

**Minimally Invasive, Integrated Endoscopic Hemilaminectomy for Hansen Type 1
Intervertebral Disc Extrusion in Chondrodystrophic Dogs**

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ABSTRACT (academic)

The objective of this prospective pilot study is to assess the feasibility of a minimally invasive, integrated endoscopic hemilaminectomy in chondrodystrophic dogs with clinically relevant Hansen type 1 intervertebral disc extrusion (IVDE). Study subjects included five client-owned chondrodystrophic dogs under 15kg with an acute, single site IVDE between T10 and L5 of less than 90 days duration and no loss of deep pain perception. The extent of the extrusion could not exceed 2/3 the diameter of the cannula to be used as defined by magnetic resonance imaging (MRI). A postoperative MRI was performed to assess remaining spinal cord compression. If significant compression remained, patients returned to surgery for a standard, open hemilaminectomy. Only the first dog required conversion to an open approach which resulted in adequate decompression. The same dog had a significant surgical complication of iatrogenic damage to the spinal cord during the minimally invasive approach. The other 4 dogs had no complications and achieved adequate spinal cord decompression. Three dogs eventually returned to normal neurologic status and another was improved compared to presentation. One dog was euthanized for reasons unrelated to IVDE. The authors conclude that a minimally invasive, integrated endoscopic hemilaminectomy is a feasible approach and can allow for adequate decompression of the spinal cord secondary to acute, single-site extrusion. Endoscopic approaches have a steep learning curve and extra care is required in the learning phase to avoid complications. Further studies are warranted to compare the safety and efficacy of this technique to a standard approach.

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GENERAL AUDIENCE ABSTRACT

Acute intervertebral disc extrusion, or “slipped disc”, is a common spinal emergency in dogs, particularly in small, chondrodystrophic breeds like dachshunds. Surgery is aimed at removing the disc material causing spinal cord compression. The traditional approach, known as a hemilaminectomy, involves elevating the muscles along the spine over multiple vertebrae, followed by creating a window in the bone with a surgical burr. Minimally invasive spinal surgery that minimizes the elevation of muscles, has the potential to decrease postoperative pain, surgical time, hospital stay, intraoperative blood loss and recovery time. This study was designed to assess the use of a minimally invasive, integrated endoscopic approach to a hemilaminectomy in clinical patients. Five dogs were enrolled with an acute, single site intervertebral disc extrusion between T10 and L5 that was no more than 2/3 the diameter of the cannula to be used in surgery. Study subjects were chondrodystrophic breeds under 15kg. All dogs had intact deep pain perception. Spinal cord compression was assessed by magnetic resonance imaging (MRI) both before and after a minimally invasive approach. If significant acute compression remained, a standard, open approach was immediately performed. Spinal cord decompression was adequate in all but one dog which required a second procedure to remove the remaining material. This same dog had accidental damage to the spinal cord during the minimally invasive approach. Three dogs eventually returned to normal neurologic status and the dog that required a second, traditional approach surgery eventually improved compared to his preoperative status. One dog was improving but euthanized eight days later due to chronic disease unrelated to IVDE. This approach is feasible for decompressing the spinal cord after a single site, acute intervertebral disc extrusion in a chondrodystrophic dog. However, like any endoscopic surgery, previous experience is of great benefit and errors are more likely to happen during the learning phase.

Dedication

This thesis is dedicated to veterinary mentors everywhere. Your endless patience and willingness to impart knowledge and experience to others is crucial to the success of so many.

“The higher education so much needed today is not given in the school, is not to be bought in the market place, but it has to be wrought out in each one of us for himself; it is the silent influence of character on character.”

- Sir William Osler

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Table of Contents

DEDICATION	IV
ACKNOWLEDGEMENTS	V
TABLE OF CONTENTS.....	VI
LIST OF FIGURES.....	VIII
LIST OF TABLES.....	XVII
TABLE 1: NEUROLOGIC GRADING SCALE FOR THORACOLUMBAR MYELOPATHY.....	XVII
LIST OF ABBREVIATIONS	XIX
CHAPTER 1: INTRODUCTION.....	1
CHAPTER 2: LITERATURE REVIEW	3
INTERVERTEBRAL DISC DEGENERATION	3
<i>A. History</i>	<i>3</i>
<i>B. Anatomy of the Intervertebral Disc.....</i>	<i>3</i>
<i>C. Hansen Type 1 vs Type 2 Intervertebral Disc Extrusion/Protrusion</i>	<i>5</i>
<i>D. Pathophysiology of clinical IVDE</i>	<i>7</i>
<i>E. Distribution of IVDE in the Canine Spine.....</i>	<i>8</i>
<i>F. Prevalence of IVDD in the Canine Population.....</i>	<i>9</i>
<i>G. Neurologic Grading of IVDE Patients.....</i>	<i>10</i>
<i>H. Diagnosis of IVDE.....</i>	<i>10</i>
<i>I. Treatment Options and Prognosis</i>	<i>11</i>
i. Conservative management.....	11
ii. Surgical Management.....	12
a. Approaches.....	13
b. Complications.....	14
c. Post-operative Care.....	15
MINIMALLY INVASIVE SURGERY IN HUMANS	19
<i>A. History</i>	<i>19</i>
<i>B. Current Use.....</i>	<i>20</i>
<i>C. Benefits</i>	<i>20</i>
<i>D. Complications.....</i>	<i>21</i>
MINIMALLY INVASIVE SURGERY IN ANIMALS	22
<i>A. History</i>	<i>22</i>
<i>B. Current use.....</i>	<i>22</i>
<i>C. Benefits</i>	<i>23</i>
<i>D. Complications.....</i>	<i>23</i>
MINIMALLY INVASIVE SPINAL SURGERY IN HUMANS	25
<i>A. History</i>	<i>25</i>
<i>B. Benefits</i>	<i>25</i>
<i>C. Complications.....</i>	<i>26</i>
<i>D. Gold standard.....</i>	<i>27</i>
MINIMALLY INVASIVE SPINAL SURGERY IN ANIMALS	28
<i>A. History</i>	<i>28</i>
<i>B. Benefits</i>	<i>28</i>
<i>C. Complications.....</i>	<i>29</i>
<i>D. Limitations</i>	<i>30</i>
CHAPTER 3: MANUSCRIPT.....	31

ABSTRACT	32
INTRODUCTION	33
MATERIALS AND METHODS	35
<i>A. Study subjects</i>	35
<i>B. Preoperative Imaging</i>	35
<i>C. Surgical approach</i>	36
<i>D. Postoperative Imaging</i>	37
<i>E. Postoperative care</i>	38
<i>F. Discharge and Follow Up</i>	38
RESULTS	40
<i>A. Study Subjects</i>	40
<i>B. Advanced Imaging and Surgery</i>	40
<i>C. Postoperative Care</i>	41
<i>D. Discharge Status</i>	41
<i>E. Short Term Outcome</i>	42
<i>F. 6 Weeks Postoperatively</i>	42
<i>G. Long Term Outcome</i>	42
DISCUSSION	43
ADVANTAGES	46
DISADVANTAGES	47
LIMITATIONS AND FUTURE STUDIES	48
CHAPTER 4: CONCLUSIONS	50
REFERENCES	51

List of Figures

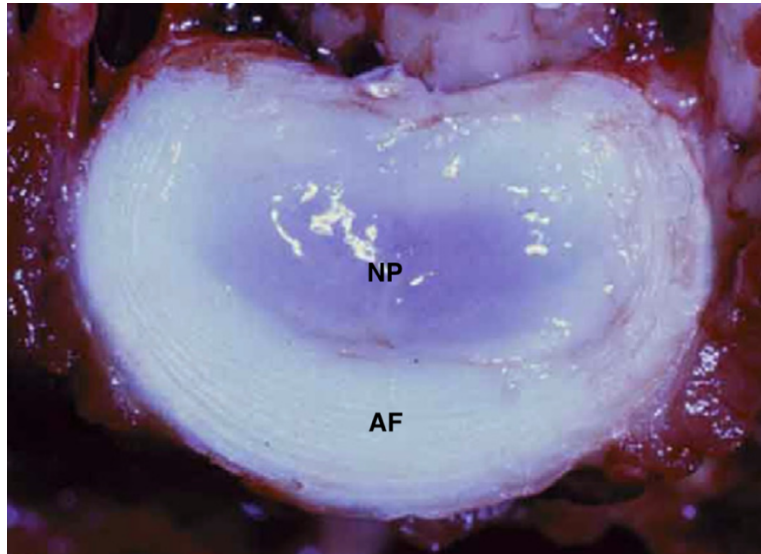


Figure 1: A transverse view of a canine lumbar intervertebral disc. The two main parts of the disc, the annulus fibrosus (AF) and the nucleus pulposus (NP), are labeled. (Brisson, B. A. (2010). Intervertebral disc disease in dogs. *Vet Clin North Am Small Anim Pract*, 40(5), 829-858. doi:10.1016/j.cvsm.2010.06.001)

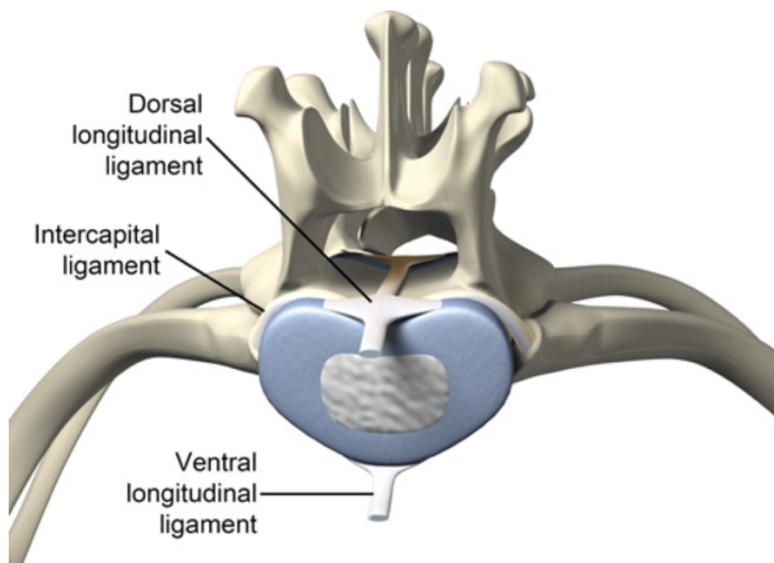


Figure 2: A transverse depiction of a canine thoracic vertebrae showing the soft tissue supportive structures present. (Dewey, C. W., & Da Costa, R. C. (2016). *Practical guide to canine and feline neurology* (Third edition. ed.). Chichester, West Sussex ; Hoboken: Wiley-Blackwell.)



Figure 3: A lateral radiograph of a canine spine showing an acute disc extrusion over the L1-2 intervertebral disc space. (Dewey, C. W., & Da Costa, R. C. (2016). *Practical guide to canine and feline neurology* (Third edition. ed.). Chichester, West Sussex ; Hoboken: Wiley-Blackwell.)

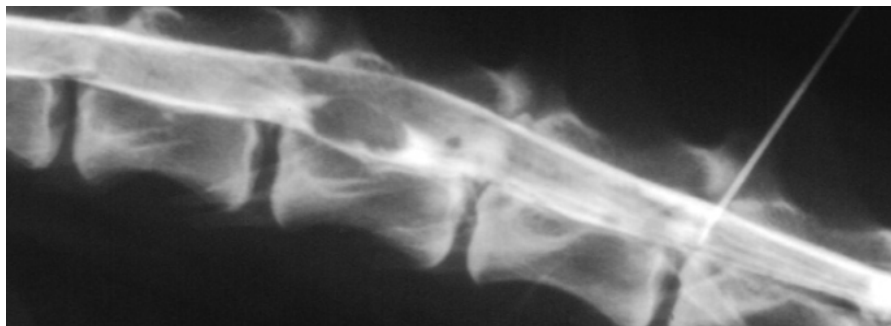


Figure 4: A lateral radiographic myelogram of a canine lumbar spine. The contrast is outlining an intradural, extramedullary spinal mass. The needle used for injecting contrast can be seen in the right of the image. (Dewey, C. W., & Da Costa, R. C. (2016). *Practical guide to canine and feline neurology* (Third edition. ed.). Chichester, West Sussex ; Hoboken: Wiley-Blackwell.)

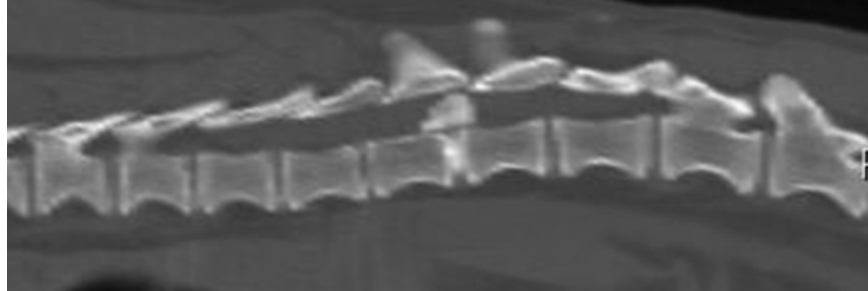


Figure 5: A reconstructed sagittal CT image of a canine lumbar spine showing an acute intervertebral disc extrusion. (Dewey, C. W., & Da Costa, R. C. (2016). *Practical guide to canine and feline neurology* (Third edition. ed.). Chichester, West Sussex ; Hoboken: Wiley-Blackwell.)

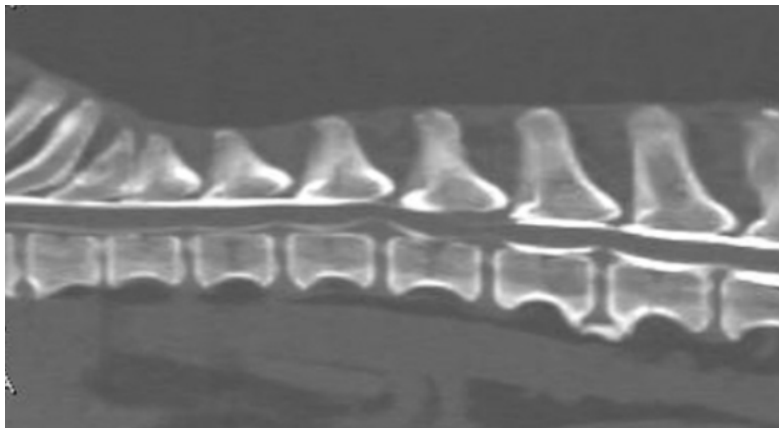


Figure 6: A reconstructed sagittal CT myelogram of a canine spine. Note the dorsal deviations of the ventral contrast column indicating an area of spinal cord compression. (Dewey, C. W., & Da Costa, R. C. (2016). *Practical guide to canine and feline neurology* (Third edition. ed.). Chichester, West Sussex ; Hoboken: Wiley-Blackwell.)

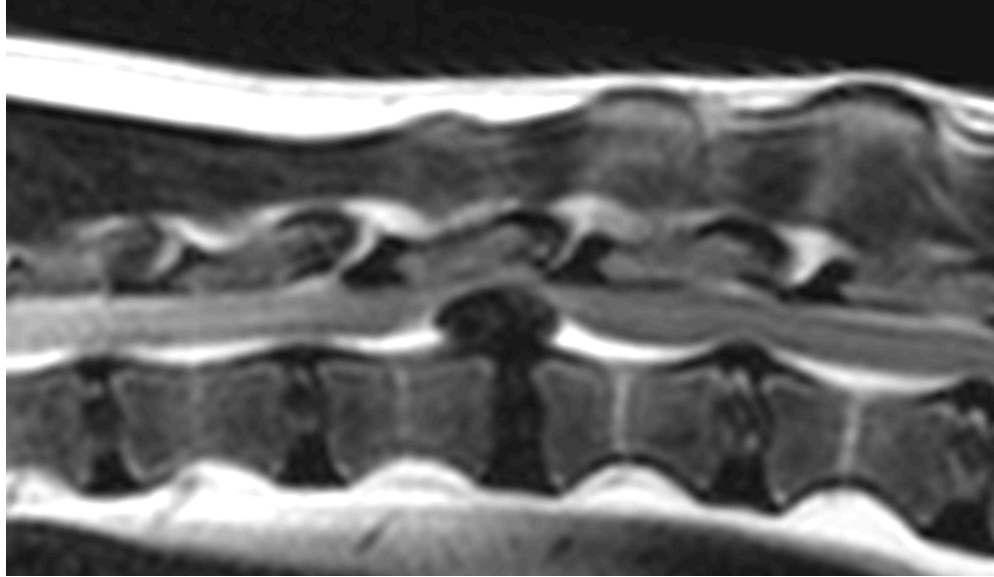
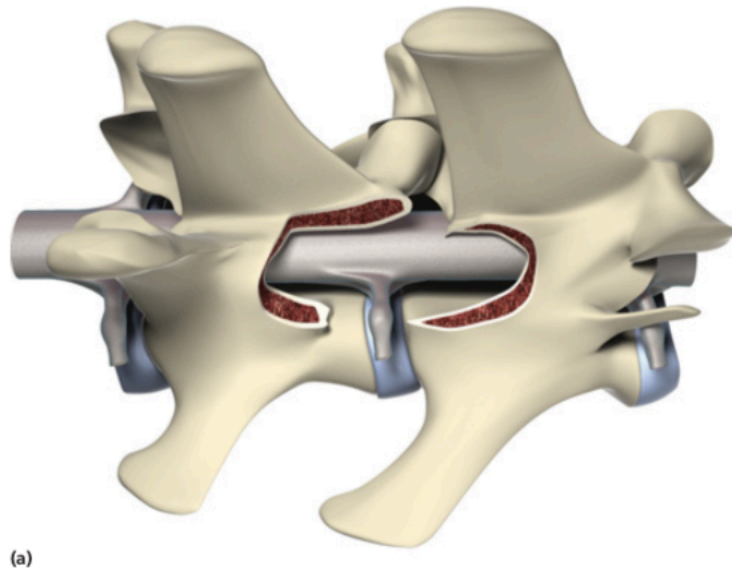


Figure 7: A sagittal T2 weighted MRI image of a canine thoracolumbar spine showing an acute intervertebral disc extrusion.



(a)

Figure 8: An artistic rendering of a dorsolateral view of a canine lumbar spine showing the bony window created with a hemilaminectomy. (Dewey, C. W., & Da Costa, R. C. (2016). *Practical guide to canine and feline neurology* (Third edition. ed.). Chichester, West Sussex ; Hoboken: Wiley-Blackwell.)

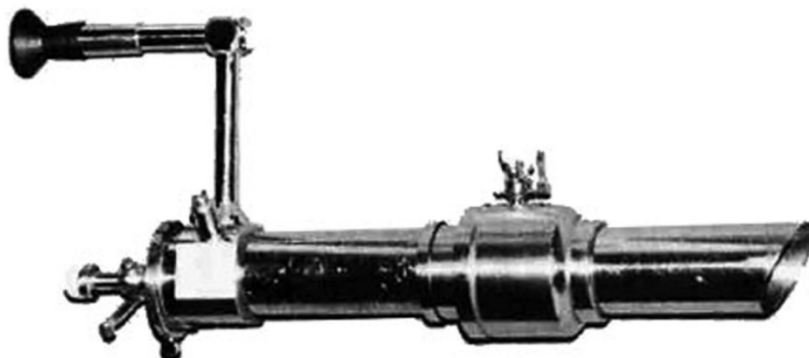


Figure 9: An early laparoscopic device for minimally invasive cholecystectomies in Germany in the 1980s. (Antoniou, S. A., Antoniou, G. A., Antoniou, A. I., & Granderath, F.-A. (2015). Past, Present, and Future of Minimally Invasive Abdominal Surgery. *JSLs : Journal of the Society of Laparoendoscopic Surgeons*, 19(3), e2015.00052.)



Figure 10: Intraoperative monitor view of endoscopic camera. (Antoniou, S. A., Antoniou, G. A., Antoniou, A. I., & Granderath, F.-A. (2015). Past, Present, and Future of Minimally Invasive Abdominal Surgery. *JSLs : Journal of the Society of Laparoendoscopic Surgeons*, 19(3), e2015.00052.)

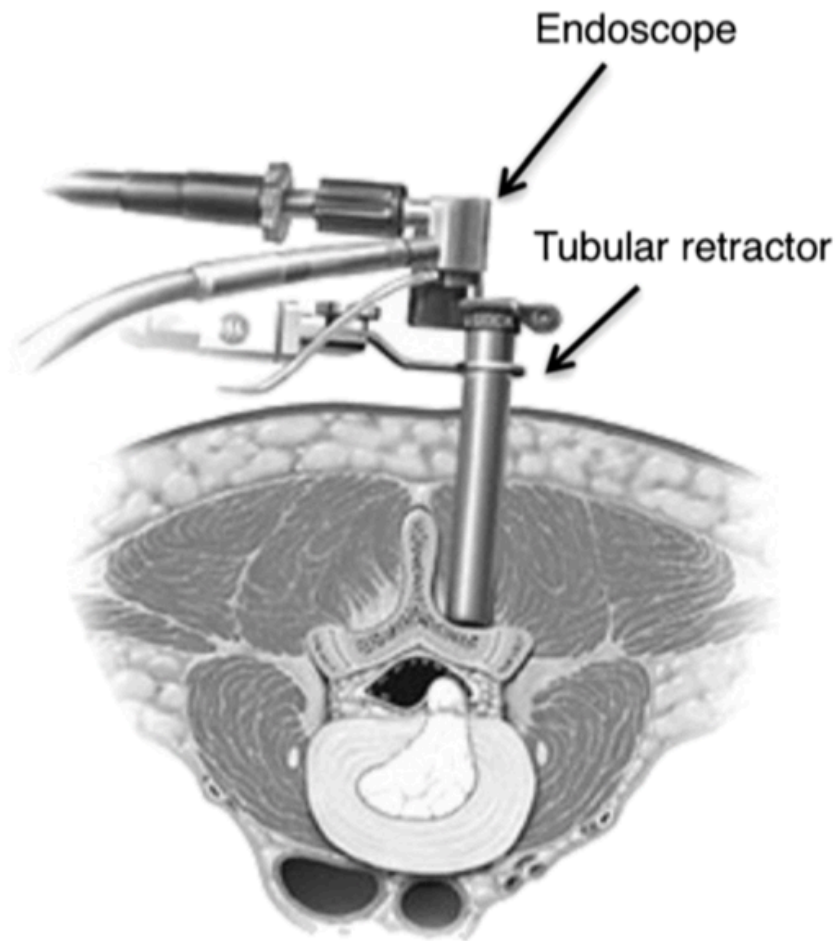


Figure 11: Drawing of transverse view of a microendoscopic discectomy in the human lumbar spine using a tubular retractor. (Kanno, H., Aizawa, T., Hahimoto, K., & Itoi, E. (2019). Minimally invasive discectomy for lumbar disc herniation: current concepts, surgical techniques, and outcomes. *Int Orthop*, 43(4), 917-922.)

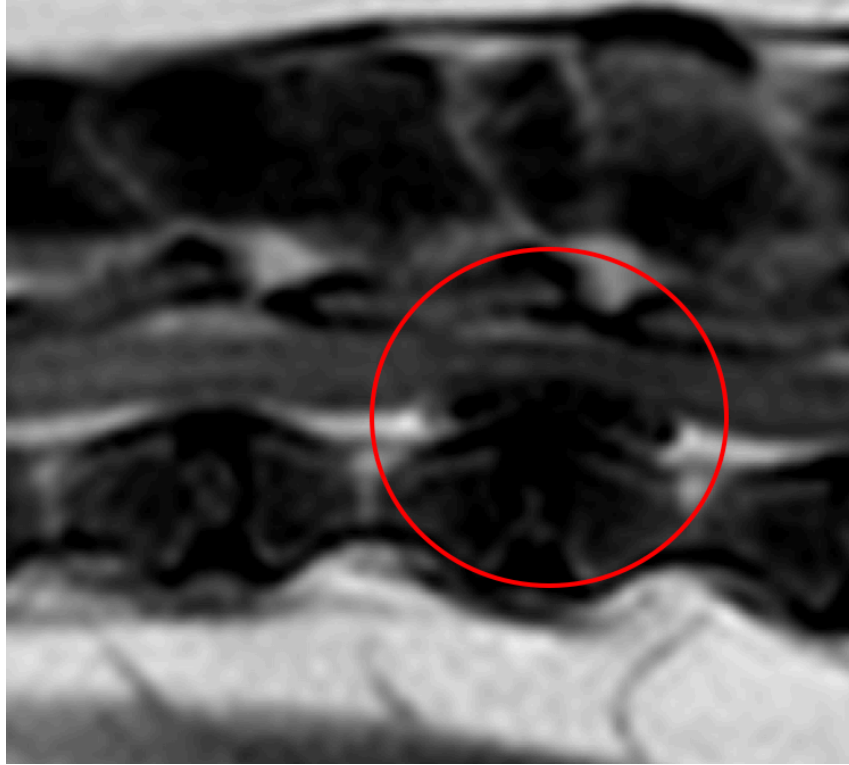


Figure 12: Preoperative sagittal T2 weighted MRI image showing an acute disc extrusion (circled) ventral to the spinal cord in a study dog.

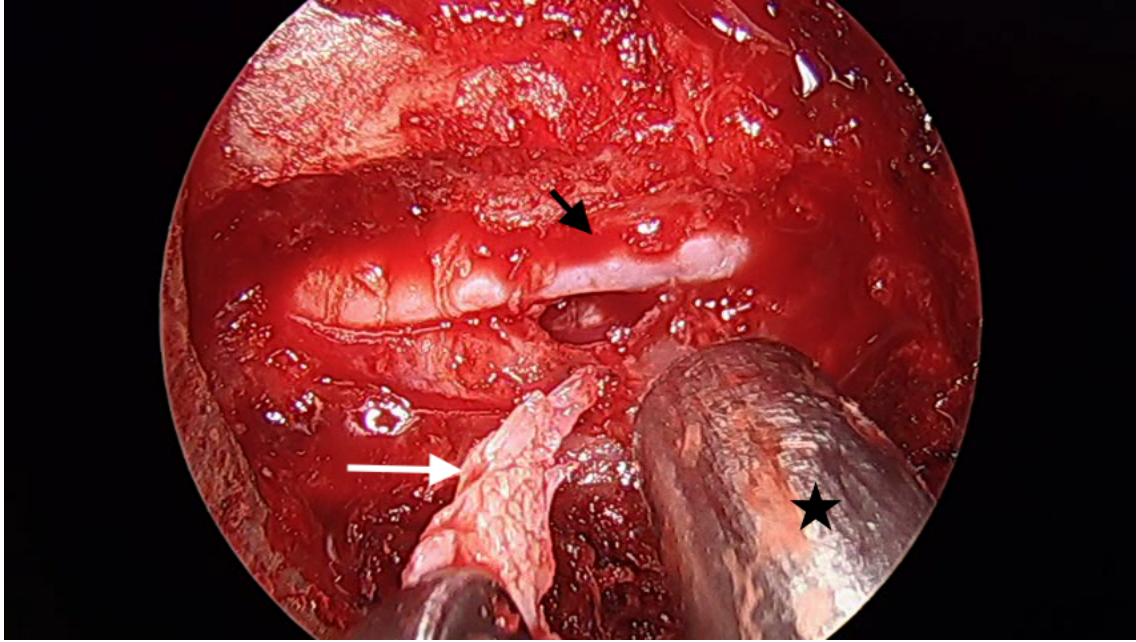


Figure 13: Intraoperative endoscopic view of herniated disc material (white arrow) being removed from ventral to the spinal cord (black arrow). Fraser tip suction (black star) is used to keep the surgical field of view clear.

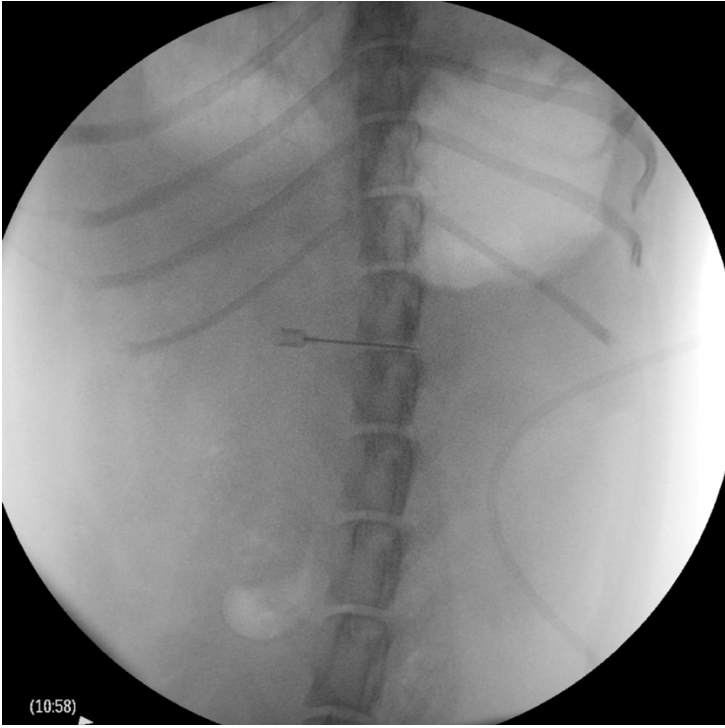


Figure 14: Intraoperative C-arm view verifying the correct surgical site marked with a 20-gauge needle.



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Figure 15: Example of a minimally invasive approach to the spine as shown on a human spine model using the EasyGO! II system. (Photo courtesy of Karl Storz Veterinary Endoscopy, Goleta, CA)



Figure 16: Expanding dilators and surgical cannula of the EasyGO I system, similar to the system used in this study. (Photo courtesy of Karl Storz Veterinary Endoscopy, Goleta, CA)

List of Tables

Grade 0	Normal with no neurologic deficits or pain
Grade 1	Thoracolumbar pain, no neurologic deficits
Grade 2	Ambulatory with paraparesis and/or ataxia
Grade 3	Non-ambulatory paraparetic
Grade 4	Paraplegic with deep pain sensation of the pelvic limbs intact
Grade 5	Paraplegic with absent deep pain sensation in the pelvic limbs

Table 1: Neurologic grading scale for thoracolumbar myelopathy

Patient #	1	2	3	4	5
Sex	Male castrated	Male castrated	Male castrated	Male castrated	Female spayed
Breed	Pekingese	Pekingese	Shih Tzu	mixed	Coton du Tulear
Age	3 years	12 years	9 years	3 years	11 years
Weight	10kg	5.9kg	5.4kg	14.7kg	5.5kg
Duration	9 days	1 day	2 days	9 days	3 days
Revision surgery	Yes	No	No	No	No
Surgery site	Right T13-L1	Left L1-2	Left T13-L1	Right L1-2	Right T13-L1
Surgery time	1) 135 min 2) 65 min	90 min	70 min	140 min	170 min
Length of extrusion	12mm	3mm	5mm	14mm	5mm
Cannula diameter	19mm	19mm	19mm	23mm	19mm
Complications	Iatrogenic spinal cord trauma	none	none	none	none
Hospitalization	7 days	3 days	4 days	2 days	4 days
Neurologic grade, preoperative	3	2	3	2	3
Neurologic grade, discharge	5	3	3	2	3
Neurologic grade, 2 weeks	5	2	2	0	N/A
Neurologic grade, 6 weeks	3	2	2	0	N/A
Neurologic grade, long term	2	0	0	0	Euthanized due to chronic kidney disease and gallbladder mucoele
Follow up period	17 months	16 months	16 months	11 months	8 days

Table 2: Patient information

List of Abbreviations

AF – Annulus fibrosus
ANNPE – Acute non-compressive nucleus pulposus extrusion
C – Cervical vertebrae
CDs – Chondrodystrophic breeds
COX - Cyclooxygenase
CRIs – Constant rate infusions
CSF – Cerebrospinal fluid
CT – Computed tomography
IV – Intravenous
IVD – Intervertebral disc
IVDD – Intervertebral disc degeneration
IVDE – Intervertebral disc extrusion
L – Lumbar vertebrae
MIS – Minimally invasive surgery
MRI – Magnetic resonance imaging
NP – Nucleus pulposus
NSAIDs – Non-steroidal anti-inflammatory drugs
T – Thoracic vertebrae
Type 1 – Hansen type 1 intervertebral disc extrusion
Type 2 – Hansen type 2 intervertebral disc protrusion
WSSS – Wrong site spine surgery

Chapter 1: Introduction

Intervertebral disc protrusions and extrusions are a common occurrence in dogs, affecting 2-3.5% of the overall canine population.[1, 2] In chondrodystrophic dogs (CD), prevalence can be as high as 61%.[1] Intervertebral disc degeneration (IVDD) can lead to extrusion or protrusion of disc material into the vertebral canal, leading to a wide spectrum of clinical signs ranging from mild discomfort to complete paralysis with an absence of nociception. Acute disc extrusions can be severely painful and even life limiting from euthanasia or the disease process itself. The recommended treatment is usually surgical, with the hemilaminectomy being the most frequent approach to acute disc extrusions in the thoracolumbar spine.[3] The procedure involves a large amount of soft tissue dissection. Muscles, tendons, fascia and blood vessels are disrupted and elevated away from the spine. For the benefit of exposure and surgical site visualization, these tissues may be disrupted not only at the site of extrusion but also the sites cranial and caudal to this to allow for greater exposure and extension of the laminectomy site if indicated based on intraoperative findings. Though difficult to quantify in canine patients, a significant portion of the post-operative discomfort in humans originates from the surgical disruption of soft tissues rather than the removal of disc material.[4, 5] Typical post-operative pain management consists of constant rate infusions (CRIs), intermittent injections, and/or oral analgesic medications, frequently opioids. Anti-inflammatory doses of corticosteroids or non-steroidal anti-inflammatory medications (NSAIDs) may be prescribed as well.

Multiple studies have shown a benefit to minimally invasive approaches to the spine in humans.[6-16] Reported advantages of minimally invasive approaches as compared to open techniques include decreased blood loss, fewer surgical site infections, faster surgery time, less post-operative pain, faster recovery, lower rates of hematomas or CSF leaks, shorter stays in the hospital, less time in the intensive care unit, lower hospital bills and lower rates or reoperation.[6-16] It is reasonable to assume that at least some of these benefits may be transferrable to our veterinary patients. While post-operative pain is more difficult to quantify in dogs as compared to humans, less discomfort may result in fewer analgesic medications being needed in the immediate post-operative period. A less invasive surgery could have a direct result of less post-operative pain and thus fewer opioids required to maintain adequate pain control in

these patients and fewer opioid associated side effects. Vomiting, nausea, panting, sedation, respiratory depression, constipation, urine retention and dysphoria are commonly associated with opioid analgesia.[17] Also, given the increased difficulty in obtaining opioid medications as a result of the world-wide opioid crisis, other options for pain control are being explored.

Our goal is to investigate the feasibility of a minimally invasive, endoscopically assisted approach to the canine thoracolumbar spine in the form of a pilot study.

Chapter 2: Literature Review

Intervertebral Disc Degeneration

A. History

This condition, originally termed as “endochondrosis intervertebralis”, was first described by Dexler in 1896.[18] However, the *de facto* father of IVDD is Hans-Jorgen Hansen who described the condition and the two main subtypes at length in the early 1950s.[18, 19] He described multiple other aspects of IVDD that have since become common knowledge in the understanding of this disease. The dachshund was by far the most common breed in his research to have IVDD and this remains true today. Hansen also identified the presence of IVDD throughout the spine of affected dogs, identifying this as a diffuse disease. The most common sites of disc extrusion were T13-L1 and T12-13. These discs are repeatedly found to be the most common areas of extrusion the canines.[20-25] He also noted an absence of extrusions in the mid to cranial thoracic spine and postulated that the presence of the intercapital ligament at those locations is the most likely reason for this. Hansen’s work has been fundamental in the understanding of this disease and the foundation of all related research.

B. Anatomy of the Intervertebral Disc

The anatomy of the intervertebral disc (IVD) is crucial to an understanding of the degenerative process. Each IVD contains two distinct sections: the outer annulus fibrosus (AF) and the inner nucleus pulposus (NP) [Figure 1].[19-21, 26] The thin region that joins the AF and NP is known as the transitional zone.[20]

The AF is comprised of fibrous collagen, primarily type I collagen, and encapsulates the NP.[22] It is made up of 2-3 dozen layers, or laminae. The fibers of each adjacent lamina are oriented in alternating directions to one another. In transverse sectioning, the AF dorsal to the NP is 1/3 the width of the AF ventral to the NP. The cranial and caudal edges of the AF are firmly adhered to the endplates of the adjacent vertebral bodies by Sharpey’s fibers.[19-22, 26] Studies have found

variable amounts and locations of blood vessels supplying the AF. It is diffusely well vascularized in neonates but the amount of vascularization decreases with age.[27] In adults, only the outermost layers of the AF have direct blood supply but the inner layers are perfused by diffusion from the vertebral end plates.[22, 27] The periphery of the AF also has a small amount of innervation whereas the more central rings have no innervation.[20, 28, 29]

The NP, in contrast, is jelly-like and made up of water and a mix of proteoglycans, hyaluronic acid and mostly type II collagen.[22] The proteoglycans are comprised of a core protein to which variable glucosaminoglycans are attached. The primary glucosaminoglycans of proteoglycans in the IVD are chondroitin-6-sulfate and keratan sulfate.[22] The glucosaminoglycans are negatively charged which attracts and binds to large amounts of water. Other molecules, such as hyaluronic acid, another glucosaminoglycan, and collagen bond multiple proteoglycans together to create a tightly linked, hydrated matrix that can withstand compressive loads.[22]

Embryologically, the NP is a remnant of the notochord whereas the AF is derived from the sclerotomes.[20, 21, 26] The fluid filled NP acts as a shock absorber and cushions the spinal cord during the impacts and bending of normal activity.[19] There is no direct blood supply or innervation to the NP.[20, 28, 29] Nutritional supply occurs through diffusion via the cartilaginous endplates which are more permeable where they come into close proximity with the NP.[30]

The IVD is encased dorsally and ventrally by the dorsal and ventral longitudinal ligaments, respectively. The dorsal longitudinal ligament is extensively innervated.[29] In addition, the IVDs from thoracic vertebrae 2 to 10 are bordered dorsally by the intercapital ligament. This ligament connects the left and right rib heads and courses between the IVD and the dorsal longitudinal ligament [Figure 2].[26, 31]

The IVD is an important structure for absorbing impact from daily forces. As Bray elucidates, this has developed a more important role in carnivores.[22] Predator species have retained their digits, maintained strength and dexterity in the distal limbs and have a highly flexible spine. These traits are advantageous due to the multitude of positions required for acquiring food and the mechanics of accelerating during running. The herbivore spine is geared more toward

standing and casual grazing. It has less mobility and more ligamentous support. Their abilities regarding speed and endurance as prey animals are a result of limb adaptations favoring longer and lighter distal limbs. This decrease in spinal mobility may be why herbivores are not commonly affected by IVDD. In cases when this does occur, IVD related disease is most prevalent in areas of higher motion, such as the cervicothoracic junction in the horse.[32]

The forces of movement and impact can cause significant increases in intradiscal pressure.[22] The compressive forces are largely absorbed by the NP like a hydraulic cushion. The hydraulic action of the NP must be contained as tensile force by the AF. The AF also must respond to bending, shearing and torsional forces. Degeneration of either structure changes the way the IVD can handle external biomechanical loads placed on the spine. These changes lead to weakening of the AF which can lead to protrusion or extrusion of material into the vertebral canal.

C. Hansen Type 1 vs Type 2 Intervertebral Disc Extrusion/Protrusion

As initially presented by Hansen in 1952, IVDD is a common aging change in dogs and has traditionally been thought to be caused by one of two distinct types of degeneration: chondroid or fibrous. Chondroid degeneration, more often associated with CDs, was considered to be the underlying cause of Hansen type 1 IVD extrusion.[18-20, 26, 33] The mechanism involves dehydration of the nucleus pulposus via loss of glycosaminoglycans and is seen in both CDs and non-CDs.[34, 35] The loss of glycosaminoglycans leads to increased collagen content and mineralization of the NP. Ultimately, this decreases the ability of the NP to absorb daily compressive forces. The AF attempts to adjust for this loss of hydraulic function to which it is ill suited.[30] Hansen type 1 IVD extrusion is the result of a tear in the AF and an acute, forceful ejection of degenerate NP dorsally into the vertebral canal.[19] As noted earlier, the dorsal AF is much thinner than the ventral AF, resulting in the dorsal direction of extrusion. The herniated disc material can cause irritation and compression of the spinal cord or nerve roots, resulting in pain and/or loss of neurologic function.[18, 19]

Fibrous degeneration is thought to be associated with Hansen type 2 IVD protrusion, usually presenting clinically in older, non-CDs.[18-20, 26, 35] Hansen type 2 protrusions are chronic,

progressive compressive spinal cord lesions with a smooth bulging of AF. Hansen type 2 protrusions are described as only a partial tear in the AF versus a complete rupture in Hansen type 1 extrusions. AF and NP extend dorsally but the outer AF is often intact.[19] The degeneration was thought to be different in that non-CDs have a higher percentage of glycosaminoglycans and glycoproteins in their NPs as they age compared to CDs.[35] The NP becomes dehydrated but does not calcify as in chondroid degeneration.

Multiple terms including herniation, prolapse, extrusion, bulge, displacement and others have been used inconsistently to describe Hansen type 1 vs type 2 IVD pathology. In an effort to foster consistent terminology for this disease process, the terms “extrusion” or “IVDE” for Hansen type 1 pathology and “protrusion” for Hansen type 2 pathology will be used throughout this document as suggested by a recent paper discussing the classification of IVDD.[36] The distinction between Hansen types 1 and 2 remains unclear and is not restricted to small breed CDs or large non-CDs respectively. Though Hansen type 2 protrusion is more commonly seen in large non-CDs, it can be found in CDs as well.[38] Studies have also shown that the majority of large non-CDs presenting for clinical signs of IVDD also tend to have Hansen type 1 extrusions.[39] Historically, Hansen type 1 and 2 have been viewed differently regarding treatment and prognosis. For the purposes of this manuscript, we will focus on Hansen type 1 extrusions only.

Chondrodystrophic disc degeneration and the chondrodysplastic body type are often thought of as being interrelated, though the relationship was ill defined for decades. A fibroblast growth factor gene (CFA18-FGF4 retrogene) was identified in 2009 that was associated with the typical CD shortened limbs.[54] This was not, however, definitively linked to IVDD. A publication in 2017 found a genetic relationship between IVDD and the chondrodysplastic body type. The researchers identified another gene (CFA12-FGF4 retrogene) that was significantly associated with chondrodystrophy and IVDD.[55] The potential additive relationship between the two previously identified retrogenes was evaluated in 2019. The gene most significantly correlated with IVDD in CDs was the FGF4 retrogene on CFA12 in regards to risk of disc extrusion and earlier age of onset of IVDD. The same gene on CFA18 was found to have little to no effect on IVDD. [56]

There has been evidence to potentially refute this distinction between the two types of IVDD. A study in 2014 showed that while there were differences in IVDD in CDs vs non-CDs, there was no histologic evidence of fibrous type degeneration.[37] Both breed groups showed chondroid degeneration and it was suggested that Hansen type 1 and 2 are actually different presentations of disease on the same spectrum of chondroid degeneration. This possibility was hinted at by Hansen who recognized that “It is probable that some of the prolapses of the present material which have been described as belonging to type II may represent either the initial stage or the final phase of a prolapse of type I.” [19]

D. Pathophysiology of clinical IVDE

The extrusion of IVD material into the vertebral canal can cause spinal cord damage in two ways: primary and secondary injury. The primary injury is related to the initial contusion and often residual compression of the spinal cord from the extruded disc material. This primary injury can damage or sever axons, rupture blood vessels or direct mechanical cell death.[40] The spinal cord tracts that are damaged from extradural contusion/compression directly relate to the level of neurologic dysfunction in IVDE patients.[41] Some of the more superficial tracts, primarily the fasciculus gracilis, fasciculus cuneatus and spinocerebellar tracts, are related to proprioception. Further away from the exterior of the cord are descending motor tracts, such as the corticospinal, rubrospinal, tectospinal, reticulospinal and vestibulospinal. The tracts for nociception, spinoreticular and spinothalamic, are some of the most centrally located. As compression or contusion disrupts spinal cord tracts from exterior to interior, neurologic status worsens. These progress from ataxia to paresis or paralysis, followed by a loss of nociception as different tracts are affected.

While the compressive material may be more involved in the delay, inhibition or prevention of recovery, the contusive injury plays a significant role in the initial and severe neurologic decline. Experimental studies in rats which induced spinal cord contusion with no residual compression resulted in severe neurologic injury.[42] Also, a study evaluating magnetic resonance imaging (MRI) of dogs suffering from acute IVD extrusion found no association between the amount of

compression and the level of neurologic dysfunction.[23] There is also a specific subtype of acute disc extrusion called acute non-compressive nucleus pulposus extrusion (ANNPE). This is an acute extrusion of non-degenerate nucleus pulposus that injures the spinal cord without significant remaining compression. Despite a lack of compression, these injuries can be severe enough to cause paralysis and a loss of pain perception.[36, 43, 44]

The primary, mechanical insult leads to damage on the cellular level, known as secondary injury. Secondary injury is not fully understood but comprises a complex cascade of interrelated events that create a worsening of the primary injury and can result in edema, demyelination, necrosis and apoptosis.[40, 45-50] The active phase of secondary damage can last hours or even days.[46, 51] Secondary injury can continue to occur independent of surgical decompression and dogs can worsen even after surgery.[52]

Multiple factors have been identified as part of the secondary injury process. Local vascular changes can include decreased perfusion, hemorrhage or thrombosis. Cytotoxic excitatory neurotransmitters, like glutamate, are released causing direct damage to the spinal cord and indirectly creating reactive oxygen and nitrogen species resulting in further damage. Ion derangements can include increased intracellular sodium and increased extracellular potassium due to dysfunction of the ATP dependent sodium-potassium pump. Increased intracellular calcium inhibits mitochondrial function and cellular respiration as well as promoting inflammation. Inflammatory products from the metabolism of arachidonic acid, such as leukotrienes and prostaglandins, and inflammatory cytokines are released after injury.[40, 45-50, 53] Histopathology of lesions secondary to IVDE are variable but can include hemorrhage, axonal spheroids, white matter edema, demyelination, glial cell swelling, cellular infiltrate and necrosis.[47]

E. Distribution of IVDE in the Canine Spine

Cervical disc extrusions represent 15-25% of all disc extrusions in dogs.[19, 20, 57]

Thoracolumbar extrusions are more common, reported as the most common cause of spinal cord dysfunction in dogs.[58] Incidence in this area has been found to range from 66 - 87%.[20] IVD

extrusions have even been rarely documented in the sacrococcygeal segment and first caudal segment of the tail.[59, 60] This literature review will focus on IVDE in the thoracolumbar spine.

IVDs are present throughout the canine spinal column from C2 caudal. There is no disc between C1 and C2. IVDE can potentially occur at any of these sites. The most common site of extrusion in the cervical spine varies by the size of the dog. C2-3 is the most frequent site in small breed dogs whereas C6-7 is the most frequent IVD affected in large breed dogs.[57] In the thoracolumbar spine, the site of and sites directly adjacent to the thoracolumbar junction are the most susceptible areas for Hansen type 1 extrusion. The IVDs T12-13 and T13-L1 are the most commonly reported sites of extrusion in the thoracolumbar spine of dogs.[18-25] The thoracic spine is generally thought to be more stable than the lumbar spine due to the additional support from structures including the ribs and intercapital ligament.

IVDE in the cranial two thirds of the thoracic spine is not common. While not definitively known, the presence of the intercapital ligament is suspected to create more stability and protection from extrusion in this area.[19] The incidence of cranial thoracic IVD extrusion has been found to be higher in large breed dogs, particularly German Shepherds.[61] Several proposed mechanisms for this uncommon location of clinical IVDD have been postulated. German Shepherds may be more prone to clinical IVD overall as they have been overrepresented in a study on thoracolumbar IVDD in large dogs.[39] Large and giant breed dogs, including German Shepherds, have also been reported to have a narrowing of the vertebral canal in T2-T4 region which could contribute to more clinically significant lesions.[62] A possible inherent weakness of the intercapital ligament has been suggested but not proven in this breed.[61, 63]

F. Prevalence of IVDD in the Canine Population

The prevalence of clinically relevant IVD extrusion or protrusion has been reported to be 2% - 3.5% of the overall canine population but is much higher in CDs.[1, 2] The study by Bergknut is based on information from insured pets in Sweden. A total of 677,057 dogs were included over an 11-year period making this the largest study population on this subject.[2] The insured dogs make up about 40% of the entire dog population of Sweden and are considered representative of

the population as a whole. Males have been found to be at a higher risk of IVD related disease than females.[2] This study also confirmed that chondrodystrophic breeds are the most likely to suffer from IVD extrusion or protrusion and that dachshunds are the most commonly affected. Dachshunds are almost universally confirmed as the most at-risk breed, being 12.6 times more likely to suffer a disc extrusion than other breeds.[64] Occurrence specifically in this breed has been reported as high as high as 20% - 61%.[1, 2] CDs are more likely to have IVD extrusion at a younger age (4-6 years of age) compared to non-CDs (6-8 years of age).[33] Mortality rates vary but can be as high as 25% in at-risk breeds like dachshunds.[2]

G. Neurologic Grading of IVDE Patients

Clinical signs of IVDE vary greatly and can include pain, ataxia of the pelvic limbs, weakness or paralysis of the pelvic limbs, bladder or bowel dysfunction, and loss of sensation in the pelvic limbs. The clinical signs present are often used as the most significant prognostic indicator. Several scoring systems have been developed to grade the neurologic status of patients with thoracolumbar myelopathies.[65-69] At our institution, we use a version of the modified frankel score to grade the level of spinal cord injury as initially proposed by Scott (Table 1).[65] This will be the basis of functional scoring in this paper.

These grades are directly related to the presumed severity of injury to the spinal cord with a higher number indicating more severe damage. Neurologic status can be a dynamic feature of dogs with IVD extrusion in the thoracolumbar spine. For example, a dog may initially show signs of pain only and then steadily progress 1 or more grades. This can happen while at home, after presentation to a veterinarian or sometimes even after surgical decompression. As noted above, the latter scenario is likely due to continued secondary injury at the cellular level. Dogs can also present peracutely in any of these categories without obvious evidence of passing through any of the other, less severe grades.

H. Diagnosis of IVDE

Multiple diagnostic modalities have been used to diagnose IVD extrusion.[70-72] Radiography often identifies calcified IVD material in situ or in the vertebral canal but has been found to have a sensitivity of only 32% and is considered unreliable as a sole imaging modality for surgical planning in cases of acute IVD extrusion [Figure 3].[70, 73] More accurate diagnoses can be obtained by performing a radiographic myelogram [Figure 4]. However, cross sectional imaging has largely replaced radiographs and myelograms in recent decades. Myelography is still commonly used in conjunction with computed tomography (CT). While myelography has been found to be comparable to CT as an imaging modality for this purpose, CT is more sensitive to the laterality and site of IVD extrusion and does not pose the same side effect risks as myelography [Figure 5].[74] CT myelography has been investigated as more accurate than either CT or myelography alone [Figure 6].[71] Magnetic resonance imaging (MRI) is more sensitive to subtle, soft tissue changes to the spinal cord, IVDs, and nerves [Figure 7]. The increased availability and use of MRI in veterinary medicine has defined this imaging modality as the gold standard.[72, 75]

I. Treatment Options and Prognosis

Medical management and decompressive surgery are the two treatment choices owners have when their dog is clinically affected by IVDE. Medical management consists of strict rest, analgesia, varying levels of nursing care, possible bladder management, and frequently anti-inflammatory (NSAID) medications. There is still considerable debate regarding the use of NSAIDs versus corticosteroids. Clinician preference plays a significant role in this choice but some studies have shown no benefit to corticosteroids or even a worse outcome or quality of life compared to NSAIDs.[76, 77]

i. Conservative management

Medical management is often chosen by owners when signs are mild or when the costs associated with advanced imaging and surgery are unaffordable. This is a reasonable option in many situations; however, there are a wide range of outcomes reported with conservative treatment. Chance of recovery is usually considered good for dogs presenting as grade 1 or 2,

with success rates reported as high as 82 – 100%.[1] However, other studies found only a 30 – 60% success rate in dogs of these same grades.[77, 78] Generally, there is a downward trend for success in medically managed dogs with worsening neurologic status. A meta-analysis of non-ambulatory dogs with IVD extrusion found that successful outcomes were reported in 79% of grade 3 dogs and 62% of grade 4 dogs.[58] This demonstrates that even in more severe cases, medical management is still a viable option if surgery cannot be pursued by the owner. In the most severe category, grade 5, conservative treatment is discouraged as success rates are reported as 0 – 10%.[58, 77]

Recurrence rates for medically managed dogs are higher than in dogs undergoing decompressive surgery. Reported recurrence rates for conservatively treated dogs range from 31 – 57%.[1, 77, 78]

ii. Surgical Management

Often, surgery is recommended to decompress the spinal cord in cases of IVD extrusion. This obviously does not address damage from the contusive injury or potentially ongoing secondary injury. It does allow for restoration of perfusion and is consistently associated with a better recovery rate, 90% or better, as compared to medical management in grades 1-4.[58] As with conservative treatment, the prognosis changes significantly for grade 5 dogs. Even with surgery, prognosis is usually estimated to be approximately 50% but has been reported as high as 58 – 60%.[58, 79] There is new evidence that indicates durotomy of grade 5 dogs in combination with decompressive surgery can improve the chances of recovery to as high as 70% when compared to surgical decompression alone.[80, 81] Chance of recurrence is also lower in dogs treated with surgery versus medical management. Mayhew reported 15% recurrence in most breeds but 25% in dachshunds.[25]

Another factor that has been debated in regard to prognosis of grade 5 dogs is timing of surgery in relation to the loss of deep pain sensation. For decades, the dogma was that grade 5 dogs had a 50% chance of recovery but only if surgery was performed within 12-72 hours of losing deep

pain sensation.[20] Recently, studies have found that the time between loss of deep pain and surgery may not have an effect on long term recovery.[79, 82, 83]

a. Approaches

The most common procedure to remove herniated disc material from the thoracolumbar vertebral canal is a hemilaminectomy [Figure 8].[3] It entails the removal of lamina, pedicle, and articular facet at the site of disc extrusion with a pneumatic drill or rongeurs. The bony window typically extends dorsoventrally from the base of the spinous process through the accessory process and from the base of the adjacent facets in a cranial-caudal direction. This provides access to the lateral and ventral vertebral canal, the most common area of extruded disc material. One study found that 88% of thoracolumbar disc extrusions were ventral to the cord, 9% were lateral, and 2% were dorsal.[24] A mini hemilaminectomy is also a widely used approach as it provides excellent access to the ventral canal but does not remove the lamina or articular facet, thus preserving more stability. One study also found that this approach resulted in less residual disc material after surgery compared to a hemilaminectomy.[84] Pediculectomy and corpectomy are also known approaches to the ventrolateral spine but not used as widely as the hemilaminectomy or mini-hemilaminectomy. In most cases, dorsal laminectomies are less preferred due to decreased access to the ventral canal. This approach has also been shown to create more instability than a hemilaminectomy.[85]

The traditional dorsolateral approach, via hemilaminectomy, mini-hemilaminectomy, pediculectomy, or corpectomy, requires extensive soft tissue dissection. Muscles, tendons, and fascia of the spinous process, lamina, articular facet, pedicle, and vertebral body are elevated or incised to expose the bony structures of the spine. A laminectomy defect is created over the site of disc extrusion and in some cases, depending on surgeon's preference and skill level, may extend cranially and or caudally by one or more intervertebral disc spaces. The large amount of soft tissue disruption is performed not only for surgical site visualization but also to verify that the surgical site is at the correct location. Distinct anatomic structures like the first lumbar transverse process and the most caudal rib head are identified to locate the disc space of interest.[86] This is a common and fairly reliable technique but can lead to incidents of improper

surgical site identification. This can be related to variations in normal anatomy or simply surgeon error. Anatomical variations, including transitional vertebrae, abnormal ribs or abnormal transverse processes, have been reported in approximately 16-30% of dogs.[20]

Once the approach is made and the vertebral canal is accessed, the goal is to decompress the spinal cord by removing as much extruded disc material as possible. The amount of material that needs to be removed to allow for adequate recovery of neurologic function is unclear. Although more material removed is generally considered better, studies have shown that dogs can have good to excellent recoveries when residual material is left in the canal. Evaluating mini-hemilaminectomies, Huska found that as much as 27.3% of compression can remain without affecting long term outcome.[87] The only dog in this study that did not recover was presented as grade 5 and was lost to follow up. Another study by Roach evaluated residual compression after hemilaminectomy in 40 dogs. The mean post-operative amount of remaining disc material was over 50% but all dogs had a positive long term (median 586 days) functional recovery. Functional recovery was defined as urinary continence and the ability to ambulate.[88] Svensson found that mini-hemilaminectomies reduced compression by only 62.6% and hemilaminectomies by only 34.6%.[84] The authors did not comment on the outcome of dogs in this study.

b. Complications

Infection and severe hemorrhage are a potential complication of any surgical procedure but are rarely reported in decompressive surgery for IVD extrusion. A surgical site infection rate in hemilaminectomies and laminectomies without the use of perioperative antibiotics was reported as 0.6%.[89] While hemorrhage during these surgeries is common, severe hemorrhage requiring a transfusion in patients without an underlying coagulopathy has not been reported in thoracolumbar hemilaminectomies. A more likely complication related to hemorrhage in dogs with IVD extrusion is the formation of a hematoma in the vertebral canal resulting in further spinal cord compression. Though not common, this is infrequently reported anecdotally. The true incidence is unknown.

As discussed above, improper surgical site identification is a potential hazard of surgical decompression. This can lead to unnecessary disruption of soft tissue and bony structures while also extending anesthesia times. Iatrogenic damage to the spinal cord or nerve roots is also possible from the drilling or manipulation of structures during attempts to remove disc material.

In severe cases (i.e. dogs with a grade 4 or 5 neurologic status), the patient may fail to improve or continue to worsen despite having adequate surgical decompression. This is likely due to ongoing secondary injury at a cellular level. In some cases, this injury can result in necrosis of the spinal cord, known as progressive myelomalacia, that moves both cranially and caudally from the site of injury. This is usually considered fatal as the cranial progression will eventually affect the muscles of respiration, resulting in asphyxiation. Approximately 11 - 17% of grade 5 IVDE patients will show signs of progressive myelomalacia.[76, 90, 91] However, studies have shown that incidence could be as high as 23 - 25%.[82, 92] Incidence may be influenced by breed as well with 33% of grade 5 French bulldogs reported as having signs of progressive myelomalacia in one study.[93] Performing a durotomy has been shown to decrease the chance of myelomalacia.[80, 81]

c. Post-operative Care

Post-operative pain can be discogenic, bone, facet, or radicular pain related to nerve root inflammation or irritation, and/or myofascial pain. Studies in humans have shown the pain related to disruption of soft tissue structures to be a significant source of post-operative discomfort.[4, 5] Pain in the post-operative period for spinal surgery is often severe in humans and addressing this has been the subject of considerable and ongoing study.[94-97] Acute, post-surgical pain is a complex process involving activation of three pain mechanisms. These include pain from nociception, inflammation or neuropathic pain.[96-98] All of these mechanisms can be activated by spinal surgery.

Nociception signals are carried by myelinated fibers (A δ fibers) as well as smaller unmyelinated fibers (C fibers).[95, 98] A δ fibers transmit mechanical or thermal stimuli as well as superficial pain. C fibers have much slower conduction and are activated by mechanical, thermal or

chemical stimuli. These fibers transmit signals for deep pain.[98] Tissue injury from surgical disruption releases a wide variety of neurotransmitters that can transmit pain signals to thalamus and forebrain.[95] This is the primary mechanism targeted by opioids, which block pain signals once they reach the brain.[99]

Neuropathic pain is related injury or irritation of nerves or nerve roots and can also be associated with allodynia.[98] Allodynia is the perception of pain to a stimulus that is not normally painful. Opioids are also effective at treating neuropathic pain but are considered a second or third line medication in humans due to side effects and potential for abuse or addiction.[100] Gabapentinoids, including gabapentin and pregabalin, are often used preferentially to treat neuropathic pain. They bind to the alpha-2/delta-1 subunit of presynaptic calcium channels, thus inhibiting the release of excitatory neurotransmitters that transmit pain signals to the brain.[97, 100]

Inflammatory pain is a complex and multifaceted system and is activated by tissue damage. Local injury causes arachidonic acid to be released from phospholipid membranes by phospholipase enzymes. The arachidonic acid is then converted by cyclooxygenases (COX) 1 and 2 to thromboxane A2 and multiple prostaglandins. The products of the arachidonic acid pathway have a broad range of systemic effects and interact with almost every organ system in the body.[101] Prostaglandins and to a lesser extent thromboxane A2 promote local inflammation, vasodilation, fever and pain.[94, 95, 101]

Treatment of the inflammatory process involves corticosteroids or NSAIDs. Corticosteroids inhibit the expression of COX enzymes and thus the arachidonic acid pathway. They also bind to intracellular glucocorticoid receptors and decrease synthesis of many pro-inflammatory mediators.[102] NSAIDs inhibit COX 1 and 2, inhibiting the inflammatory response of the arachidonic acid pathway.[95, 101] There is overlap of the systemic effects of COX 1 and 2 regarding inflammation and normal organ function. COX 2 may have a more prominent role in pain and inflammation whereas COX 1 may be more involved in physiologic homeostasis of the GI tract. In an effort to reduce GI ulceration as a significant complication related to NSAID use, selective COX 2 inhibitors have been used. However, cardiovascular complications were a

serious concern and a clear benefit to selective COX 2 inhibitors has not been shown.[95, 101, 103]

While exact analgesia protocols vary widely by clinician and hospital, it is usually multimodal and can include local anesthetics, anti-inflammatory medication (NSAIDs or corticosteroids), intravenous (IV) opioids (intermittent injections or CRIs) often transitioned to oral opioids 2-3 days following surgery, dissociative medication such as ketamine, and nerve pain medication such as gabapentin. The mainstay of immediate post-operative analgesia is usually an opioid such as fentanyl, buprenorphine, methadone, morphine, or hydromorphone. Due to the opioid crisis in the United States, written protocols for post-operative analgesia often include the phrase “if available”. Changes in manufacturing, distribution, and monitoring of these medications as a result of wide spread opioid misuse and addiction has made acquisition of opioids in veterinary medicine inconsistent and increasingly more difficult.

As patients recover from surgery, medications are transitioned from IV to oral. For the majority of IVDE spinal surgery patients, if they remain comfortable on oral medications and nursing care (including bladder management) improves to a level that is reasonable for owners to handle at home, patients are discharged for further care with the owners. At this point, owners are instructed to institute the same restrictions and management at home as with medical management. This allows patients to safely recover from surgery as well as to minimize the chance of further extrusion of disc material from the annular defect.

The AF heals poorly in adult vertebrates and may be due to several factors including limited blood supply, low resident cellularity and inflammation.[27, 104] Healing of the AF after injury is repaired via a fibrous cap over the defect with little to no healing of the AF itself.[104-106] In dogs with experimental stab wounds applied to the AF in the lumbar spine, there was no repair of the AF at 12 weeks.[105] Another study that introduced partial thickness incisions in the IVDs of sheep found no healing of the incised AF and continued degeneration of the remaining intact, inner AF 18 months later.[106] The strict rest period postoperatively is not to allow the AF to heal but rather for a fibrous scar to form over the defect which has been shown to be fully

formed at 3 weeks postoperatively.[105] Therapies to stabilize or improve repair of the AF after injury are being explored in humans as a way to decrease the chance of recurrence.[104, 107]

Minimally Invasive Surgery in Humans

A. History

Minimally invasive techniques have become widely accepted in human medicine though this acceptance has not come easily. Simple endoscopic devices were described over 1000 years ago.[108] The concept of endoscopy for surgical use was initially documented in the early 1900s.[109] Advances in technology have been a factor in making minimally invasive approaches more viable. However, the medical community as a whole has been slow to accept this idea until the last 2-3 decades. Now, there are less invasive versions of many open surgeries across different specialties. Benefits to less invasive approaches have been shown in human medical literature and patients often prefer a less invasive option.

Rigid tubes inserted into body cavities for visualization have been around for centuries. Endoscopic devices were described in Arabia around the year 1000 A.D and later by the German physician Bozzini in 1805.[108] The first person to coin the term “endoscope” was Desormeaux, a French physician in the mid 1800’s, who used these devices to examine the urethra and bladder of human patients.[108] Interestingly, some of the earliest reports of laparoscopic surgical procedures were performed on canine subjects in the first years of the 20th century.[109] These were soon followed by case studies in human patients. The concept of minimally invasive surgery (MIS) still did not start to take hold until the second half of the century. Gynecology as a specialty was the first to regularly use laparoscopic techniques starting in earnest in the 1970s. These techniques were eventually adopted by surgeons for more varied procedures.[110] Figure 9 shows an early version of a laparoscope used by surgeons [Figure 9]. Resistance to endoscopic approaches was still prevalent until the 1980s when computer chip technology allowed for the magnified internal view to be projected onto a video screen.[108] This visual step forward may have been what resulted in the overall acceptance of endoscopy as a legitimate technique [Figure 10]. Growth of the endoscopy field has been rapid since then and is now present in almost every surgical and medical discipline. At the time of writing, a pubmed.gov search for “minimally invasive surgery” found 567,105 results since 1928 with over 427,000 of those results since the year 2000.

B. Current Use

Minimally invasive or endoscopic approaches are present in almost every area of human medicine. General surgery in large body cavities via laparoscopy and thoracoscopy were originally the more common uses of surgical endoscopy. It has also become frequently used in other areas such as orthopedics (arthroscopy), surgical oncology (biopsies, tumor removal), urogenital disease (urethroscopy, cystoscopy, hysteroscopy), neurosurgery (intracranial endoscopy, microendoscopic discectomy) , internal medicine (esophagogastroduodenoscopy, colonoscopy), pulmonology (bronchoscopy), and others.[111-120]

C. Benefits

One significant benefit of minimally invasive procedures is the decrease in soft tissue disruption and smaller surgical scars. The cosmetic effect of surgical scars is important to human patients. One study cited 85% of patients undergoing hysterectomy had concerns about surgical incision appearance.[121] While veterinary patients do not have the same emotional involvement with surgical scars, this can be a serious source of psychological trauma for humans.[122] They can create or contribute to mental illness by causing depression, anxiety, and anger. It can change perceptions of self-worth or how a person is able to interact socially, professionally, and personally. Scars can have physical effects and can be a source of discomfort or restricted movement. Minimizing scar tissue formation should be considered whenever possible.

Another benefit of endoscopic procedures is visualization. The field of interest can be illuminated and magnified in a way that cannot be duplicated with surgical loupes. Even exoscopes or operating microscopes, magnifying lenses, and light sources positioned outside of the surgery site provide unmatched detail and sensitivity. This can facilitate precision of hemostasis, margins, and pathology identification during surgery. Colonoscopy, for example, is the gold standard for colorectal cancer screening due to the direct tissue visualization and ability to biopsy precancerous lesions without having to surgically open the abdominal cavity.[115]

The other, and most compelling, potential benefit of endoscopic procedures is that they may show improvements in outcomes when compared to open approaches. Many studies have shown benefits including lower infection rates, shorter hospital stays, reduced blood loss, lower complication rates, and lower morbidity and mortality across multiple procedures.[112, 123-127] The possibility of improving outcomes and decreasing complications for patients is the primary goal of using a minimally invasive approach to any surgical procedure.

D. Complications

Complications can occur in any surgery but some are unique to endoscopy, the first being perforation. When endoscopy is being performed within a contained structure, such as the stomach, lungs, intestines, or bladder, damage to the wall of these structures can have significant consequences. Perforated bowel can lead to a septic abdomen, damage to lungs can cause pneumothorax, etc. Damage can also occur secondary to trochar or Veress needle insertion into a body cavity. This can involve solid organs, vessels, or bowel. One review paper found complications involving access to the abdominal cavity was 0.3% intraoperatively and 5% within the first 3 months.[128]

Another aspect of endoscopy that is not encountered in open surgery is the challenge and difficulty involved in using the equipment and becoming familiar with the surgical view on the screen. Orientation must be maintained throughout the procedure between the area of interest in the patient, the surgeon and the camera view. Manipulating the instruments in the field of view takes significant practice to become competent. While there is a learning curve to any surgical procedure, the learning phase appears to be more challenging using endoscopy. Studies looking at upper and lower gastrointestinal endoscopy have shown that 150 to 275 procedures are required to become proficient.[113, 129]

Minimally Invasive Surgery in Animals

A. History

Dogs were used to evaluate the use of early endoscopes but it wasn't described for veterinary purposes until decades later in 1935. The English veterinarian A.W.N. Pillers employed a bronchoscope to identify a tracheal infection by lung worms (*Oslerus osleri*) in a dog.[130] A similar method was reported in the United States but not until 1962.[130] MIS did not gain wide spread use in veterinary medicine until the 1990s and 2000s after the explosion of endoscopic procedures in human medicine in the 1980s. Even now, minimally invasive surgeries are much less common in animals than their human counterparts. Literature reviews and meta-analyses are also severely lacking, making it difficult to adequately analyze our understanding of the subject and how to apply it clinically.

B. Current use

Though not as pervasive as equivalent procedures in humans, endoscopic approaches have now become common place in several veterinary fields, primarily in veterinary surgery. Soft tissue surgery has quickly adopted minimally invasive options.[131] Laparoscopy is rapidly gaining popularity for many procedures including liver biopsies, ovariectomy, gastropexy, and others. Thoracoscopy is routinely an option for pulmonary and cardiac procedures. Orthopedic surgeons use many of the procedures found in human medicine as well. Arthroscopy is commonly performed for evaluation and treatment of many joint diseases. The use of endoscopy for biopsies or tumor removal is often preferred by oncologic surgeons.

Minimally invasive procedures have gained popularity in non-surgical areas as well. The internal medicine arena applies these techniques to many of their patients. Endoscopic esophageal and gastric foreign body removal is frequently the first treatment option prior to an open gastrotomy.[132] Cystoscopy and urethroscopy is often used for the management of cystoliths and urethroliths, bladder lumen biopsies, and ectopic ureter correction.[133] Rhinoscopy combined with CT imaging is the standard of care for diagnosis of nasal disease.[134]

Interventional cardiology has found success with minimally invasive techniques too.[135] Even dermatologists regularly use endoscopic equipment in the treatment of their patients. Video otoscopic evaluation of the outer and middle ear is the gold standard for management of otitis media.[136]

In short, there are very few veterinary specialties that have not adopted some form of endoscopic or minimally invasive approach. One exception is neurology. There have been minimally invasive approaches described to the brain and spine but these are a rarity in comparison to standard, open techniques. It is difficult to compare the human and veterinary neurology specialties directly. Intervertebral disc degeneration in dogs is most often related to Hansen type 1 extrusions whereas in humans, it is often more comparable to Hansen type 2 protrusions. Also, the cost of specialized equipment is not as easy to justify for veterinary practices. Regardless, the benefits described for minimally invasive approaches in humans may be translatable to veterinary patients and should be considered.

The field is being advanced not only by veterinarians but also pet owners. Owner demand for these procedures is rising. This is likely related to the popularity of minimally invasive surgery in humans. Rapidly increasing owner interest is another reason to explore less invasive options.

C. Benefits

Veterinary studies of minimally invasive approaches have shown decreased postoperative pain, faster return to function, decreased surgical site infections, decreased use of rescue analgesia, fewer adhesions, decreased scar formation associated, and lower mortality.[131, 137-142]

Animals do not have the same psychological associations with scars as humans, but pet owners may have emotional responses to surgical scars on their dog or cat. A study evaluating owner satisfaction of a surgical procedure found that the visual appearance of the surgery site may have influenced the overall perception of outcome in 37% of cases.[143]

D. Complications

Described complications are generally similar to those in human medicine. Iatrogenic damage, hemorrhage that obscures the view of the surgical field, pneumothorax, perforation have been reported in various veterinary endoscopic surgeries.[133, 137, 140, 142, 144] One aspect that seems more prevalent in veterinary laparoscopy is splenic laceration during trochar or Veress needle insertion. Mayhew reported splenic lacerations in 3-18% of small animals undergoing laparoscopy vs less than 0.1% in human.[137]

Minimally Invasive Spinal Surgery in Humans

A. History

Minimally invasive approaches to the spine began nearly a century ago and have persisted and improved continually. Endoscopic evaluation of the lumbar vertebral canal, termed “myeloscopy”, was described by Pool in the late 1930s and early 1940s.[145] This was done only for diagnosis and sample collection and was not utilized for therapeutic purposes. Enzymatic injection into the disc to dissolve the nucleus pulposus was first described by Smith in 1963 in rabbits.[146] It was then reported in humans the following year.[147] In 1972, fluoroscopy was first described as a way to verify location of the correct IVD.[148] The first minimally invasive percutaneous discectomy is credited to Hijikata in 1975.[149-151] Onik reported a percutaneous discectomy in 1985 using a “nucleotome aspiration probe”. [152] It functioned like a tru-cut biopsy needle with integrated lavage and suction to slice off pieces of protruding disc. Others reports were published in the 1980s and 1990s describing various percutaneous approaches to remove disc material combined with endoscopy.[153-158]

The technology has continued to improve but the concept is still to create minimal soft tissue disruption while providing adequate access to the affected area to allow for spinal cord or nerve root decompression. Minimally invasive procedures to decompress IVD protrusion or extrusion in humans consist of several techniques: microdiscectomy, microendoscopic discectomy, or full endoscopy. They have relatively minor technical differences and are all under the umbrella of MIS of the spine. Figure 11 illustrates an example of the approach for a microendoscopic discectomy [Figure 11]. Spinal fusion is also commonly performed for clinical IVDD in humans (open and MIS) but not commonly in dogs so this will not be addressed in this paper.

B. Benefits

Some of the described benefits of MIS in the human spine include decreased surgical site infections, decreased blood loss, shorter surgical times, shorter time in hospital, decreased postoperative pain, faster return to ambulation, and decreased re-operation rates.[6-16] Another

benefit of minimally invasive surgery in humans is positive patient perception. A 2018 study found that most patients had negative associations of open spine surgery compared to MIS.[159] A second study found a positive correlation between patient satisfaction and a minimally invasive approach.[160]

There are biases that may be contributing to some of the studies showing clear benefits of minimally invasive approaches. The tumors selected may have been smaller, disc extrusions may have been more straightforward or patients may have had fewer comorbidities in the MIS groups compared to open approaches. The majority of studies have either not identified or accounted for significant bias affecting the results but it is important to be aware of this possible influence.

C. Complications

Complications include hemorrhage (primarily from the venous sinus), infection, iatrogenic damage to spinal cord or nerve roots, iatrogenic damage to great vessels (anterior/ventral to the spine), lack of improvement, and recurrence. Recurrence or lack of improvement is a well-documented problem known as “failed back surgery syndrome” usually consisting of persistent low back pain +/- leg pain. This occurs in 10-40% of patients that have undergone at least one spinal surgery.[5]

Another complication seen more commonly in humans than animals is a dural tear or “cerebrospinal fluid (CSF) leak”. It has been reported in 5.5-9% of first time lumbar spinal surgeries. Clinical signs are often headaches but can also present as meningitis, infection, nausea, pain, tinnitus, blurred vision, CSF seroma, and poor functional outcome.[161] This has not been reported in dogs, partly because they cannot report headaches and also because of their horizontal spinal orientation. The vertical direction of the spinal column in bipeds makes changes to subarachnoid pressures more pronounced.

MIS spinal approaches are similar to arthroscopic procedures in that they occur within a very small space and have potential for disorientation. Research evaluating arthroscopic hip procedures found that 20-500 surgeries are needed before a surgeon achieves proficiency.[111,

162] A review paper noted that in MIS of the lumbar spine specifically, 15-72 cases are required to reach a surgical “plateau” where minimal improvements are seen in subsequent surgeries.[163] While there are potential benefits to minimally invasive approaches, there is clearly a significant amount of skill and experience to be acquired before these benefits can be fully realized.

D. Gold standard

There is currently no established gold standard surgical technique for IVD extrusion or protrusion in humans. Though many benefits have been described, as listed above, there are authors and surgeons that question the true benefit of MIS to address clinical IVDD. Multiple review papers and meta-analyses have found no difference in long term outcomes of MIS when compared to open IVDD surgery. Clark highlighted less blood loss, postoperative analgesia, and overall cost for a tubular microdiscectomy but no difference in short- or long-term outcomes compared to a traditional approach.[114] Blamoutier found that MIS patients had less blood loss and shorter hospital stays but no difference in outcome versus a standard discectomy.[164] In regard to intradural-extramedullary spinal cord tumors, Wong and Raygor again found no difference in postoperative outcomes related to reoperation or recurrence, respectively, between open surgery and MIS. They did both find that minimally invasive surgeries had lower levels of blood loss and Wong also found that hospital stays were shorter.[165, 166]

Minimally Invasive Spinal Surgery in Animals

A. History

Veterinary minimally invasive neurosurgery is in its infancy and reports on treatment of IVD related disease in live animals are sparse. Early reports were related to percutaneous discectomy as another method of fenestration.[167, 168] Percutaneous disc ablation or chemonucleolysis, methods that are not commonly used today, have been described as minimally invasive methods to treat clinical IVDD.[169-172] Minimally invasive approaches to the cervical spine and lumbosacral space have been reported on both cadavers and live patients.[173-176]

Almost all veterinary literature on minimally invasive techniques to decompress the spinal cord in the thoracolumbar spine have been either on cadavers or live, healthy dogs. Experimental studies have been published on corpectomies, foraminotomies, pediculectomies, mini-hemilaminectomies, and hemilaminectomies.[177-182] All of these studies are important for understanding the minimally invasive options that could be considered for dogs with IVD extrusion or protrusion. These findings are difficult to interpret when they have not been applied to patients suffering from IVD related problems.

There is only one report in veterinary literature related to a minimally invasive approach in the thoracolumbar spine to address clinically significant IVDD for the purposes of spinal cord decompression. Guevar published a clinical case report on a microsurgical approach to an IVD protrusion in a large breed dog with excellent results.[183] The procedure performed was a foraminotomy and lateral corpectomy. Given the rising popularity of minimally invasive techniques among pet owners and surgeons, more clinical studies are needed on this topic.

B. Benefits

Give a lack of available data, the benefits of minimally invasive spinal surgery in veterinary medicine are assumed to be the same as those described in human medicine. Comparison of complications, surgery times, and outcomes between MIS and open approaches will require

specific studies with large numbers to be convincing. If clinical trials can continue, hopefully advantages of these techniques can be well described and lead to more wide spread use.

The intraoperative imaging required to locate the correct surgical site is more precise than the typical approach of correctly identifying local anatomy with digital palpation alone.

Ultrasonography has been described as a more accurate way of finding the correct site compared to percutaneous palpation but is not widely used.[184] Fluoroscopy is a standard adjunct to human spinal procedures to identify the spinal area of interest but errors are still made even with this modality. The term “wrong-site spine surgery (WSSS)” is used to describe surgical errors of performing surgery on the spine at an incorrect level or side. Incidence is likely lower now but was reported in 2013 as between 0.04-5.3% of spinal surgery cases.[185] The use of fluoroscopic imaging in surgery to verify the correct surgery site is a potential unintended benefit of a minimally invasive approach.

Another benefit of MIS is improved teaching associated with improved visualization. The ability of anyone other than the primary surgeon to have consistent and meaningful visualization of the surgical field is minimal. The most common form of neurosurgical magnification, operating loupes, provides visual advantages only to the individual wearing them. The images from an endoscope or exoscope however are transmitted to a large screen so everyone in the surgical suite is able to easily see every step of the procedure. The video from the scope can also be sent to other locations in the hospital for viewing by others not able to be in the OR. This has the potential to help students learn anatomy and to fully grasp the different steps of the procedure. While it may only be a benefit within teaching hospitals, this could provide a much richer learning experience for those who are still inexperienced. In addition to student teaching, recording surgical procedures also provides the surgeon with a learning opportunity. Reviewing a procedure to evaluate the surgical technique could be a useful tool to improve operator skill.

C. Complications

Complications are mostly hypothetical as there are few reports of MIS in the spine of animals. Dural tears do not seem to be a significant issue in small animal patients and have not been

described in the current veterinary literature as a reported complication. Hemorrhage, infection, iatrogenic damage, lack of improvement and recurrence are all potential complications but have not been described in the veterinary literature.

D. Limitations

The most significant limitation that can be directly applied from human MIS of the spine is likely the significant learning curve involved in achieving proficiency. Though complication rates have been shown to be decreased compared to open surgery, these may be increased in the learning phase. Experience is easier to be gained by human neurosurgeons as they frequently have a steady case load. Limited by owner finances and the emergent nature of IVD extrusion in dogs, veterinary neurosurgeons may take years to accumulate the same amount of cases that a human surgeon could in a few months.

Chapter 3: Manuscript

Minimally Invasive Hemilaminectomy for Hansen Type 1 Intervertebral Disc Extrusion in
Chondrodystrophic Dogs

Abstract

Objective: Determine the clinical feasibility of performing a minimally invasive hemilaminectomy in small, chondrodystrophic dogs to address Hansen type 1 intervertebral disc extrusion (IVDE)

Study Design: Pilot study

Animal Population: 5 client-owned chondrodystrophic dogs less than 15kg

Methods: Patients were identified with a less than 3-month history of acute onset thoracolumbar pain, with or without neurologic deficits, referable to the T3-L3 spinal cord segments and intact deep pain perception intact. For inclusion, dogs needed to have MRI confirmed disc extrusion between the T10 and L5 vertebral bodies. Extension of the disc material had to be within the reference range as defined by a previous cadaver study: 2/3 the diameter of the cannula to be used. The surgical site was identified using an image intensifier (C-arm). A minimally invasive, integrated endoscopic hemilaminectomy was performed to remove compressive disc material. Following surgery, an MRI was repeated to determine adequate spinal cord decompression as determined by remaining T2 hypointense material in the epidural space causing spinal cord compression or displacement.[186] If significant compression remained, the patient was immediately returned to surgery for a traditional open approach to remove remaining compression.

Results: Adequate decompression was achieved in 4/5 dogs, with 1 dog requiring an additional open approach. This dog also had iatrogenic spinal cord damage during the minimally invasive approach.

Conclusion: A minimally invasive, integrated endoscopic hemilaminectomy is a feasible approach for spinal cord decompression secondary to acute, single-site IVDE. Careful and repeated checks for correct orientation are crucial to ensure success.

Clinical Significance: In this small study population, a minimally invasive approach was able to provide spinal cord decompression and a successful outcome in small, chondrodystrophic dogs.

Introduction

Hemilaminectomy for intervertebral disc disease is the most common neurologic surgery in veterinary medicine.[3] Amongst dogs presented for intervertebral disc disease, chondrodystrophic dogs are over represented.[18, 19] A genetic link, specifically the 12-FGF4 retrogene, has been identified between chondrodystrophy and intervertebral disc disease.[55, 56] Developing a minimally invasive approach to this procedure could have significant impacts on chondrodystrophic breeds prone to intervertebral disc extrusion (IVDE) by decreasing post-operative pain and morbidity. Fewer medications and days in hospital may also result in reduced costs to owners.

Minimally invasive techniques in spinal surgery are ubiquitous in human medicine but have been slow to be adapted in veterinary patients [Figure 15]. Many studies in the human literature have shown benefits of minimally invasive procedures, including decreased surgical infection rates, blood loss, hospital stays, time to ambulation, and postoperative pain.[6-13] IVDE in dogs is often an acute, traumatic injury to the spinal cord that can result in severe or complete loss of neurologic function and sensation caudal to the site of damage. These cases often require emergency surgery to decompress the spinal cord. The traditional hemilaminectomy in veterinary medicine involves elevation of muscles and soft tissues off of the spine over two or more vertebral bodies for a single site IVDE. The removal of compressive disc material is the most important step in allowing the spinal cord to recover, but the significant amount of soft tissue dissection may have a direct effect on postoperative pain, speed of recovery, and time in the hospital.

Several veterinary studies have been performed on minimally invasive approaches to spinal surgery but the subject is infrequently reported. Some involve percutaneous procedures that are uncommonly performed including disc ablation or partial discectomy.[167-172] Others are focused on a ventral approach to the cervical spine.[173, 174] The remainder describe procedures in the thoracolumbar spine on cadavers or healthy study dogs.[175-182] Only a single case report on a minimally invasive approach to the thoracolumbar spine for clinically significant IVDD exists.[183] This describe a microsurgical approach to a Hansen type 2 disc in a German

Shepherd dog. There is clearly a lack of literature describing outcomes of minimally invasive approaches to clinical IVDE in the thoracolumbar spine of dogs.

A previous study of the same technique used in this study has been completed on large breed cadavers.[181] It defined parameters of access using the same surgical system used in the current study. The working surgical window created was defined as $\frac{2}{3}$ the diameter of the cannula to be used. The window was also offset caudally with $\frac{1}{3}$ of the bony window cranial to the center of the disc space and $\frac{2}{3}$ caudal to it.

The objective of this study was to assess the feasibility of a minimally invasive, integrated endoscopic hemilaminectomy in clinically affected, chondrodystrophic dogs with Hansen type 1 IVDE. This was designed as a prospective pilot study using the IDEAL guidelines for surgical innovation.[187] If the procedure is demonstrated to be feasible, larger studies can be considered to evaluate the surgical morbidity and long-term outcome of these patients and compare them to subjects receiving traditional hemilaminectomies.

Materials and Methods

A. Study subjects

This study was approved by the Virginia Tech institutional animal care and use committee (protocol 18-263). All clients were given a consent form describing the procedure and risks associated with surgery.

Dogs included in the study were client-owned, chondrodystrophic breeds with an acute onset of thoracolumbar pain and/or neurologic deficits referable to the T3-L3 spinal segments. Clinical signs related to this must have started no earlier than 3 months prior to presentation and deep pain perception was required to be intact. Dogs had to weigh less than 15kg and have an acute, single site IVDE between T10 and L5 confirmed by MRI. Dogs were excluded if they were evaluated as having an absence of deep pain perception, had a history of prior thoracolumbar surgery, or concurrent, acute spinal disease (i.e. spinal fractures, neoplasia, infectious/inflammatory disease, etc.). If animals were able to be enrolled, funds were provided to cover the postoperative MRI, a second surgery if needed, and any additional anesthesia charge related to these. Clients were also given a \$500 gift to go toward their hospital bill.

B. Preoperative Imaging

All diagnostics and procedures were performed at the Virginia-Maryland College of Veterinary Medicine Small Animal Hospital. A complete blood count and serum chemistry were performed on all cases. Patients were anesthetized by the Anesthesia Department using standard protocols for dogs with thoracolumbar intervertebral disc extrusion (IVDE) tailored to each dog. Surgery and total anesthesia times were recorded. MRI imaging was performed in a 1.5 tesla magnetic resonance imaging (MRI) scanner (Philips Medical Systems, Cleveland, OH) to identify the affected spinal cord segment. Scanned sequences of the entire thoracolumbar spine were standard for IVDE dogs at this institution and included sagittal and transverse T2 weighted, dorsal stir, and HASTE images. Dogs were enrolled in the study if MRI findings confirmed a single-site disc intervertebral disc extrusion (IVDE) between the 10th thoracic vertebrae and the

5th lumbar vertebrae and the extension of the herniated disc material fell within the reference range defined in a previous cadaveric study using the same endoscopic surgical system.[181] The reference range was defined as a cranial to caudal extension of no more than 2/3 the diameter of the cannula to be used. No more than 1/3 of the herniated material could be cranial to the center of the intervertebral disc. Dogs with disc extrusion parameters outside of the size or location ranges were not candidates for this study.

C. Surgical approach

The surgical procedure was performed by one of two operators, a neurology resident with previous experience in this specific procedure in cadaver dogs or diplomate of the American College of Veterinary Surgeons (ACVS) with over 20 years of experience in endoscopic procedures including in the spine. Following MRI, the dogs were placed in sternal recumbency and the dorsum was clipped and aseptically prepared according to hospital policy. The cutaneous area aseptically prepared was large enough to allow for an open approach if necessary. A 2-inch, 20-gauge sterile needle was inserted percutaneously onto the articular facet over the affected intervertebral disc and verified using an imaging scanner intensifier (C-Arm, Philips Medical Systems, Cleveland, OH). The needle was repositioned as necessary to identify the correct site. A 4cm incision was made over the articular facet in a cranial to caudal direction just off of midline using a #10 scalpel blade. Both layers of the epaxial fascia were sharply dissected using a #15 scalpel blade and the correct facet was confirmed with digital palpation.

Next, a series of expanding dilators of increasing diameter (EasyGO! II, Karl Storz Veterinary Endoscopy, Goleta, CA) were inserted over the articular facet, elevating and retracting the soft tissues from their attachments to the facet [Figure 16]. This was performed twice to maximize exposure of the facet. The dilators were then removed and the site was kept open using gelpi retractors. The remaining muscular attachments were removed from the facet using bipolar electrocautery and freer periosteal elevators. The facet was then removed using Ruskin rongeurs. Once the surgical site was adequately exposed, local landmarks were identified. These included the accessory process ventrally, the base of the spinous process dorsally and the base of the next articular processes cranially and caudally. Then a cannula (EasyGO! II, Karl Storz Veterinary

Endoscopy) was inserted over the facet which would become the working surgical window. The cannula used was the smallest that would accommodate the extrusion, which could not be longer than 2/3 the diameter of the cannula. The cannula (19mm or 23mm diameter) served as a retractor of soft tissues as well as the receptacle for the endoscope. The cannula was secured by attachment to a multi-jointed locking arm (EasyGO! II, Karl Storz Veterinary Endoscopy) clamped to the surgery table. A 25-degree integrated endoscope (EasyGO! II, Karl Storz Veterinary Endoscopy) was then inserted into a sheath inside the cannula.

Visualization for the rest of the procedure was on the endoscopy tower screen (Stryker Corporation, Kalamazoo, MI) via the endoscope. The outer cortical, medullary, and inner cortical bone was drilled away using a steel 70mm length steel burr (4mm oval, 3mm round or 2mm round) and a pneumatic drill (Surgairtome Two, Conmed, Utica, NY). Hemostasis was achieved using bipolar cautery and/or bone wax. The bony window extended from the cranial to the caudal edge of the cannula and dorsoventrally from the articular surface of the facet to the base of the accessory process. When the window was cleared of all bone, the periosteum was breached using a nerve hook and then removed using Love-Kerrison rongeurs. Compressive disc material was removed using a nerve hook and micro biopsy forceps until the cord appeared decompressed and no further disc material could be produced. The amount of intraoperative hemorrhage was recorded as either minimal, mild, moderate or severe based on the impression of the surgeon.

Once any minor hemorrhage was controlled, the hemilaminectomy window was covered with a thin piece of gelfoam or subcutaneous fat. The cannula was removed and the fascia was closed with 2-0 PDS suture in a simple continuous pattern. The subcutaneous and intradermal layers were closed using 3-0 monocryl suture in a simple continuous and horizontal mattress pattern, respectively. The incision was covered with a non-adherent sterile bandage.

D. Postoperative Imaging

Directly after surgery, anesthetized patients were returned to radiology for an abbreviated postoperative MRI. Scanned sequences included sagittal and transverse T2 weighted images of

only the surgical site and the disc space cranial and caudal. The spinal cord was evaluated for remaining compression by the primary surgeon with consultation with a radiologist. The presence of remaining disc material was subjectively determined by the presence of T2 hypointense material in the epidural space causing spinal cord compression or displacement.[186] If there was no remaining compression assessed, they were recovered from anesthesia and moved to the ICU for monitoring and postoperative care. If there appeared to be remaining spinal cord compression as compared to the preoperative MRI, the patient would return immediately to the operating room for a standard, open hemilaminectomy to remove residual compression.

E. Postoperative care

All dogs received IV analgesia consisting of a ketamine CRI. An opioid CRI or intermittent IV opioid injections were used as rescue pain relief if ketamine was initially assessed as inadequate by the surgeons or as needed overnight as assessed by the ICU staff with parameters listed on the treatment sheet. The use of opioids as a CRI or rescue pain relief was recorded. When alert, oral pain management was started including an opioid +/- gabapentin. Anti-inflammatory medication (NSAIDs vs corticosteroids) was continued based on how the patient had previously been managed by the referring veterinarian and continued for 2 weeks after surgery. If no anti-inflammatory medication was previously prescribed, an NSAID was used unless contraindicated by other systemic disease. Maintenance IV fluids (LRS 50ml/kg/day) were continued overnight after surgery. Bladder management consisting of manual expression was instituted if the patient was unable to urinate voluntarily.

F. Discharge and Follow Up

As soon as patients were comfortable on oral pain medications, they were discharged for further recovery at home. In the event that manual bladder expression was still required, owners were taught how to perform this at home. Rechecks were requested at 2 and 6 weeks postoperatively. Neurologic status was recorded at discharge and at both rechecks. In the event that clients were unable to return for any rechecks, information on their progress was gathered by video or by

communication with the referring veterinarian or owner. All clients (except case 5) were contacted a final time prior to submission of this manuscript for an update.

Results

A. Study Subjects

Five dogs were able to be enrolled in the study over a 10-month period. Patient information is summarized in Table 2. The median age was 9 years (range 3 – 12 years). Median weight was 5.9kg (range 5.4 – 14.7kg). Four were castrated males and 1 was a spayed female. Breeds included Pekinese (2), Shih Tzu, Coton de Tulear, and a mixed breed. Median duration of signs was 3 days (range 1 – 9 days). All dogs were non-ambulatory paraparetic on presentation except case 4 which was ambulatory paraparetic.

Baseline blood work was unremarkable in 4 dogs. Case 5 had azotemia and evidence of cholestasis on serum chemistry. The blood urea nitrogen was 50mg/dl (reference range 9-30) and the creatinine was 1.44mg/dl (reference range 0.7-1.3). Alkaline phosphatase was 1321U/L (reference range 8-70) and gamma-glutamyl transferase was 22U/L (reference range 1-5). An abdominal ultrasound was performed under anesthesia and revealed a gallbladder mucocele, vacuolar hepatopathy, splenic nodular hyperplasia and nonspecific renal changes. Median creatinine kinase was 194 U/L (range 93 – 327).

B. Advanced Imaging and Surgery

The resident was the primary surgeon for cases 1 and 5 while the ACVS diplomate was primary for cases 2-4. Sites of disc extrusion included T13-L1 (3) and L1-2 (2). Three were right sided and 2 were left sided. Median cranial to caudal length of disc extrusion was 5mm (range 3 - 14mm) [Figure 12]. A 19mm cannula was used in all dogs except case 4 which used a 23mm cannula. This was the largest dog (14.7kg) and had the longest extension of disc material (14mm). Intraoperative hemorrhage was assessed as minimal in all cases. Complications only occurred in one patient (case 1) and consisted of iatrogenic damage to the dorsal spinal cord with the burr. The dura was briefly contacted with the burr which did not penetrate the dura but caused marked bruising and edema of the cord.

Four of 5 cases did not have any remaining acute disc material or compression the spinal cord visible on postoperative MRI and were recovered from anesthesia. Case 1 had residual material caudal to the center of the intervertebral disc space and returned to the operating room for a second procedure. The second surgery proceeded without complication and the remaining disc material was removed.

Median anesthesia time was 370 minutes (range 255 – 510 minutes) and median surgery time for the minimally invasive procedure was 135 minutes (range 70 – 170 minutes). Surgery time for the open approach revision of case 1 was 65 minutes.

C. Postoperative Care

After recovery, all dogs received a ketamine CRI at 2mcg/kg/min. Rescue IV opioids were used in case 1 (2 doses of hydromorphone 0.2mg/kg q4-6 hours) and case 3 (single dose buprenorphine 0.03mg/kg). A fentanyl CRI (2-5mcg/kg/hr) was also added for pain control to case 1 after adequate analgesia was not achieved with a ketamine CRI and intermittent IV opioid injections. When alert, oral pain management was started, including codeine (1-2mg/kg TID) and gabapentin (10mg/kg TID) in all cases except case 5 that received codeine only. The codeine in case 4 was given in the form of acetaminophen 300mg/codeine 60mg (Tylenol 4). NSAIDs were continued in cases 1-4 and prednisone was continued in case 5. Methocarbamol (250mg PO TID), initially started by the referring veterinarian, was continued in hospital to help provide mild sedation for case 4. Medications were added to case 1 for bladder management including prazosin (0.5mg PO TID) and diazepam (1mg PO TID).

D. Discharge Status

At discharge, cases 2-5 retained the same neurologic status but had evidence of improvement on the exam in the form of increased comfort or subjectively improved motor function. Case 1 declined after surgery and was paraplegic with bilateral loss of deep pain sensation at the time of discharge. Ability to urinate was retained in all dogs after surgery with the exception of case 1 which required manual bladder expression for 3-4 weeks at home.

E. Short Term Outcome

Case 1 remained paraplegic and deep pain negative at the 2-week recheck performed in the hospital. Further follow ups were performed via phone or email with videos. Cases 2-4 were all ambulatory at the 2-week recheck. Cases 2 (in hospital) and 3 (via phone) were ambulatory paraparetic with mild ataxia and case 4 (in hospital) had a normal neurologic exam. Case 5 presented to the referring veterinarian 4 days after surgery for anorexia and vomiting. Serum chemistry found worsening cholestasis and azotemia. These values continued to worsen after several days of supportive care in the hospital and evidence of severe hepatocellular damage became present as well. The owner elected humane euthanasia 8 days after surgery.

F. 6 Weeks Postoperatively

Case 1 was non-ambulatory paraparetic with voluntary control of urination and defecation and no discomfort, confirmed via phone and emailed videos. Case 2 (in hospital) was ambulatory with minimal ataxia and no discomfort. Case 3 (emailed videos) was ambulatory with very mild ataxia and paraparesis and was comfortable as confirmed by the referring veterinarian. Case 4 did not return for a 6 week recheck but remained neurologically normal and comfortable according to the owner (via phone).

G. Long Term Outcome

Median follow up for all patients was 16 months (range 8 days – 17 months). At the time of writing, case 1 is grade 2, ambulatory with significant paraparesis and ataxia. The owners report normal control of bladder and bowels and no discomfort. Case 2 was evaluated in the hospital 9 months after surgery and was neurologically normal with no hyperpathia. The owners report no changes since that time. Case 3 was unable to return to the hospital for follow up due to living a significant distance from the hospital. A video was sent by the referring veterinarian 26 days after surgery that showed an ambulatory status with mild paraparesis and ataxia. Long term follow up by phone indicates a return to normal ambulation with no discomfort and normal urination and defecation. Case 4 remains unchanged according to the owners since a normal

exam at the recheck 2 weeks after surgery. No evidence of recurrence or discomfort has been reported in any case.

Discussion

The goal of this study was only to assess technical feasibility regarding IVDE in clinically affected chondrodystrophic dogs. 4/5 dogs had adequate decompression based on post-operative MRI with no appreciable acute disc material. Case 1 had obvious remaining compressive disc material (approximately 80% of the initial extrusion) and necessitated a repeat surgery with a standard, open approach. All cases that survived long-term (4/5) had adequate spinal cord decompression and an improved neurologic outcome compared to presentation. The only case that did not survive long-term (case 5) had adequate spinal cord decompression and had been improving at the time of hospitalization for worsening systemic disease (chronic kidney disease, gallbladder mucocele). This case was euthanized before complete neurologic recovery. While the decline of this dog was not attributed to the surgical procedure, we cannot rule out effects of anesthesia contributing to acute kidney injury.

The long-term outcome of case 1 is improved from the preoperative status of non-ambulatory paraparesis but recovery took significantly longer due to a severe intraoperative complication. After examining the patient and equipment following the surgical error, the endoscope camera was found to have inadvertently rotated, changing the orientation of the surgical field on the viewing screen. Drilling was more dorsal than expected and the burr entered the vertebral canal at the base of the spinous process, leading to contact with the dorsal dura.

This highlights how disorientation can occur using endoscopy and the importance of identifying anatomic landmarks to confirm positioning and alignment not only at the start of the procedure but throughout the procedure. Minimally invasive endoscopic surgery of the spine is similar to arthroscopy in that it allows access to a surgical area where small changes can cause a radically different field of view and orientation. Arthroscopy has a well-documented learning curve during which complication rates and surgery times are much higher before the surgeon becomes proficient. The number of procedures necessary to become proficient varies widely. Thirty procedures is used as a cut off in several studies but the range can be from 20 – 500.[111, 162]

The solution devised to avoid complications in the subsequent cases in this study was to visually and audibly confirm the landmarks, or define an anatomic compass, prior to drilling as well as periodically throughout the procedure. Camera position was also verified multiple times throughout the procedure to avoid unintentional rotation. The landmarks (base of the spinous process, accessory process, and base of cranial and caudal facets) were first identified when the facet was removed and the surgical site was held open with gelpi retractors. Once the cannula and endoscope lens were inserted, these were again identified on the endoscopy screen and the camera was rotated appropriately to maintain a consistent orientation with the gross view of the surgical site. Also, defining a strict dorsoventral limit to the bone window is another way to ensure that accurate drilling margins are maintained. In our cases, using the articular surface of the facet as the dorsal margin of the hemilaminectomy window was helpful in preventing drilling that would be too dorsal. This dorsal margin may not apply to all situations, such as a more dorsolateral disc extrusion, but provides adequate access for most ventral or ventrolateral extrusions. Identifying and re-verifying specific anatomic land marks and camera position during the procedure is crucial for a successful outcome, particularly in the learning phase.

Anesthesia times were long in several cases. Times under anesthesia can often be prolonged at a veterinary teaching hospital and the two shortest cases (3 and 4) were within the realm of a normal anesthetic event for MRI and hemilaminectomy. The three longest events (cases 1, 2, and 5) were longer than preferred. This is likely due to a combination of factors. The use of the equipment that is not standard to an open hemilaminectomy (C-arm, minimally invasive endoscopic system) added to this time. Additionally, the postoperative MRI is not performed in standard approaches and added a median of 65 minutes (range 55 – 95) of anesthesia time. Case 1 had a second surgery time of 65 minutes and case 5 underwent abdominal ultrasound while anesthetized, adding 60 minutes. By correcting for anesthesia time via removing minutes for additional procedures (2nd MRI, 2nd surgery, abdominal ultrasound), the median anesthesia time becomes 305 minutes (range 200 – 350). Then, as mentioned above, there is a learning phase to any new procedure, particularly endoscopy, that initially results in longer surgery times. A recent study evaluating anesthesia time in 297 dogs with absent deep pain perception secondary to

IVDE found an overall median time of 4.2 hours (range 3.3 – 5.3).[92] The range of our corrected anesthesia times was 3.3 – 5.8 hours.

In the 4 cases without procedural complications, median time in hospital, including the day of surgery, was 3.5 days (range 2-4). In the authors' experience, this is similar to paraparetic dogs undergoing a traditional hemilaminectomy for IVDE.

Three cases had postoperative pain adequately controlled with only a ketamine CRI (2mcg/kg/min). Rescue analgesia in the form of IV opioids was only deemed necessary in cases 1 and 3. Case 1 had significant postoperative discomfort due to the spinal cord trauma that occurred during surgery. Pain was not adequately controlled after two intermittent injections of hydromorphone (0.2mg/kg Q4-6hr) in addition to a ketamine CRI (2mcg/kg/min) so a fentanyl CRI (2-5mcg/kg/hr) was initiated. This was weaned down over 24 hours and discontinued along with the ketamine CRI and his pain was controlled with oral medications at that time. Given the iatrogenic injury, it is unsurprising that additional analgesia was required. Case 3 required a single dose of buprenorphine (0.03mg/kg) and was otherwise comfortable on a ketamine CRI (2mcg/kg/min) until a transition to oral medications the day following surgery. IV opioids are commonly part of the postoperative analgesic protocol in other hospitals, either with intermittent injections or CRIs. The other three cases in the study had their pain well controlled with ketamine CRIs only until transitioned to oral medications. There was no aspect of surgery for case 3 noted that may have led to increased postoperative discomfort. The need for additional analgesia in case 3 may have been patient dependent.

During the time between cases 1 and 5, the surgeons in this study performed hemilaminectomies on a total of 32 canine patients not included in this study. 21 surgeries were multiple sites, leaving 11 that could have potentially undergone a minimally invasive approach. Time of day was frequently a factor in not including dogs in the study. Since additional anesthesia time and radiology personnel were required, emergency cases added during a busy day or after hours were generally not considered for inclusion in the study. Regardless of the ability to include all single site extrusions, over 50% of surgical cases were multi-site extrusions and not realistic candidates for an endoscopic approach based on current understandings of the technique. To become

proficient and efficient with this technique, a neurosurgeon and their support staff would need to have a well-established protocol and a large amount of case experience. Given the difficulty in gaining regular experience due to scheduling constraints and the frequency of multisite extrusions, a minimally invasive approach may not be well suited for emergency surgical cases without a dedication to this technique. It may, however, lend itself very well to non-emergent, focal spinal cord compression such as Hansen type 2 protrusions. Because spinal cord compression is chronic in these cases, decreasing soft tissue disruption may provide a greater benefit in the postoperative period. The only reported minimally invasive approach to clinical IVDD in the thoracolumbar spine was in a German Shepherd dog with a chronic protrusion.[183] The dog returned to a normal neurologic status and no postoperative deterioration was seen. Large breed dogs with chronic protrusions have a much worse outcome than small breed dogs with acute extrusions.[39] A minimally invasive approach to Hansen type 2 protrusion should be further investigated.

Advantages

Of the benefits found using an endoscopic approach, visualization of the surgical site was the most striking [Figure 13]. The magnification and illumination of the disc material, spinal cord, venous sinus, and other structures in the surgical field was markedly improved compared to surgical loupes and a head lamp. By creating strict boundaries for the hemilaminectomy window, evaluation of the space ventral to the spinal cord was readily achieved.

Hemorrhage was very easy to pinpoint and quickly control due to the improved visualization. Overall blood loss for all procedures was assessed as minimal. While hemorrhage is not frequently a significant complication to hemilaminectomies, it can be persistent and frustrating. In some cases, it can directly interfere with the ability to visualize disc material or even force surgery to end prior to ideal spinal cord decompression. The endoscopic view allowed for very specific identification of the source of hemorrhage and led to very efficient hemostasis.

The use of a C-arm in surgery was necessary for confident identification of the correct articular facet [Figure 14]. While this method is commonplace in human spinal surgery, intraoperative

imaging is rare in the veterinary counterpart. The correct site was quickly and easily identified in all 5 cases and removed the potential for uncertainty compared to the standard approach. Dissection of multiple sites to identify the rib head of T13 and the transverse process of L1 and counting back to the correct site is a common method for identifying the articular facet of interest. Alternatively, some surgeons use a needle, placed using radiography, to mark a vertebrae or facet for surgery. The needle is either cut at the hub or a dye is injected and then the needle removed. During transportation to the operating room, needles can become dislodged or dye can diffuse to a larger area than expected. The use of intraoperative imaging in real time is a reliable technique to ensure surgery is performed at the correct site as well as reduce the need for additional soft tissue dissection. As veterinary surgery continues to advance, the use of this equipment should be considered on a regular basis.

Disadvantages

The primary disadvantage to this approach was the challenge of the learning phase and potential disorientation involved in a new procedure using an unfamiliar technology as discussed above. Though these can lead to increased surgical complications rates and prolonged anesthesia times, these have been found to decrease with experience.

Another disadvantage is that this procedure may only be feasible in a fraction of patients compared to the total number presented for IVDE. Only 5 of 37 thoracolumbar surgical cases the surgeons were involved in were able to be enrolled over a 17-month period. Over half of all cases had disc extrusions that extended beyond the length that could be accessed with the minimally invasive approach as defined by our study. In addition, the emergency nature of many dogs with IVDE often resulted in cases that were addressed late in the day or after normal hours. The timing often did not allow for the additional diagnostics and anesthesia length associated with the study protocols to be coordinated with other services.

The equipment required for this approach consists of the EasyGO! II spinal surgery set, endoscope camera, endoscopy tower and the C-arm. These may be cost prohibitive for many hospitals and without proven reduction in hospital stay, would result in additional cost to owners.

There is not enough evidence in this small pilot study to compare speed of recovery between standard or minimally invasive hemilaminectomies. Though there was not a subjective benefit in recovery of dogs using this novel technique, a potential benefit may not become apparent until the surgeon become proficient using this system. Much larger numbers of patients treated by a surgeon experienced in minimally invasive hemilaminectomies would be needed before a determination could be made comparing the two approaches.

Limitations and Future Studies

The very limited study population makes statistical comparisons or certainties impossible. To verify a success rate similar to that of an open approach (90%) with a confidence level from 85-95%, 135 dogs would need to undergo a minimally invasive approach. To compare outcomes of a traditional hemilaminectomy to a minimally invasive approach, 236 dogs (118 in each group) would be needed for 80% power. Given the length of time required to enroll the 5 dogs in our study, these studies would likely be a significant undertaking. A multi-center prospective randomized study to enroll 236 dogs may improve enrollment but create confounding factors by the number of surgeons involved and different levels of experience.

Our neurologic grading scale is commonly used but could be too rudimentary to detect subtle difference in rates of recovery if comparing an open vs endoscopic approach. Other scoring systems to evaluate neurologic function with more nuanced grades have been proposed.[67, 69] To accurately evaluate and compare recovery after surgery, a more refined scale could be considered.

Pain assessment was measured subjectively in this study. Many grading schemes have been created to assess pain in dogs and cats.[188] To accurately compare this technique to a standard hemilaminectomy regarding postoperative discomfort, a consistent pain scoring system should be applied and detailed records should be kept on the analgesia required.

Other measures of outcome should also be considered in a large-scale study to compare two methods of surgical spinal cord decompression. Long term incidence of recurrence should be monitored as the preservation of musculature and ligamentous structures with an endoscopic approach may help maintain spinal structural support and integrity. Other factors to compare include intraoperative hemorrhage or other surgical complications, incidence of surgical site infections, time in hospital, anesthesia/surgery time, total cost, and owner satisfaction with outcome and cosmesis.

Chapter 4: Conclusions

Early results of this study indicate that minimally invasive, integrated endoscopic hemilaminectomy is a feasible approach for spinal cord decompression secondary to IVDE in small, chondrodystrophic dogs. This study also highlights that previous experience with minimally invasive techniques was of great benefit. If the surgeon does not have significant experience with minimally invasive procedures, the time to become proficient with the procedure is very significant and the potential for complications during the initial learning phase is to be expected. Early and repeated identification of local anatomical landmarks and verification of camera position are needed to minimize the chance of complications. Further studies are needed to identify potential benefit compared to a standard, open hemilaminectomy in regard to postoperative pain and long-term outcome.

Enrollment of large case numbers in an emergency setting may be challenging. During the active period of this study, approximately 69% of potentially eligible surgical cases of acute, single site IVDE were unable to be included in this study. Staffing requirements, timing of presentation to the hospital, and other factors may create difficulties in completing a sufficient prospective study to better evaluate the use of this system for acute IVDE.

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