ANNPE prior to diagnostic
188 tests being performed due to the highly characteristic clinical presentation.[1] When making
189 a presumptive diagnosis based on clinical presentation, it should be emphasized to the
190 owner that and any deterioration or failure to improve as expected should lead to a re-
191 evaluation of the diagnosis. A definitive diagnosis of ANNPE can only be achieved through
192 visualization and histological examination of extruded non-degenerate nucleus pulposus
193 material in the vertebral canal.[26] However, as this can only be confirmed on post-mortem
194 examination, in clinical cases a presumptive antemortem diagnosis is based on combining
195 the typical clinical presentation with supportive diagnostic imaging findings.[7,27,28] The
196 potential uses and limitations of individual diagnostic tests are outlined below.
197
198 *Radiography and myelography*
199 The main use for survey radiographs is to rule out vertebral fractures and subluxations in
200 cases with a history of external trauma immediately preceding the onset of clinical signs.
201 However, the sensitivity for detecting vertebral fractures and subluxations using survey
202 radiographs is only 72% and 77.5%, respectively.[29] In ANNPE it can be possible to identify
203 a narrowed IVD space on survey radiographs. This radiographic finding is however not
204 specific for animals with ANNPE.
205 Although myelography has now largely been superseded by advanced cross-sectional
206 imaging modalities, it can be used to exclude compressive spinal conditions such as Hansen
207 Type I IVD extrusion.[30] In ANNPE myelography may reveal a small, focal extradural
208 lesion overlying an IVD, with an adjacent intramedullary pattern due to focal spinal cord

swelling.[9] However, it will not allow accurate differentiation between ANNPE and other causes of an intramedullary lesion such as ischemic myelopathy.

Computed Tomography

As with myelography, computed tomography (CT) can be used to exclude selected compressive conditions such as "Hansen Type I" IVD extrusion [30,31], as well as being the diagnostic imaging modality of choice for excluding vertebral fractures and subluxations.[29] However, CT will also not allow differentiation between other intramedullary spinal cord lesions. The use of CT or myelography does however allow the exclusion of differential diagnoses which require urgent surgical intervention. It can therefore guide an appropriate management plan if no MRI is available.

Magnetic resonance imaging

MRI is the diagnostic imaging modality of choice for diagnosing ANNPE (**Figure 2**).[7,27] The following criteria can be used to make a presumptive diagnosis of ANNPE using MRI [7]:

- Focal intramedullary spinal cord T2-weighted hyperintensity (typically isointense on T1-weighted sequences)
- Lesion located overlying an IVD space, often lateralized
- Reduction in volume of the T2-weighted hyperintense nucleus pulposus
- Mild narrowing of the affected IVD space
- Small volume of extradural material or signal intensity change dorsal to the affected IVD, with minimal to no spinal cord compression

The intramedullary lesion, representing an area of spinal cord edema secondary to contusive injury, is typically well demarcated and may affect grey matter preferentially. Although mild post-contrast enhancement of the lesion on T1-weighted sequences has been reported[21], usually this is not present.[7] In dogs with this typical clinical presentation, a common differential diagnosis for such a focal intramedullary spinal cord T2-weighted hyperintensity is ischemic myelopathy.[7,27] A recent study has shown moderate interobserver and moderate to good intraobserver agreement for differentiating between ANNPE and ischemic myelopathy using the criteria outlined above.[27] The findings of this study also suggested that a smaller, focal intramedullary lesion length is more often associated with a diagnosis of ANNPE compared to longer lesions in ischemic myelopathy, as well as lesions diagnosed as ANNPE being more often lateralized.[27]

Treatment

There are currently no neuroprotective treatments available with proven efficacy in directly treating the contusive primary spinal cord injury. Treatment of ANNPE therefore involves supportive medical management, consisting of restricted activity, supportive nursing care and physical rehabilitation.[7] As 48% to 57% of dogs with ANNPE present with evidence of spinal hyperesthesia [7,13], appropriate analgesia may be indicated for the first few days. Restricted activity with short lead walks has been recommended in the management of ANNPE for a period of 4-6 weeks, to minimise the risk of further extrusion of nuclear material.[7,22] Nursing care requirements essential to prevent complications and aid recovery vary between cases depending on the severity of neurological dysfunction, and may involve:

- Manual bladder expression or urinary catheter maintenance in cases of urinary incontinence
- Monitoring for and management of respiratory dysfunction in severe cervical myelopathies. This includes regular turning of recumbent patients every 4 hours to avoid lung atelectasis or accumulations of secretions
- Prevention of dermatological consequences of prolonged recumbency such as urine scald, pressure sores and decubital ulcers
- Nutritional support to maintain body condition and support physical rehabilitation

Physical rehabilitation is increasingly recognized as important in supporting the recovery of patients with spinal cord injuries in both human and veterinary medicine.[32,33] The aims and requirements of physical therapy will be dictated by the severity of neurological dysfunction, but typically aim to maintain joint range of motion, minimize muscle atrophy and prevent patient discomfort during the recovery period.[34]

Outcome

Overall recovery rates are variable with successful outcomes ranging from 66.7% to 100%.[7,9,13,21] It is however difficult to compare findings between studies due partly to differences in definitions of "successful outcome", inclusion criteria, and management protocols, as well as the limited number of animals with the most severe injuries.[7,9,13,21] **Table 1** shows a summary of outcome data in studies including at least 10 dogs. Factors reported to be associated with a poor prognosis include severity of neurological dysfunction and the extent of intramedullary lesions on MRI.[7] Severity of neurological

dysfunction has been shown to be associated with an unsuccessful outcome, with 0 out of 8 cases with paraplegia and absent nociception and only 7 out of 13 tetra/paraplegic dogs with intact nociception having successful outcomes in one study.[7] In the same study all 21 dogs with less severe neurological grades had successful outcomes.[7] Although long-term outcome has only been reported for a limited number of cases with paraplegia and loss of nociception, only 2 of a total of 14 reported dogs were reported to have a successful outcome **(Table 1)**.[7,13,21]

Using MRI, outcome has been shown to be associated with the length of the intramedullary T2-weighted hyperintensity on sagittal images and lesion cross-sectional area as a percentage of total spinal cord area on transverse images.[7] The maximal cross-sectional lesion area has been suggested to represent the best predictor of outcome in dogs with ANNPE, with a cut-off value of >90% to predict unsuccessful outcome with a sensitivity of 86% and specificity of 96%.[7] Several studies have found urinary or fecal incontinence to be a possible long-term complaint following ANNPE, with 10 out of 42 [7], 7 out of 46 [9] and 7 out of 26 [13] dogs experiencing long-term reduced urinary or fecal continence (**Table 1**). The ability to manage the consequences of urinary or fecal incontinence may therefore be an important factor in determining long-term outcome, as well as an important consideration in the care of affected animals.[7,13]

Overall recovery times following ANNPE are variable and are likely influenced by the severity of spinal cord injury.[7] Reported recovery times in dogs diagnosed with ANNPE include median durations of hospitalization from 3 (range 0 – 58)[13] to 4.5 (range 0 – 29)[7] days, with time to independent ambulation varying from a median of 2[13] (range 0 – 84) to 16.5[7] days (range 2 – 93). It may take several months before maximum improvement is

reached, with a median time to maximum clinical improvement of 2 months (range 0 – 48) reported in one study.[13]

Acute non-compressive nucleus pulposus extrusion in cats

Although ANNPE has also been reported in cats, the current literature is limited to case reports and small case-series.[20,23,24] Affected cats also present with a peracute onset of non-progressive and variably painful clinical signs.[23,24] In contrast to dogs, cats most often present with symmetrical instead of lateralized clinical signs and up to three quarters of affected cats present after external trauma, such as a road-traffic accident or a fall from a height.[24] This highlights that also in cats ANNPE should be considered an important differential diagnosis for vertebral fracture and luxation. The cervical spinal cord segments are not often affected in cats.[24] Although prognosis for neurological improvement is good, it seems unlikely for affected cats to experience a full neurological recovery. A recent case series indicated that all cats for which long-term outcome was available had regained an ambulatory status, but none of them had become neurologically normal.[24]

HYDRATED NUCLEUS PULPOSUS EXTRUSION

More recently, another type of minimally to non-degenerate nucleus pulposus extrusion has been reported in dogs.[8,35] In contrast to animals with ANNPE, an amount of well-hydrated, gelatinous, extradural material can be identified in the vertebral canal, which is associated with varying degrees of spinal cord compression.[8] Although there is some controversy about the most appropriate terminology [8,14,36], acute compressive hydrated nucleus pulposus extrusion (HNPE) is currently considered most appropriate.[36] Because of

similarities between MRI findings in dogs and discal cysts in humans, this condition was initially referred to as "canine intraspinal discal cysts".[35] Human discal cysts are extradural lesions that communicate with the IVD. Affected people present most often with a chronic progressive history of a painful lumbar radiculopathy. Surgery in people confirms an obvious cyst wall, consisting of dense fibrous connective tissue and the serous or serosanguinous content of these cysts lack IVD material.[37] Dogs however present with an acute onset of clinical signs, surgery has not been able to demonstrate an obvious capsule or cyst wall delineating the extradural material and cytological or histopathological evaluation of the liquid extradural material has consistently revealed findings compatible with minimally degenerate nucleus pulposus.[8,11,12,14,35] It has therefore been suggested that these lesions should not be referred to as 'canine instraspinal discal cysts' and that acute compressive HNPE might appear more appropriate.[36] Because cytological and histological examination of collected extradural material consistently reveals a degree of partial nucleus pulposus degeneration, it has more recently been suggested to refer to this condition as 'partially degenerated disc extrusions'.[14] As outlined above, it can however be impossible to distinguish changes seen in early pathological IVD degeneration from age-related changes.[5] Although the pathophysiology of HNPE is currently unknown, there are possible similarities with ANNPE with extrusion of hydrated nucleus pulposus through a single fissure in the dorsal annulus fibrosus secondary to sudden changes in IVD pressure and biomechanics.[12]

Clinical presentation and differential diagnosis

HNPE has a predilection for the cervical region and clinical signs are therefore reflected by acute cervical spinal cord dysfunction. Clinical signs are often severe and symmetrical (i.e. not lateralized) with non-ambulatory tetraparesis and tetraplegia being the most common clinical presentations. Cervical spinal hyperesthesia is only noted in a minority of cases.[8,11,12,38,39] Although so far only one case has been reported with possible HNPE affecting the thoracolumbar vertebral column [35], the authors of this manuscript have seen several dogs with clinical and imaging findings compatible with thoracolumbar HNPE **(Figure 3).** Cervical HNPE can affect small and large chondrodystrophic and non-chondrodystrophic dogs.[8,11,38,39] Affected animals are generally older with a median age around 9 years.[8,39] Onset of clinical signs is spontaneous and only rarely associated with intense physical exercise.[8,12,39]

Differential diagnoses for cervical compressive HNPE include other causes of acute cervical myelopathies such as cervical ANNPE, ischemic myelopathy and compressive "Hansen type I" intervertebral disc extrusion. In contrast to dogs with ANNPE or ischemic myelopathy, onset of clinical signs is only rarely associated with intense physical exercise and neurological deficits are typically symmetrical.[8,11,12] Dogs with cervical HNPE have more severe neurological deficits and less severe cervical hyperesthesia compared to dogs with other compressive cervical myelopathies, such as acute 'Hansen type I" cervical intervertebral disc extrusions.[38]

Diagnosis

Magnetic resonance imaging is the diagnostic modality of choice to diagnose HNPE and several studies have reported consistent, almost pathognomonic, MRI findings.[8,11,12,14] MRI abnormalities in dogs with cervical HNPE include **(Figure 4)**:

- Ventral, midline, extradural compressive material homogenous hyperintense on T2-weighted sequences and isointense in all sequences to normal, non-degenerate, nucleus pulposus lying immediately dorsal to the affected IVD
- The compressive material can have a characteristic bilobed or "seagull appearance", which can possibly be explained by the location of the compressive material ventral to the apparent intact dorsal longitudinal ligament[12]
- The affected intervertebral disc space is narrowed, has a reduced volume of nucleus pulposus and an ill-defined dorsal annulus fibrosus[8]
- The overlying spinal cord can demonstrate focal intraparenchymal hyperintensity suggestive for spinal cord contusion and the extruded material can demonstrate variable degrees of contrast enhancement[8,12,14]

A recent study has evaluated the usefulness of CT to evaluate cervical HNPE. Although unenhanced CT was not useful in detecting a lesion, IV contrast enhanced CT revealed a lesion in all, but one case. The observed lesion was a well-demarcated hypodense lesion dorsal from the IVD space showing rim enhancement.[39] Contrast enhanced CT had a sensitivity of 91% and specificity of 100% to differentiate between HNPE and "Hansen type I" IVD extrusion.[39]

Extruded material removed during surgery can have a white, water-like, opaque and liquid to gelatinous appearance.[8,12,14] Cytology and histology of compressive material reveals

findings compatible with nucleus pulposus with evidence of early degeneration **(Figure 5).**[11,12,14,39]

Treatment and outcome

Outcome seems dependent on severity of clinical signs with unsuccessful cases demonstrating tetraplegia with respiratory compromise at initial presentation.[8,39] Despite these often severe neurological deficits, good outcomes, characterized by rapid and complete neurological recoveries, have been reported after both medical and surgical treatment.[8,11,12,35,39,40] Medical management can consist of restricted exercise in combination with appropriate nursing care, physiotherapy, hydrotherapy and appropriate anti-inflammatory drugs and analgesia. Surgical treatment typically consists of decompressive surgery by a ventral slot procedure. The ideal type of treatment is currently uncertain.[36,39] Although it is unclear which dogs would benefit from surgical therapy instead of medical management, the combination of severe neurological signs and obvious spinal compression on MRI have been considered indications for surgical treatment.[8,12,1] The acute onset of severe clinical signs and reported rapid improvements after initiation of medical treatment could suggest that spinal cord contusion plays a major role in the pathophysiology of HNPE, questioning the value of surgical decompression in this condition.[11] Furthermore, several reports have indicated spontaneous regression of extradural compressive material in animals that underwent medical management.[11,40] Further research is therefore necessary to compare the clinical presentation and outcome of dogs treated medically or surgically for cervical acute compressive HNPE. A recent study has compared the clinical presentation and outcome of 18 dogs treated medically and

16 dogs treated surgically for cervical HNPE. Although more dogs in the surgical group demonstrated cervical hyperesthesia, no other significant differences were seen for signalment, clinical presentation or imaging findings. All dogs for which long-term outcome was available had experienced an excellent neurological recovery and no significant differences in short –and long-term outcome variables were seen between dogs treated surgically or medically for cervical HNPE.[41]

SUMMARY

ANNPE and acute compressive cervical HNPE are increasingly recognized as common spinal emergencies in dogs. A reliable presumptive clinical diagnosis can be obtained by combining typical clinical characteristics and well-described MRI findings. Although the pathophysiology of both conditions is not yet fully elucidated, good outcomes can be obtained if appropriate treatment is initiated. Further research is needed to evaluate the best type of treatment in dogs with acute compressive cervical HNPE.

ACKNOWLEDGEMENTS

The authors wish to thank Dr. Laureen Peters and Dr. Thomas Eley from the Department of Pathobiology and Population Sciences, Royal Veterinary College, University of London for their help with the preparation and interpretation of figures 1 and 4.

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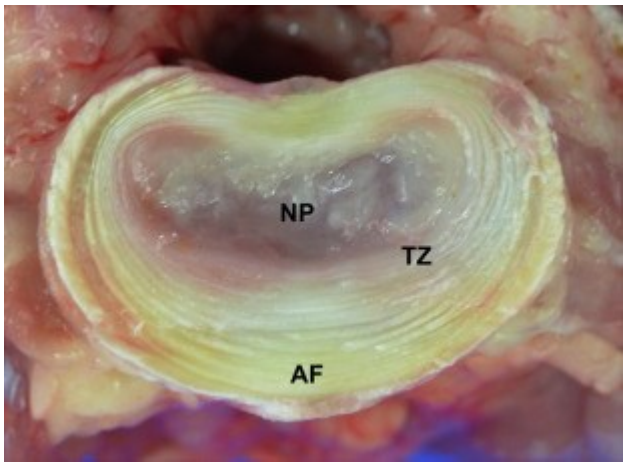
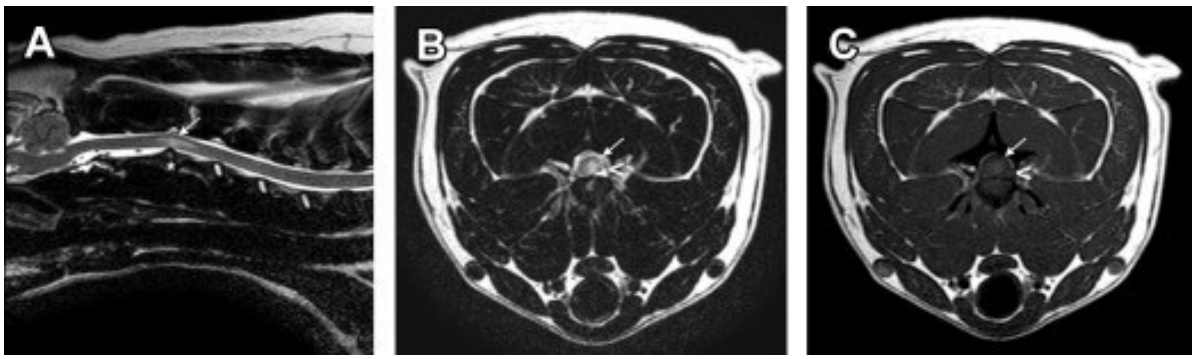
FIGURE LEGENDS

Figure 1. Transverse section through a normally hydrated L1-L2 intervertebral disc illustrating the centrally located nucleus pulposus (NP), annulus fibrosus (AF) and transitional zone (TZ). Note the eccentric location of the NP and wider ventral AF.



552 **Figure 2.** (A) Mid-sagittal T2-weighted magnetic resonance image (MRI) of the cervical
553 vertebral column of a dog with a C2-C3 ANNPE. There is a focal, intramedullary hyperinstensity
554 of the spinal cord immediately dorsal to the C2-C3 intervertebral disc (IVD) space (arrow). The
555 C2-C3 IVD nucleus pulposus has a markedly reduced volume and signal intensity (asterisk). (B)
556 Transverse T2-weighted image at the level of C2-C3 IVD space. There is a focal, lateralized
557 intramedullary hyperintensity of the spinal cord predominantly affecting the grey matter (arrow).
558 There is also a small volume of markedly hyperintense extradural material ventrolateral to the
559 spinal cord (open arrowhead), causing minimal compression. (C) Transverse T1-weighted MRI at
560 the same level as (B). The intramedullary lesion is isointense to spinal cord grey matter, and the
561 extradural material is hypointense to adjacent epidural fat.

562 

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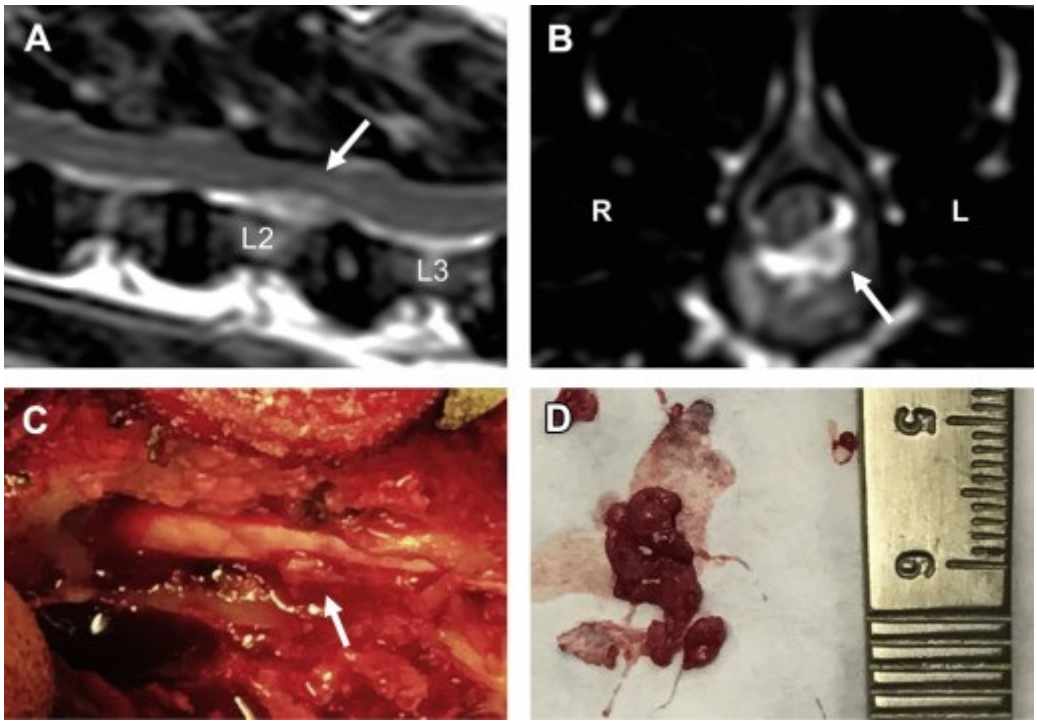
565 **Figure 3.** (A) Mid-sagittal T2-weighted magnetic resonance image (MRI) of a dog with an
566 L2-L3 compressive hydrated nucleus pulposus extrusion (HNPE). Note the hyperintense
567 nature of the extruded material (arrow) and decreased volume of hydrated nucleus pulposus
568 in the L2-L3 intervertebral disc (IVD). (B) Transverse T2-weighted image at the level of
569 the L2-L3 IVD space. There is left lateralized ventral extradural compression of
570 hyperintense material (arrow). (C) Intraoperative image of the same dog illustrating focal
571 spinal cord compression (arrow). (D) The gelatinous nature of the compressive nature can
572 be appreciated after surgical removal



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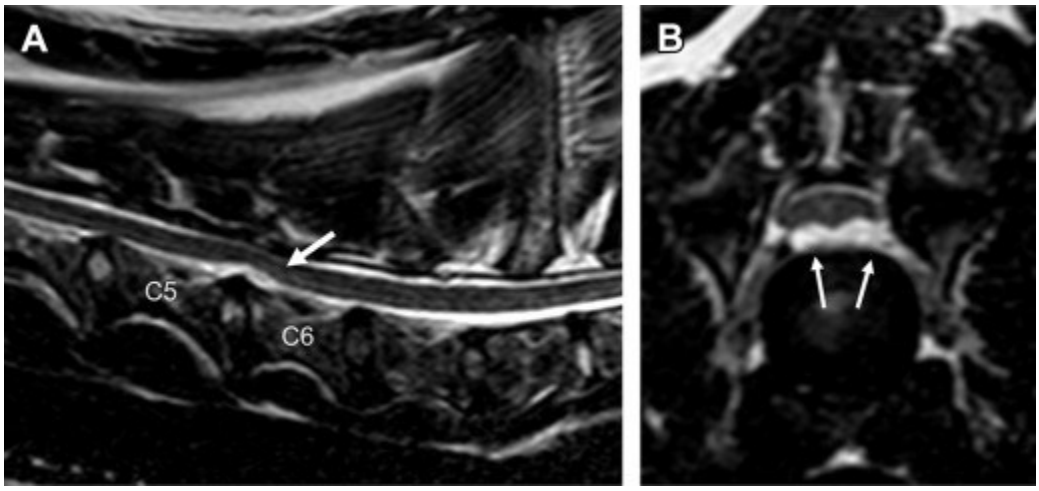
575 **Figure 4.** (A) T2-weighted sagittal magnetic resonance image (MRI) of a dog with a C5-
576 C6 acute compressive hydrated nucleus pulposus extrusion (HNPE). A ventral extradural
577 compression overlying the C5-C6 intervertebral disc (IVD) is visible (arrow). The
578 compressive material has the same intensity as normally hydrated nucleus pulposus. The
579 intervertebral disc space is mildly narrowed and contains a reduced volume of normally
580 hydrated nucleus pulposus. (B) T2-weighted transverse MR image at the C5-C6 IVD space.
581 The extruded material has the typical bilobed or 'seagull' appearance (arrows).

582 

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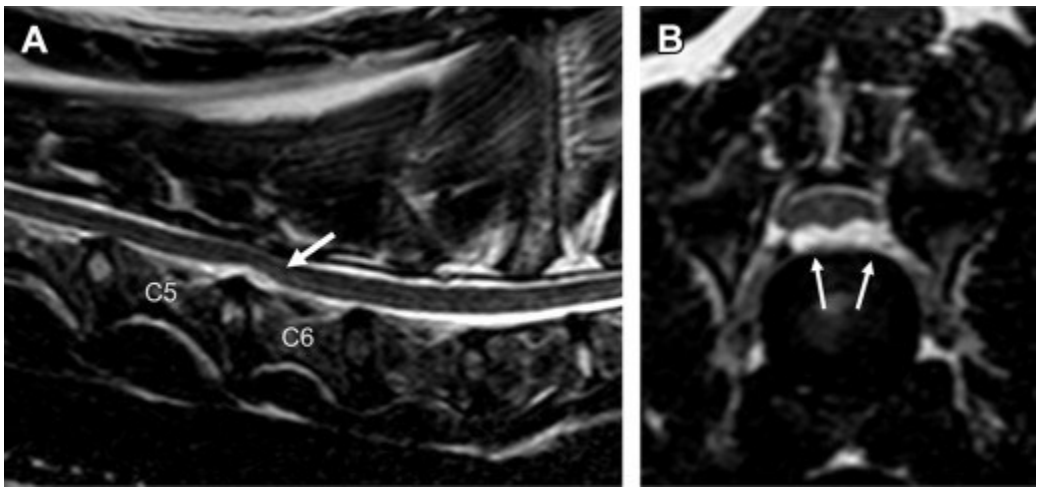
585 **Figure 5.** (A) Intraoperative image of the same dog as in Figure 4. The transparent water-
586 like extruded material is visible (arrow) after completion of the ventral slot. (B) Impression
587 smear cytology of the extruded material reveals basophilic cells with characteristics of
588 notochordal cell and chondrocytes, consistent with extruded nucleus pulposus with signs
589 of early degeneration.



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593 **Table 1.** Long-term follow-up of studies including more than 10 dogs diagnosed with acute

594 non-compressive nucleus pulposus extrusion

Reference	Number of dogs	Dogs reported to demonstrate functional recovery (%)	Dogs with long-term continence data available	Dogs with long-term reduced continence	Comment
Chang et al, 2007	11	10 (90.0)	0	n/a	10 out of 11 dogs recovered partially or completely, including 2 of 3 with loss of nociception
De Risio et al, 2009	42	28 (66.7)	42	10 (23.8)	Success defined as able to perform daily activities and complete urinary and fecal continence. Unsuccessful outcome in all 8 cases with loss of nociception
McKee et al, 2010	46	46 (100)	46	7 (15.2)	Outcome reported as ability to urinate. Two dogs with loss of nociception euthanized shortly after diagnosis and not included in follow-up
Fenn et al, 2016	37	30 (81.1)	26	7 (26.9)	Success defined as able to perform daily activities and complete urinary and fecal continence. Unsuccessful outcome in all 3 cases with loss of nociception

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